Abstract

Indian fisheries and aquaculture is an important sector of food production, providing nutritional security to the food basket, contributing to the agricultural exports and engaging about fourteen million people in different activities. With diverse aquatic resources, the country has shown continuous and sustained increments in fish production since independence. Constituting about 6.3% of the global fish production, the sector contributes to 1.1% of the GDP and 5.15% of the agricultural GDP. The total fish production of 10.07 million metric tonnes, presently has nearly 65% contribution from the inland sector and nearly the same from culture fisheries. However, occurrence of disease has become a primary constraint to sustainable aquaculture production and product trade, thereby affecting the socioeconomic status of fishers in country like India. Different stress factors such as inadequate physicochemical and microbial quality of culture water, poor nutritional status and high stocking density can cause infection by opportunistic pathogens. Acute level of pollutants and suspended solids can directly bring about abnormalities and mortalities in seed fishes and adults. Different opportunistic bacterial pathogens and parasites cause devastating loss to fish industry in terms of high morbidity and mortality, diminishing growth and enhanced expenditure on use of chemicals as preventive and control measures. The prevention of fish diseases is essential for the betterment of the fisheries industry, the improvement of farming production, and the increase in fish resources. The details of fish diseases in Indian freshwater aquaculture system and potential for future development have been elaborated.

Keywords

Antibiotics; Anti-Parasitic; Aquaculture; Chemicals; Feed Supplements; Fish Health Management; Probiotics

Introduction

The aquaculture sector in Asia has shown continuous growth and has contributed significantly to global aquaculture production. It is the fastest growing food production sector with an average annual growth rate of around 7.5%. The fisheries sector supplies 17% of animal protein and supports the livelihood of 12% of world’s population [1]. The global aquaculture production during 2014 was estimated to be 74 million tonnes with an estimated value of US$160.2 billion [2]. In India, with constant population growth, there has been rising demand for cheap source of animal protein for billions, emphasis has been given on up-scaling of aquaculture with species diversification and culture of fast growing fish species [3]. The fact that production from open water resources like rivers, wetlands, lakes and marine sector has shown declining trend, emphasis has now been given on aquaculture [4]. Thus, aquaculture sector has expanded rapidly to become a major global industry. While, Asia contributes more than 90% to the world’s aquaculture production, India now takes the second position with regard to annual fisheries and aquaculture production, only after China [5] and the country contributes to about 7.3% of the global aquaculture production [1]. India harbours more than 10% of global fish biodiversity [6] and there has been significant development in species diversification...
with intensification of culture methods. In India, more than 14.5
million people are directly or indirectly dependant on fisheries
for their livelihood security and it has been a major driver of so-
cio-economic development of rural poor, specifically in coastal
communities [7]. Transformation of the Indian fisheries sector
from traditional to commercial scale has led to an increase in
fish production from 7.5 lakh tonne in 1950-51 to 107.95 lakh
tonne during 2015-16 [6,8]. Fisheries sector contributes over 1%
of the total national Gross Domestic Product (GDP) and 5.3%
of agricultural (GDP). The sector has shown significant annu-
al growth at the rate of over 10%, which is one of the major
contributors to foreign exchange. The export earnings from the
sector has registered at 30,420.83 crore Indian Rupees (INR)
during 2015-16 (US$ 4.69 billion) [6,8,9]. It has been predicted
that fish consumption in developing countries will increase by
57 percent, from 62.7 million metric tons in 1997 to 98.6 million
in 2020 [4,10].

With the introduction of exotic Specific Pathogen Free (SPF) pa-
cific white shrimp, *Penaeus vannamei* in the year 2009 in India,
there has been remarkable growth in shrimp production during
last few years, touching all time high of 433448 metric tonnes
during 2014-15, with export revenues of over US$ 5.0 billion
[1,9,11]. The country has plans to increase the fish production
and productivity by 8 per cent annual growth rate and to reach 15
million tonnes mark by 2020 [8]. Despite phenomenal growth of
aquaculture sector both in fish and shrimp production during last
few years, the progress of aquaculture has caused some unwar-
ranted activities both for the species and environment. The con-
sequence has been increasing array of emerging and reemerging
diseases in aquaculture, adversely affecting growth of the sector
[12]. The total loss to aquaculture sector world-wide has been
estimated to be more than US$ 6.0 billion per annum [1]. In In-
dia, the loss due to disease outbreaks during 2006-08 in shrimp
farms located in nine coastal districts was estimated to be 1000
crores Indian Rupees (INR) [13]. This review examines present
status of fisheries and associated problems relating to occurrence
of emerging and reemerging diseases in fish and shellfish culture
with future scope of aquaculture development in India.

### Aquatic Resources in India

Aquatic resources in India are vast and diversified. The country
is bestowed with varied potential resources in the form of rivers
and canals (1.95 lakh km), floodplain lakes (7.98 lakh hectare),
ponds and tanks (24.33 lakh hectare), reservoirs (29.26 lakh
hectare) and brackish water (11.55 lakh hectare). The marine
fisheries resources are estimated at 4.41 million metric tonnes
and its activities spread along the country’s long coastline of
8118 km with 2.02 million square km Exclusive Economic Zone
(EEZ) [14,15]. In India, the aquatic resources are categorized as
i) Freshwater aquaculture ii) Brackishwater aquaculture iii)
Open water aquaculture (Wetlands, estuaries, Reservoirs, canals
e.) iv) Marine aquaculture/Mariculture. Cage culture is prac-
tised in open water resources especially in reservoirs and lakes.
The present status of Indian fisheries and aquatic resources have
been presented in table 1.

