Sea Urchins (Echinodermata: Echinoidea): Their Biology, Culture and Bioactive Compounds

M. Aminur Rahman*, A. Arshad, and Fatimah Md. Yusoff

***Abstract*—**The gonads of both male and female sea urchins, commonly known as "Sea urchin Roe", are culinary delicacies in many parts of the world. The roe of sea urchins is considered as a prized delicacy in Asian, Mediterranean and Western Hemisphere countries and have long been using as luxury foods in Japan. Japanese demand for sea urchins raised concerns about overfishing, thus making it one of the most valuable sea foods in the world. The population of the Asian Pacific Region has been using it for long time as a remedy for improving general living tone and treatment for a number of diseases. Sea urchin gonads are also rich in valuable bioactive compounds, such as polyunsaturated fatty acids (PUFAs) and β-carotene. PUFAs, especially eicosapentaenoic acid (EPA, C20:5) (n-3)) and docosahexaenoic acid (DHA C22:6 (n-3)), have significant preventive effects on arrhythmia, cardiovascular diseases and cancer. β-Carotene and some xanthophylls have strong pro-vitamin A activity and can be used to prevent tumor development and light sensitivity. Sea urchin fisheries have expanded so greatly in recent years that the natural population of sea urchins in Japan, France, Chile, the northeastern United States, the Canadian Maritime Provinces, and the west coast of North America from California to British Colombia have been overfished to meet the great demand. Not surprisingly, the decrease in supply and the continued strong demand have led to a great increase in interest in aquaculture of sea urchins. Most, if not all, sea urchin fisheries have followed the same pattern of rapid expansion to an unsustainable peak, followed by an equally rapid decline. World landings of sea urchin, having peaks at 120,000 mt in 1995, are now in the state of about 82,000 mt. However, over half this catch comes from the recently expanded Chilean fishery for *Loxechinus albus*. In Europe, the sea urchin stocks (*Paracentrotus lividus*) of first France and then Ireland were overfished in the 1980s to supply the French markets. These decreasing patterns clearly reflect the overexploitation of most fishery grounds and highlight the need for conservation policies, fishery management and aquaculture development. When the wild stocks decline, high market demand for food, nutraceuticals and pharmaceuticals, raises the price of the product and, as a result, culturing is most likely to become commercially viable. As this review shows, there have been dramatic advances in the culture methods of sea urchins in the last 15–20 years; we can conclude that currently the major obstacles to successful cultivation are indeed managerial, cultural, conservational and financial rather than biological and ecological. Therefore, the fate of the sea urchin fishery is closely connected to that of the fisheries, whose fortune will eventually depend upon the stock enhancement, culture improvement, quality roe production and market forces that will shape this rising industry in a very worthwhile and significant manner.

***Keywords*—**Sea urchin, Biology, Aquaculture, Enhancement, Roe, Bioactive compounds.

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I. Introduction

SEA urchins are classic objects of research in different fields of biology, ecology, biodiversity and evolution. At the same time, they are used as raw material to produce foodstuff, in particular, the product of processing gonads known as "Sea urchin Roe" [1−3]. The roe of sea urchins is considered to be a prized delicacy due to its tasty qualities in Asian and Mediterranean countries, and also in Western Hemisphere countries such as Barbados and Chile [1, 4−6]. The gonads of sea urchins either fresh or in the form of processed food have long been using as luxury foods in Japan [7]. Sea urchin is usually known as “uni” in Japan and its roe can retail for as much as AU$450/kg [8]. It is served raw as *sashimi* or in *sushi*, with soy sauce and *wasabi*. Japan imports large quantities from the United States, South Korea and other producers. Japanese demand for sea urchin has raised concerns about overfishing, thus making it one of the most valuable sea foods in the world [9]. The population of the Asian Pacific Region has also been using it for long time as a remedy for improving general living tone, treatment for a number of diseases and strengthening of the sexual potency of men, especially the middle aged [5, 10]. Sea urchin fisheries have expanded so greatly in recent years that the natural population of sea urchins in Japan, France, Chile, the northeastern United States, the Canadian maritime provinces, and the west coast of North America from California to British Colombia have been overfished to meet the great demand [11−15]. Not surprisingly, the decrease in supply and the continued strong demand have led to a great increase in interest in aquaculture of sea urchins, particularly, in those areas where their populations have been depleted [4]. The sea urchin gonads that are of commercial importance can be obtained from a number of genera: *Centrostephanus*, *Diadema*, *Arbacia*, *Echinus*, *Loxechinus*, *Paracentrotus*, *Psammechinus*, *Anthocidaris*, *Colobocentrotus*, *Echinometra*, *Evechinus*, *Heliocidaris*, *Hemicentrotus*, *Strongylocentrotus*, *Lytechinus*, *Pseudoboletia*, *Pseudocentrotus*, *Toxopneustes*, and *Tripneustes* [16−19].

