cells form multicellular complexes after SW transfer, indicating that chloride cells are equipped with an autonomous mechanism of functional differentiation, independent of embryonic endocrine and nerve systems. The yolk-ball incubation system definitely serves as an excellent experimental model for further studies on chloride cell differentiation and functions.

Biology and Aquaculture of Bivalves in the Tropical Pacific Region

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Bivalve molluscs (Phylum Mollusca, Class Bivalvia) are common animals in coastal habitats in almost all geographical areas. The group includes oysters, clams, mussels, cockles, arkshells and the like, inhabiting a variety of microhabitats in the coastal zone.

In addition to forming an important part of the coastal ecosystem a large number of these bivalves are fished for human consumption. For many coastal communities, such as those of Pacific islands, they form an integral part of the diet. Due to the demand for these species and the prices they fetch, they are major aquaculture animals around the world. According to Food and Agricultural Organisation data (FAO, 1998) total global production of bivalve molluscs, excluding pearl oysters, in 1998 was 8.02 metric tonnes worth a staggering US$7.9 billion. Table 1. Below shows the level of production of different bivalve groups in 1998 (FAO, 1998).

In the Pacific region, Australia and New Zealand are the major producers of bivalves through aquaculture. Most of the island nations of the Pacific, except Cook Islands and French Polynesia, do not have bivalve aquaculture industries of any significance, however, successful breeding and hatchery rearing of some bivalves has been accomplished by several of these countries. Cook Islands and French Polynesia have been most successful in the culture of Blacklip pearl oysters. New Caledonia is the only country in the Pacific that has been producing edible oysters of the species, *Crassostrea gigas* (Pacific oyster) through aquaculture. Table 2 below lists some of the countries of the Pacific, including Australia and New Zealand, and the bivalve species which are being bred or cultured in these countries.

The aquaculture of most bivalves is based on a very simple principle which involves collecting or gathering naturally produced larvae or juveniles (called spat) and then growing these spat to marketable size. The success of an aquaculture venture

Table 1. World production level of bivalve molluscs in 1998.

Bivalve	Production (metric tonnes)
Oysters	3, 537,830
Mussels	1, 377,830
Scallops, Pectens	874, 255
Clams, Cockles, Arkshells	2, 226, 025
TOTAL	8, 015, 940

Table 2. Some of the bivalve species cultured or hatchery produced in the Pacific Region and 1998 production level.

Countries	Bivalve species cultured or hatchery produced	Production in 1998 metric tonnes
Australia	*Ostrea* sp. (flat oyster)	—
	Crassostrea gigas (Pacific oyster)	3852
	Saccostrea commercialis (Sydney oyster)	5328
	Crassostrea sp. (other oysters)	26
	Mytilus planulatus (Australian mussel)	1482
	Pecten fumatus (scallop)	—
	Pinctada maxima (Silver lip pearl oyster)	—
	Pinctada margaritifera (Blacklip pearl)	—
	Tridacna sp. (Giant clams)	—
New Zealand	*Crassostrea gigas* (Pacific oyster)	13,000
	Perna canaliculus (Green mussel)	75,000
Cook Islands	*Pinctada margaritifera* (Blacklip pearl)	—
Fiji	*Perna viridis* (Mussel)	—
	Tridacna sp. (Giant clams)	—
	Pinctada margaritifera (Blacklip pearl)	—
	Pteria penguin (Winged pearl oyster)	—
Federated States of Micronesia	*Tridacna* sp. (Giant clams)	—
	Pinctada margaritifera (Blacklip pearl)	—
French Polynesia	*Mytilidae* (Mussel)	—
	Pinctada margaritifera (Blacklip pearl)	—
Kiribati	*Pinctada margaritifera* (Blacklip pearl)	—
New Caledonia	*Crassostrea gigas* (Pacific oyster)	45
Papua New Guinea	*Crassostrea rhizophorae* (Mangrove oyster)	5
Samoa	*Tridacna* sp. (Giant clams)	—
Solomon Islands	*Tridacna* sp. (Giant clams)	—
	Pinctada margaritifera (Blacklip pearl)	—
Tonga	*Tridacna* sp. (Giant clams)	—
	Pinctada margaritifera (Blacklip pearl)	—
	Pinctada maxima (Silverlip pearl oyster)	—
	Pteria penguin (Winged pearl oyster)	—

is very critically dependent on sufficient spat numbers and timing of spawning. A clear knowledge of the reproductive biology helps in the understanding the life history of the species and shows the suitability of the species for aquaculture. The study of the reproductive biology involves the study of gametogenesis, spawning, gonad regression, sex ratio and larval development among other things. This type of knowledge is immensely useful for a farmer dependent on natural spatfall, as well as to a farmer who produces larvae in a hatchery.