Most, if not all, sea urchin fisheries have followed the same

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pattern of rapid expansion to an unsustainable peak, followed by an equally rapid decline. World landings of sea urchin (Fig. 1), having peaks at 120,000 mt in 1995, are now in the state of about 82,000 mt with an alarming decreasing rate of 32% [20, 21]. Nevertheless, over half amounts of this catch comes from the recently expanded sea urchin (*Loxechinus albus*) fishery from Chile [22]. The other major sea urchin fisheries, in terms of tonnage landed, are in Japan, Maine (USA), British Colombia (Canada) and California (USA) [23]. In Europe, the sea urchin (*Paracentrotus lividus*) fishery of France and Ireland were overfished to supply the French markets [24]. There are large populations of edible urchins in Scotland (*Echinus esculentus* and *Psammechinus miliaris*) and Norway (*Strongylocentrotus droebachiensis*), but these stocks are not suitable to commercial fishing as their roe content is either very low or too variable [22, 25−27]. However the continuous decreasing patterns clearly reflect the overexploitation of most fishery grounds and highlight the need for appropriate conservation strategies, fishery management policies and aquaculture development initiatives.

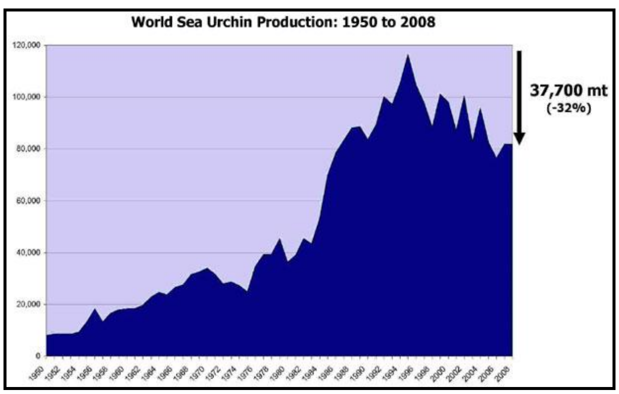

Fig. 1. Global sea urchin fisheries from 1950 to 2008 by fishing [20].

II. Sea Urchin Biology And Ecology

The major sea urchin producing areas of the world are associated with major sites of primary productivity. In the temperate regions, these are usually associated with kelp forests and in the subtropical and tropical regions, with sea grass beds. Given the similar habitat types, the various species of edible sea urchins share some similarities in distribution and reproduction. However, they are varied in their basic biological characteristics, such as growth, maturity and longevity.

Tripneustes gratilla

This species (has a circumtropical distribution extending into the subtropics. It is found in the waters of the Indo-Pacific, Hawaii, and the Red Sea and is distributed from Mozambique to the Red Sea, westward to Hawaii and Clarion Island, eastward to Paumotu, and as far south as Port Jackson. It also occurs at Shark's Bay on the west coast of Australia. It is most common in very shallow water on a variety of hard substrates and is found at depths of 2 to 30 meters [19]. They graze near the substrate, and their diet comprises algae, periphyton, and sea grass. Growth is rapid and longevity low. A maximum size of 160 mm TD (test diameter) is reported, which corresponds to an age of four to five years. Individuals can reach 75 mm TD in the first year. *Tripneustes gratilla* has an annual reproductive cycle mediated by seawater temperature, day length and feeding activity. Spawning occurs during mid and later winter, when temperatures and day lengths are the lowest.

Kina (Evechinus chloroticus)

Kina is endemic to New Zealand where its distribution is strongly associated with kelp beds with individuals occurring either within beds or aggregating in adjacent barrens. Kina is usually found from the intertidal zone to 14 m but have been recorded from 60 m. It has a moderate growth rate with individuals reaching 50 mm TD at 4 years of age. The maximum size of 80 to 100 mm TD is attained in 8 to 9 years. The mean longevity of individuals varies between sites but is between 10 to 20 years [28]. Kina attains sexual maturity at 40 to 50 mm TD (3 to 4 years of age) and spawning occurs in spring.

Purple sea urchin (Heliocidaris erythrogramma)

This sea urchin is distributed in the shallow coastal waters (intertidal to 35 m) of southern Australia. In Tasmania, it is common in kelp communities and in barrens, where it feeds by grazing and capturing drift weeds. On the Australian mainland, it can occur in high densities in association with sea grass beds [29]. Growth rates vary depending on nutrition but are generally moderate with individuals attaining 40 mm TD at one year and harvestable sizes (60 mm TD) at 3 to 5 years. Invalidated aging suggests that individuals can live for over 10 years and maximum sizes of 122 mm TD have been observed [30]. Sexual maturity is reached at 40–50 mm TD and 5 to 6 years of age [31]. Spawning occurs from summer to autumn with the best roe recoveries (10–14%) in August to December.