Environmental factors, mainly temperature and nutrition, are reported to have major influence on the reproductive biology of bivalves. In a hatchery situation, manipulation of these factors can be used to bring bivalves to mature and spawn out of season.

During this study the reproductive biology of the Sydney rock oyster, *Saccostrea commercialis* was studied. The study was undertaken on Magnetic Island, an island in the tropical region of Australia, near Townsville (Prasad, 1997). *S. commercialis* is the main species of edible oyster cultured in the temperate and subtropical region of Australia. Although the distribution range of this species extends into the tropical part of Australia, significant large-scale farming does not occur in this region. It is very likely that the edible oysters found on the coast of Fiji and other Pacific islands is the same species.

The study was conducted over a period of fifteen months. Histological preparations and analysis were used to categorise the oyster gonads into developmental, ready to spawn or regressing stages. The gonads of males and females were treated the same, and eight arbitrary stages were identified as follows:

— three developing stages, 1d, 2d and 3d;
— one ripe, ready to spawn stage, 4;
— three regressing stages, 3r, 2r and 1r;
— one indifferent or resting stage, 0.

The proportion of oysters in each of the different stages were determined every month to ascertain whether there was any particular time of the year when there were more oysters in the ready to spawn state, or conversely, in a resting state. The definition given to this study was " determination of the reproductive seasonality of the oyster species". Sex ratio of females to males was also determined.

In conjunction with the reproductive study, the temperature and chlorophyll a content of the medium was monitored, and subsequently correlated with reproductive seasonality.

The results showed that oysters in advanced gametogenic stages and ripe oysters were present in almost every month of the year. Early gametogenic stages as well as regressing stages were also found throughout the year. This result demonstrated that gonad development and spawning in this oyster population were not synchronised. However, greater proportion of oysters in advanced developmental and ripe stages during summer and autumn (November–March), suggested that breeding activity is intensified over this period. The proportion of oysters in resting stages was higher in the cooler months, pre-winter, winter and post-winter (May–September).

The conclusion drawn from the results was that *S. commercialis* on Magnetic Island in tropical Queensland reproduces continuously throughout the year, with a protracted period of intensified reproductive activity over summer and autumn. Gametogenesis and spawning slow down during the cooler months but are not completely absent.

A disproportionate sex ratio was found in the study population. There were 67% females to 33% males. The biased sex ratio may be a result of sex change, that is reported to occur in oysters, as they grow older. However, no hermaphroditic individuals were found during the study.

A significant correlation was seen between reproductive activity and temperature. Low condition indices in oysters were found during the warmer months. However, the results also suggest that temperature in the tropical region was favourable enough for reproductive activity to occur throughout the year. The effect of temperature is more pronounced in the temperate and subtropical regions where the variation in water temperature is large between summer and winter.

However, no significant correlation between chlorophyll a in the water column and reproductive activity was demonstrated during this study. Often the level of nutrition in the water is dependent on season and water temperature, higher level occurring during summer. In the tropical region such variation may not occur, hence any significant correlation.

The results obtained in the above study could be very useful baseline information necessary for oyster aquaculture in the tropical region. One very important information is that tropical species have the ability to spawn throughout the year, therefore, a continuous supply of spat for aquaculture is possible.

Since most of the bivalves inhabit the coastal areas, aquaculture of bivalves in most cases are conducted in the coastal areas. Therefore, bivalves, whether they are naturally present or are cultured, become an integral part of the coastal ecosystem. They contribute significantly to the ecosystem. Conversely, they are affected by any negative impacts on the ecosystem.