Erizo (Loxechinus albus)

The erizo or Chilean Red Sea Urchin, Loxechinus albus, is a relatively slow-growing urchin found along the Pacific coast of South America from Isla Lobos de Afuera in Peru to the Southern tip of South America at depths ranging from intertidal to as deep as 340 m. [32]. These urchins can live to as old as 20 years and reach sizes up to TD 130 mm [23]. It is one of the most economically important species along the SW coast of South America where it has been used as a food source since pre-Columbian times. These urchins have a strong preference for exposed habitats and are rare in protected environments, apparently for reasons related to differential availability of larvae [32]. Its distribution is associated with kelp beds and it is most abundant below 40^{o}S. The species is relatively slow growing, reaching a maximum size of 130 mm TD and may live to 20 years. Spawning time varies along its distribution; occurring in spring to summer in the north, summer in the south and spring in the extreme south.

Lytechinus variegatus

This species is distributed through the shallow waters of the tropics to subtropics of the western Atlantic, from Florida, through the Caribbean to Brazil [33]. It is associated with sea grass beds and hard bottoms covered with algae. Growth is rapid and longevity is limited. Individuals can reach 40 mm TD at one year and a maximum size of 92 mm TD is reported with a maximum age of 3 years. Mean longevity is between 1 and 2 years. Sexual maturity is reached at 40 mm TD and there is no seasonality to spawning.

Common sea urchin (Paracentrotus lividus)

This sea urchin is distributed through the shallow (sublittoral to 20 m) waters of the Mediterranean and the north east Atlantic. It is strongly associated with sea grass meadows and also occurs on encrusted rocky substrates where it will form permanent burrows. Growth rates are moderate with individuals of 40 mm TD being 4 to 5 years old and individuals of 70+ mm being older than 12 years. A maximum size of 75 mm TD is reported [34]. Individuals mature at 13 to 20 mm TD and spawning occurs in spring to early summer.

Psammechinus miliaris

This species is restricted to the southern and eastern waters of the North Sea where it occurs from the littoral to depths of 100 m. Its distribution is highly associated with the kelp *Laminaria*. Growth rates are moderate and longevity is short. A maximum size of 45 mm TD is reported which corresponds with an age of between 3 to 4 years. Sexual maturity is attained in the first year at 6 to 7 mm TD and spawning occurs in summer.

Green sea urchin (Strongylocentrotus droebachiensis)

The green sea urchin has a circumpolar distribution, which provides for a very wide distribution through the North Atlantic (Scandinavian and North American coasts, Iceland and Greenland) to the North Pacific (North American and Siberian coasts). Fisheries for *S. droebachiensis* are concentrated in Maine and the Canadian Maritimes but smaller fisheries are prosecuted in Alaska, BC, Washington and Iceland. It is most common in the intertidal zone to 50 m where it is associated with kelps [35]. Growth rates are moderate and off Maine two distinct growth forms have been identified. A fast growing form reaches the minimum legal size at 4 to 6 years and may live for 16 to 20 years. The slow growing form lives for 8 to 12 years and never reaches the minimum legal size [23]. The minimum legal size in BC is 55 mm TD and the time required to grow to this size is thought to range between 4 and 8 years in most cases [36]. The maximum size is around 100 mm TD. Individuals reach sexual maturity and first spawning at 45-50 mm TD. Spawning is generally occurring from mid-winter to early spring.

Red sea urchin (Strongylocentrotus franciscanus)

The red sea urchin *Strongylocentrotus fransiscanus* is the largest sea urchin in the world and is common along the West Coast of North America from Baha California to the Aleutian Archipelago and the coast of Siberia and north Asia. They have been reported from as far south as the tip of Baja California, Mexico (23^{o}N) but their abundance declines at sites south of the Vizcaino Peninsula (27^{o}N). Their range extend northwards up the west coast to Sitka and Kodiak AK at 58^{o}N [37]. It is common in the subtidal zone to 50 m and is strongly associated with kelp forests. Early growth is relatively rapid and the species exhibits extreme longevity. Size at recruitment is around 90 mm TD which is reached in around 6 to 8 years. The maximum size is around 200 mm TD and individuals over 150 mm TD are older than 100 years [37]. Sexual maturity is attained at about 50 mm TD and spawning occurs over spring and summer.

Strongylocentrotus intermedius

The Japanese green sea urchin, *Strongylocentrotus intermedius,* is the second most commercially important urchin in Japan. This species is distributed along the Asian and Siberian coast of the Pacific. It is common in shallow waters around Hokkaido and is harvested commercially in Irate, Aomori and Hokkaido [38]. It usually occurs on shallow rocky bottom and is associated with kelp [38]. It has small reddish-yellow gonads which have a nice sweet taste and is listed on Tsukiji as Japanese. This species is adapted cold water though and the growth restriction does not appear to be a temperature related limit [38]. Growth varies depending on density and nutrition. In high growth conditions, individuals reach 40 mm TD in 2 to 4 years and maximum sizes of over 55 mm at ages of 6 to 10 years. Sexual maturity occurs at around 30 to 35 mm TD (2 years of age) and spawning occurs in spring and autumn.

Strongylocentrotus nudus

Strongylocentrotus nudus listed on Tsukiji as Japanese, is the most commonly harvested edible sea urchin in Japan and accounts for ~ 44% of the total commercial harvest [39]. It is found on inter- and sub-tidal rocky bottoms extending from Dalian, China northwards to Primorskyi Kray, Russia and in Japan where it is found in the Pacific from Sagami Bay to Cape Erimo on Hokkaido and in the Sea of Japan from Omi Island in Yamaguchi to Soya Cape northern Hokkaido. The urchins generally reach the legal size (40 mm) in 2 to 4 years when feeding on perennial Laminarians whereas they may take 7 to 8 years on coralline flats. It occurs in the intertidal to subtidal rocky reefs and is strongly associated with kelp communities. Juveniles recruit to coralline flats and move to adjacent kelp forests. In kelp forests individuals reach 50 mm TD in 2 to 4 years, whilst this will take individuals 7 to 8 years on coralline flats [39]. Maximum longevity is reported as 14 to 15 years. Sexual maturity is attained at 40 to 45 mm TD, and spawning takes place in autumn.

Purple sea urchin (Strongylocentrotus purpuratus)

The purple sea urchin is distributed along the Pacific coast of North America and is abundant in the intertidal zone but has been recorded to 150 m [37]. It is strongly associated with kelp forest beds. Growth is highly variable and dependent on food availability. The maximum size is around 100 mm TD and age at first maturity is one or two years.

Purple crowned urchin (Centrostephanus rodgersii)

This species has a subtropical distribution through waters of eastern Australia and New Zealand. Recent reports of a southerly range extension into Bass Strait and the east coast of Tasmania [40] are probably associated with warming of coastal waters, but this may be episodic [41]. It is associated with hard corals in the north of its distribution and kelp communities in the south, where it forms extensive barrens. Growth rates are moderate with individuals of 70 to 90 mm TD being between 4 to 10 years old. The maximum size of 120 mm TD corresponds with an age of up to 20 years old. Sexual maturity is attained at 40 to 60 mm TD, and spawning occurs in winter.

White sea urchin (Salmacis sphaeroides)

Salmacis sphaeroides, commonly known as short-spined white sea urchin, is one of the rare species of regular echinoids, although it can be found in the warm Indo-West Pacific from China to Solomon Islands and Australia [42, 43], and Singapore [44]. It has almost cloudy while test (5.0 to 8.0 cm diameter) with numerous short white spines (1.0 to 1.5 cm). Some may have white spines with maroon bands, others with all maroon spines, and yet others with green and maroon bands. It can be found in the warm temperate regions including Johor Straits, between Malaysia and Singapore [14, 15, 44]. This sea urchin can be occurred at depth range between 0 and 90 m, however it is also found in shallow waters, especially in amongst sea grass meadows, coral reef and in muddy sublitoral zone or washed ashore [43]. *Salmacis sphaeroides* gets their food from algae, bryzoans, seaweeds and detritus and frequently feeds on algae that grow on the substrates. Spawning occurs throughout the year.

Echinometra

The various species of *Echinometra* have a circumtropical distribution and occur in shallow water but have been recorded to 20 m. They occur commonly in and around reefs and found from central Japan in the north, to southeast Australia in the south, and from Clarion Island off Mexico in the east, and to the Gulf of Suez in the west [12, 45]. They are generally small bodied, with maximum sizes of 85 mm test diameter (TD) and may live 8 to 10 years. They form burrows and territories that are defended. The species is the most effective herbivore and in the absence of predators can occur in densities that exceed the primary production potential [46].

III. Sea URCIN Aquaculture, Management And Enhancement

A. Aquaculture

Generally, the edible sea urchins belong to the regular Echinoids [19], having separate sexes and are broadcast spawners. During the breeding season, the matured individuals shed their gametes in seawater column where fertilization occurs. The fertilized eggs develop to form pluteus larvae, which after a period of planktonic development, feeding on microalgae, settle to a suitable substratum and undergo metamorphosis to form tiny juvenile sea urchins. Larval life cycle is almost around 1 month at 26-28°C, including the feeding or four-armed stage, the six to eight-armed stages and settling competent stage (Fig. 2). The juveniles then grow on microalgae and the estimated time for these young urchins to reach marketable size (40–50 mm) is commonly in the range of 1–3 years, but varying according to species [22].