Bivalves being filter feeders, make significant contributions to the ecosystem by extraction of particulate matter from the water column. Studies have shown (Dame *et al.*, 1984, 1985, 1989; Dame and Libes, 1993) that intertidal oyster reefs play a very important role in nutrient recycling. Oyster reefs uptake particulate organic carbon (POC), total organic carbon (TOC), nitrogen (N) and phosphorous (P) and are able to convert particulate materials into dissolved constituents. Carbon and Nitrogen are subsequently released as dissolved organic carbon and ammonia. The rates of uptake has been calculated (Dame *et al.*, 1984, 1989) as follows:

Phosphorous— $98\ g\ P\ m^{-2}\ yr^{-1}$
Nitrogen— $189\ g\ N\ m^{-2}\ yr^{-1}$
Total Organic Carbon— $1200\ g\ C\ m^{-2}\ yr^{-1}$
Particulate Organic Carbon— $1400–4400\ mg\ m^{-2}\ h^{-1}$

The rate of release of ammonia was calculated to be 1700–7250 $\mu g\ m^{-2}\ h^{-1}$. Conclusion drawn by Dame *et al.* (1989) was that oyster reefs processed carbon, nitrogen and phosphorous at high rates and appeared to function as retention mechanisms for nitrogen and phosphorous in estuaries.

Based on the filtering ability of bivalves, aquaculturists and scientists have been exploring the possibility of using bivalves as 'biological filters' of effluent with high nutrients, discharged from land based aquaculture systems or other sources.

Another important ecological role that bivalves play in the coastal ecosystem is the addition of larvae into zooplankton. One female oyster has the capacity to produce 50 million eggs in a single season. Due to a relatively long larval period of up to three weeks in the zooplankton, larvae become an important part of the food chain.

The long larval period also enables a wide dispersal range of bivalve larvae. Larvae of oysters are capable of dispersion over a distance as great as 1300 km. This dispersal capability contributes to colonisation of new areas, enhancement of bivalve populations, enrichment of the coastal ecosystem and maintenance of genetic variability.

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Major Changes in Environmental Conditions during a Decadal Time Scale of a Tropical Lagoon along East Coast of India

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Chilka lake (19° 28′–19°54′N; 85°05′–85°38′E) situated along the eastern seaboard of India is one of the largest water bodies in the tropics of Asia. The physical setting and hydrographical regime of the lake composing of brackish characteristics contribute to a highly productive ecosystem. During winter, it attracts more than one million migratory waterfowl from Siberia. Due to its rich biodiversity, it has been identified by the Government of India as a Ramsar site, under the convention of wetlands of international importance, since 1981. More than 100,000 fishermen depend on the lake resources directly or indirectly for their sustenance. Thus, the lake has a considerable impact on the socio-economic conditions of the people living in its vicinity and therefore needs regular monitoring and management from an ecological point of view.

The lake is formed by accumulation of coastal sediment in the beaches of the barrier berm spit over a period of time. The water-spread area of the lake varies between 1165 to 906 km^2 during the monsoon and summer seasons, respectively. A narrow intricate channel, 35 km long and 150 m wide, connects the main body to the Bay of Bengal. The lagoon receives drainage from the branches of a major Indian River system from the north and is surrounded by hills in the south. During the monsoon months, heavy precipitation results in the increase of water levels to over a meter. The tidal fluctuation inside the lagoon is small (around 0.2 m). Though tides of about 0.9–2.4 m occur along this coast, it is not strong enough to override the long channel and initiate an active circulation inside the lake. A huge amount of coastal sediment moves along this coast during the monsoon season (April to September), which results in blockage of the channel mouth or if carried through the channel, leads to siltation. All these factors lead to spatial stratification of the lake, and the lake is broadly classified into four/five major ecological sectors on the basis of its hydrographic distribution. The lake has undergone rapid changes in the last two decades and is facing major transformations such as shrinkage in total lake area, siltation/sedimentation, eutrophication and depletion of fishery resources, etc. As a part of a restoration program and to enhance the productivity of the lake, several developmental projects are on its way. A new mouth was cut across along the outer channel to the Bay of Bengal on the 23rd of September 2000 in order to improve the water quality and circulation pattern in the lake.

This paper highlights some of the major changes in the environmental conditions of the lake during a decadal time-scale based on our long-term field survey and Indian Remote Sensing (IRS) satellite data. A comprehensive assessment of the integrative physical, chemical and biological factors crucial to the functioning of the lake's ecosystem is reviewed and discussed. Some of the fundamental questions related to the pollution and fisheries of the lake are examined.

Limnological, meteorological and biological parameters monitored during the last 10 years at different seasons were found to be dependent on the physiographic conditions of the lake. The southern and central zones of the lake are deeper (~2 m) whereas the northern portion of the lake is very shallow (0.5~1 m) due to heavy sedimentation. Relatively warmer water is observed in the southern portion of the lake, largely attributed to the weak water exchange. The average salinity of the lake ranges from 0.55 to 16 psu. High saline water occupies in the central sector and the distribution pattern shows a