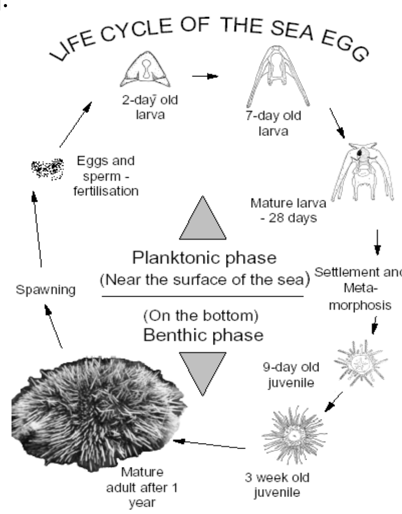

Fig. 2. Spawning, fertilization and a complete larval life-cycle of the white sea urchin (*Tripneustes ventricosus*) [47].

Sea urchin culture has been accomplished on a large scale in Japan for many decades. Millions of juvenile urchins are produced in their hatcheries, for release to managed areas of seafloor on the intertidal areas. The nationally co-ordinated reseeding program has developed to the extent that over 66 million juveniles were released on the reefs within which, over 80% were *Strongylocentrotus intermedius* [48]. The contribution of released sea urchins to the overall catch has been estimated to be between 62 and 80%. There are also much smaller-scale reseeding programs operating in South Korea and on Luzon Island in the Philippines [23]. The researchers and farms in southern Ireland, have been developing methods for sea urchin (*Paracentrotus lividus*) cultivation for over 20 years [49], and until relatively recently in France [50]. Echinoculture (*Psammechinus miliaris*, *E. esculentus*, *P. lividus*) has been conducted in Scotland since 1995 and there are also established research teams on the east coast of North America – Florida, Alabama, Maine, New Hampshire, New Brunswick and Newfoundland – working on

S. droebachiensis and *Lytechinus variegatus*; on the west coast of North America, including California and British Columbia (*S. droebachiensis*, *S. franciscanus*, *S. purpuratus*); in Chile (*Loxechinus albus*); Norway (*S. droebachiensis*); Israel (*P. lividus*); and in New Zealand (*Evechinus chloroticus*) [22].

Brood stocks of sea urchin are usually collected from the wild when they attain appropriate sexual maturity. Gametes from both female and male urchins are obtained by injecting 0.5 M KCl into the coelomic cavity. Eggs are collected by inverting female urchins over a glass beaker filled with filtered sea water (FSW), while sperms in the most concentrated form are pipetted off the genital pores [14, 45, 51, 52]. Fertilization is usually done at limited sperm concentration and the resulting embryos are reared. The fertilized eggs hatch in approximately 10–15 h, depending on the species, to develop to a ciliated blastula. When the larvae attain feeding stage (four-armed pluteus), they are cultured in glass bottles on a rotating roller with a larval density of 1-2 individual/ml. Larvae are supplemented with a cultured phytoplankton (*Chaetoceros calcitrans*, *Isochrysis galbana*) at concentrations of 4000, 6,000 and 8,000 cells per ml of medium daily at four-, six- and eight-armed pluteus stages, respectively, until attaining metamorphic competence within 1 month after fertilization (Fig. 3). For the large-scale culture in Japan, partial water exchange systems [53] and continuous flow-through systems are used [9]. The costly aspect of larval culture is the need for the simultaneous production of microalgae as live feed. However, sea urchin (*Lytechinus variegatus*) larvae have recently been proven to be suited for culture on artificial diets [54].

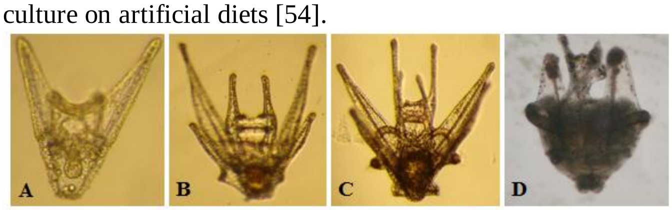

Fig. 3. Larval developmental stages of shrot-spined white sea urchin (*Salmacis sphaeroides*: A) 4-arm pluteus, B) 6-arm pluteus, C) 8-arm pluteus, D) Competent larva with complete rudiment growth [14].

Settlement and metamorphosis are the most critical stages in the development and culture of sea urchin larvae. High survival is dependent on the larvae being competent to metamorphose and then responding to settlement cues. Induction of metamorphosis in small-scale culture has recently been performed on coralline red algal extracts + Chaetoceros diatom (50:50) in petri dishes (9.0 x 3.0 cm) containing FSW [14]. Majority of the competent larvae are metamorphosed to young juvenile within 1 day post-settlement (Fig. 4A). They were then cultured on coralline algal stones in aerated aquaria for three months by which time they attained appropriate juvenile sizes (Fig. 4B) for stocking in grow out culture system. Sea urchin juveniles have been produced on a commercial or semi-commercial scale by hatcheries in Japan, South Korea, Ireland, Norway, Scotland and in British Columbia, Canada.

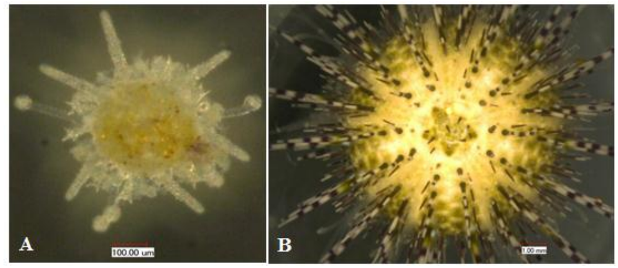

Fig. 4. Juveniles of *Salmacis sphaeroides*: A) 1-day-old juvenile, B) 3-month-old juvenile [14].

Most culturists use a natural biofilm or a specially seeded diatom substrate created from species isolated locally and grown on a PVC wave plate. Optimizing diets for the early juveniles and/or the replacement of diatom biofilms with artificial diets is probably one of the most challenging areas left to research. The variation in size and subsequent variation in growth rates of post-larvae remain a bottleneck in the supply of hatchery-reared juveniles. Hatchery reared juveniles are robust enough to survive, transfer to sea cages or other grow-out systems from a small size (5-mm test diameter) [53, 55]. At this point they are weaned onto other diets, soft macroalgae or artificial diets, depending on the grow-out culture protocols.

In the indoor small-scale aquaria-rearing condition, 1-day-old juveniles are reared in small aquaria (25 x 20 x 10 cm) with aerated filtered seawater, and pieces of dead coral with coralline red algae as food [12, 45, 51]. Seawater is partially changed twice a month with freshly filtered sea water. This is continued for up to three months, by which time the juveniles attain 9.0–10.0 mm in test diameter. The three-month-old juveniles (Fig. 5A) are then transferred to glass aquaria (46 x 30 x 30 cm) supplied with aerated seawater at the culture unit of the laboratory of Marine Biotechnology, Universiti Putra Malaysia. Stocking density is maintained at 20 juveniles in each replicate aquarium and the urchins are fed with red alga (*Amphiroa fragilissima*), brown alga (*Sargassum polysystum*) and sea grass (*Enhalus acoroides*) All the juveniles were fed ad libitum and water in each cultured aquarium was completely changed at every 2−3 months. After the culture period of one year, the urchins attain sexual maturity (Fig. 5B) and the red alga-fed urchins performed the best over the brown- and sea grass-fed urchins (Rahman unpublished data). In contrast to the Japanese systems where hatchery-reared juveniles are mainly released to managed areas of seafloor [9, 22, 53], researchers in other countries have experimented with a wide range of grow-out systems for juvenile and adult urchins, ranging from relocation from poor to good feeding grounds [56] to the ranching of urchins caged on the seafloor [57]. Hatchery-reared juveniles have been grown in suspended culture (Kelly 2002, 2005) in closed recirculation systems [50] and in dammed rock pools in southern Ireland. A sea-cage cultivation system of stacking baskets suspended from a ladder-like structure over which a work barge or raft can operate is being developed by Norwegian researchers

[58]. The time taken for juveniles of most species to reach market size is in the order of 1–3 years [22].

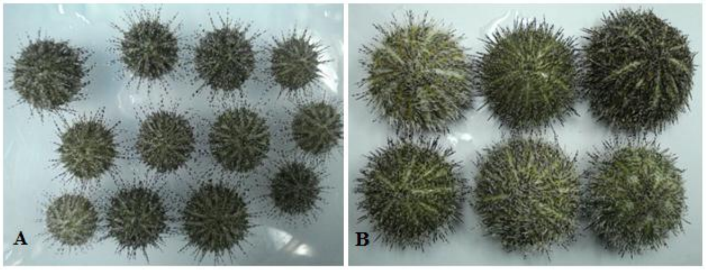

Fig. 5. Juveniles and adults of cultured *Salmacis sphaeroides*:
A) Three-month-old juveniles for stocking in grow-out culture,
B) Sexually matured adults after the culture period of one year in captive aquaria-rearing condition.

B. Management

Systems that accelerate growth to market size while producing a uniform size class would give an economic advantage. One possible route to obtaining sustainable and environmentally friendly systems for urchin culture is to further examine their potential in integrated systems. They have already been shown to thrive in polyculture with the Atlantic salmon [59] and to have a role in land-based integrated systems [60]. However, many species are true omnivores, so the potential for their integration into systems where natural prey items, for example, mussels, are already produced should be explored.

Classical fisheries science was developed in consideration of offshore, open access and industrial fishing situations and the resulting management systems are not well adapted, or particularly robust, when applied to more complex spatial structure of small scale, inshore fishery resources [61]. The social significance of small scale inshore fisheries is much greater, given the numbers of fishermen and other players involved, than the sometimes more productive offshore fisheries, which generally involve larger enterprises, higher capital investment and limited numbers of fishermen. As a result, much of the challenge in ensuring the sustainability of shellfish fisheries lies in developing and applying appropriate utilization, assessment and management models. The management measures that explicitly acknowledge spatial structure of fishery resources, and are therefore the most suitable for these sorts of fisheries, include [61]:

i. territorial property and use rights including lease, traditional tenure systems etc.;
ii. harvest rotation coupled with pulse fishing and/or thinning;
iii. reproductive refugia and Marine Protected Areas;
iv. experimental management with spatial control, contrasting treatments and replication;
v. localized enhancement including habitat manipulation, seeding and predator control.

C. Enhancement

Overfishing and a decline in world production have prompted increasing in enhancement as a means of at least maintaining production. It is most developed in Japan where the 1974 Coastal Fishing Ground Improvement and Development Law provide the basis for stock enhancement [62]. The goal of this program is to "develop and improve coastal fishing grounds systematically by the construction of artificial reefs and the release of seedlings". Enhancement can comprise a number of different activities including direct stock enhancement through seeding of hatchery-raised juveniles, habitat improvement or restoration, creation of artificial reefs, predator control, thinning and/or roe enhancement through supplemental feeding to increase the product recoveries etc. Re-seeding has been especially applied in Japan since the late 1980's. The numbers have been fairly stable since 1997 with about 70-85 million juveniles reared to about 5-10 mm TD and released each year primarily in the areas with the largest historical harvests. *Strongylocentrotus intermedius* accounts for about 85% of the urchins released by the Japanese in Hokkaido [23]. Predator removal is required as excess predation by sea stars etc. has been implicated in the few cases where the re-seeding did not have any benefit on the subsequent urchin production and crabs and sea stars are removed from the grounds using baited traps prior to the release of the urchins to control mortality in the immediate period after release. Government has considerable involvement in the management of coastal fisheries, particularly in the provision of subsidies for enhancement and infrastructure development as well as management coordination. A couple of studies have looked at the contribution of re-seeding or habitat enhancement to the actual abundance of urchins in harvest areas in a sort of round-about way at localized sites around Hokkaido and estimated that re-seeded urchins comprised 62%, 66% and 80% of the catch in 1994, 1995 and 1996 respectively [62].

In Japan, translocation of the urchins is used for a number of related reasons. In areas where kelp forest development is held back by excessive urchin densities, urchins are sometimes removed and replaced with adult kelps to permit rapid development of complex kelp forests [62]. The urchins may then be placed into intensive sea ranching pens where they are fed ad libitum and prepared for harvest some months down the road. Experiments have shown that Green Sea Urchins (GSU) at densities up to 35 kg/m have recorded recovery increases from 6% to over 18% in 11 weeks on an artificial diet [58], although further finishing for about 6 weeks on a natural kelp diet is still required to get an acceptable taste profile at this point. The sea urchin *Evechinus chloroticus* is widely distributed around New Zealand but attempts to establish a commercial fishery have, like Norway, not succeeded because of the poor product quality and low recoveries. Experiments with ponding over 2 month periods have seen recoveries increase to near 20% and produced other quality improvements that bode well for the future but further research is still needed to reach an economic breakeven. There are a number of aquaculture sites around New Zealand which are currently considered marginal for mussel farming which would be suitable for urchin ponding or culture [63]. Multi-disciplinary approaches are therefore needed for stock enhancement and both scientific and user group advisors should be involved [64]. One method of enhancement that apparently works very well with Green Sea Urchins simply requires the presence of a salmon net pen. The urchins can apparently settle out quite abundantly on such structures and grow quite nicely by feeding on the fouling organisms on the mesh. This has also provided some good opportunities for Canadian fishermen in BC for some easy harvests.

The current market system used for the urchin trade developed in tandem with the wild fishery but this will no doubt change dramatically once cultured product is available in substantial quantities. Cultured production is more tightly controlled than from the wild fishery so that, as with the cultured salmon, the consistent availability of an invariably high quality product throughout the year will have a tremendous impact on the urchin markets throughout the world. Traditional harvesters of sea urchins do not generally know much about the potential of aquaculture [65] and will likely tend towards obstructing its development as opposed to recognizing the available advantages and applying them to their own benefit. This will be unfortunate because if the wild and cultured urchin fisheries could be more closely integrated, both would stand to benefit. For example, the gonad size and quality are quite easy to manipulate and the economic yield of the roe can be dramatically and fairly easily increased. This knowledge is probably directly applicable to the wild fishery and could contribute to an increase in quality, value and profitability. Already, fisheries and aquaculture are blurring together with respect to product (gonad) enhancement and re-seeding of juveniles is coming to the fore in a number of countries [65]

IV. Bioactive Compounds From Sea Urchins

Alike many other marine invertebrates, sea urchins have been considered as well as to be examined as a source of biologically active compounds with biomedical applications [22]. However, the potential of echinoids as a source of biologically active products are largely unexplored [66]. The marine environment is an exceptional reservoir of bioactive natural products, many of which exhibit structural and chemical features not found in terrestrial natural products. The richness of diversity offers a great opportunity for the discovery of new bioactive compounds. Modern technologies have opened vast areas of research for the extraction of biomedical compounds from ocean and seas to treat the deadly diseases. The number of natural products isolated from marine organisms increases rapidly, and now exceeds with hundreds of new compounds being discovered every year [67]. The secondary metabolites have various functions; it is likely that some of them may be pharmacologically active on humans and useful as medicines [68]. A majority of pharmacologically active secondary metabolites have been isolated from echinoderms [69]. There are much valuable information for new antibiotic discoveries and give new insights into bioactive compounds in sea urchin. The sea urchin shells are containing various polyhydroxylated naphtoquinone pigments, spinochromes [70] as well as their analogous compound echinochrome A, of which was showed bactericidal effect was reported by Service et al. [71]. The phenolic hydroxyl groups in these molecules also suggested that they could participate in antioxidant activity as was observed in other well-known antioxidant polyphenols such as tea catechins. The similar structured compounds are also found in the shells of sea urchins and thus suggesting that they as well as echinochrome A would act as antioxidant substances similar to other polyphenolic antioxidants in edible plants [72]. While squaric acid ester-based methodology was used in a new synthesis of echinochrome A, a polyhydroxylated napthoquinone pigment commonly isolated from sea urchin spines [73]. The Sea urchin gonads contain polyhydoxylated naphthoquinone, echinochrome A, which is potential in antioxidant activity [74]. Sea urchin gonads are also rich in valuable bioactive compounds, such as polyunsaturated fatty acids (PUFAs) and β-carotene [75]. PUFAs, especially eicosapentaenoic acid (EPA, C20:5) (n-3)) and docosahexaenoic acid (DHA C22:6 (n-3)), have significant preventive effects on arrhythmia, cardiovascular diseases and cancer [76]. β-Carotene and some xanthophylls have strong pro-vitamin A activity and can be used to prevent tumor development and light sensitivity [77]. The composition of these valuable components, however, varies greatly among different urchin species and is influenced by their natural diet as well as physiological processes i.e. reproductive stage [19, 78]. On the other hand, the high levels of AA and EPA recently detected in *Diadema setosum* and *Salmacis sphaeroides* supported the development of aquaculture of sea urchins [79], since PUFAs are important for human nutrition [19].

V. Conclusion

This paper has been produced as a background document for a review of the World's sea urchin fisheries. To summarize the views, reports and publications of other scientists/researchers, it is apparent that sea urchin fisheries have a poor record of sustainability, as evidenced by the declines recorded in Japan, Maine, California and South Korea among others, as well as by the ad hoc and/or ineffective management in many sea urchin fisheries. Very few stocks have been formally assessed, meaning it is near impossible to qualify declines as the fish-down of accumulated biomass, which does not arrest the productivity of the stock, or as a case of over-fishing in which case its productivity may be forced into permanent decline. Small-scale management is mentioned time and again as offering the most promise for ensuring long term sustainability. The strong and consistent spatial structure inherent in sea urchin stocks combined with excessive effort from mobile fleets and inappropriately large scale, and therefore ineffective management all contribute to declining production in many of the world's sea urchin fisheries. This is particularly the case for the world's largest sea urchins fishery in Chile where the risks of collapse cannot be discounted. Given that this fishery alone contributes upwards of 55% of the global harvest, a significant decline in Chile's fishery would likely lead to structural realignment in the market and higher prices for mid-range products until aquaculture production ramped up. There is also general agreement that some form of exclusive access as a prerequisite condition to promote meaningful enhancement and intelligent harvesting to maximize roe value will provide the best hedge against uncertainties in fisheries productivity and market stability. In the short term it is likely that global production of sea urchin roe from wild fisheries will decline, with the major production being provided by those fisheries that have supported active management strategies to readjust effort and contain catches to levels that provide long-term sustainability. Given that demand is unlikely to decline; future production will be increasingly valuable. In order to make sea urchins fisheries viable and profitable, the following actions are suggested:

- Refinement of artificial diet formulations for juveniles and adults to maximize growth rates and survivorship and produce gonads of the desired taste, texture, flavor and color.
- Optimization of grow-out facilities for juveniles and adults either at sea (in containers or 'ranched') or land based;
- Regulations regarding fishing methods, fishing areas and protection of company investments need to be developed.
- Better surveillance of sea urchin density to guarantee a steady flow of raw materials.
- Areas need to be thinned out to get the best possible product for the market, this is also necessary for the kelp forest to grow back.
- More capital needs to be directed towards investing in technology for processing to reduce labor costs and preserve product quality.
- Improved cooperation between fishermen and processors, when marketing and selling the sea urchins.

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