### Status of Indian Fisheries

| Global Position of Indian Aquaculture | Aquatic Resources |
|--------------------------------------|-------------------|
| 3rd in Fisheries; 2nd in Aquaculture | Coastsline: 8129 kms |
| Contribution of Fisheries to GDP (%) | Exclusive Economic Zone: 2.02 million sq.km |
| Contribution to Total Agricultural GDP (%) | Continental Shelf: 0.506 million sq.km |
| Per Capita Fish Availability (Kg.) | Rivers and Canals: 1,91,024 km |
| Annual Export Earnings (in million Indian Rupees) | Reservoirs: 3.15 million ha |
| Employment in Sector (million) | Ponds and Tanks: 2.35 million ha |
| | Wetlands/ Oxbow lakes and derelict waters: 1.3 million ha |
| | Brackishwaters: 1.24 million ha |
| | Estuaries: 0.29 million ha |

**Table 1:** Status of Aquaculture and Aquatic Resources in India (Adapted from NFDB [16]).
Freshwater aquaculture sector in India

Freshwater aquaculture sector contributes about 85% of the inland share. Average annual yield from freshwater system is around 3.0 tonnes/ha. The majority of aquaculture production of fish, crustaceans and molluscs continues to come from the freshwater environment (57.7% by volume and 48.4% by value) [17]. The fisheries in freshwater aquaculture are broadly of two types, fisheries in open water resources and fish culture in ponds or tanks. Three types of culture practices are being followed in open-water systems: i) Fish culture in small reservoirs/wetlands, ii) cage culture in reservoirs and iii) Fish culture in sewage fed bheries.

Aquaculture in ponds and tanks: The freshwater aquaculture sector has made significant progress from a domestic activity in eastern Indian states of India in West Bengal and Odisha to an enterprise in the states like Andhra Pradesh, Punjab, Haryana, Maharashtra, developing fish culture as a trade and enterprise. The largest area under aquaculture being in the state of Andhra Pradesh (0.52mha), followed by Karnatakta (0.41mha) and West Bengal (0.276mha). These three states account for about 50.5% of India’s aquaculture areas [18]. Currently, only an estimated 40% of the available resources in India, is in use for aquaculture because of technical and market access issues and there is lot of scope of development of aquaculture [5]. With technological inputs, productivity has gone up from 500-600kg/ha to 3000 kg/ha, with several farmers and entrepreneurs achieving higher production levels of 6-8 ton/ha/yr. The national average productivity has increased from 50 kg/hectare/year in 1974-75 to about 2135 kg/hectare/year in 1994-95 and 2,270 kg/ hectare/year in 2003-04 [19].

The freshwater aquaculture comprises of the culture of mainly three species of Indian Major Carps (IMC) viz. Catla catla (Catla), Labeo rohita (Rohu), and Cirrhinus mrigala (Mrigal) which constitute between 70% and 75% of the total freshwater fish production, with maximum emphasis on Labeo rohita production. Survey in different commercial farms indicated that most of the advanced farmers stock only IMCs in their ponds with variable proportion of these three species viz. Catla catla: Labeo rohita: Cirrhinus mrigala in the proportion of 80:15:5 or 90:10:0, whereas most traditional farmers stock in the proportion of 70:20:10 of these species, respectively. IMC culture has been popular in Indian subcontinent because of easy availability of quality fish seed and comparatively better growth potential (1.0–1.2 kg in 8-9 months of zero-point size stocking). In some farms three exotic species Hypophthalmichthys molitrix (Silver carp), Ctenopharyngodon idella (Grass carp) and Cyprinus carpio (Common carp) are cultured along with IMCs [18]. In some aquaculture zones, moniculture of catfishes (air breathing and non-air breathing) are also being carried out but market availability of fish seed has been a constant problem. Culture of Giant freshwater prawn, Macrobrachium rosenbergii (Scampi), which gained importance during post-tiger shrimp havoc, has less popularity because of non-availability of quality prawn seed and slow growth of the species. In India, three types of Tilapia are presently being cultured. Black Tilapia (Oreochromis mosambicus and Oreochromis niloticus) have been cultured in most parts of the country. Since this species fetch low market value, farmers imported red Tilapia from America and started breeding it. Recently MPEDA imported grey Tilapia from Philippines and opened its hatchery in Krishna district, Andhra Pradesh. At present, there’s a lot of demand for this fish and so MPEDA is working on its development, in coordination with other research Institutes and hatcheries [20].

Besides Tilapia, another exotic fish species, Pangasius (Pangasiandron hypophthalmus) has gained popularity in freshwater aquaculture for its high rate growth potential and less disease problems. However, quality seed availability of Pangasius and its lower consumer demand compared to IMCs, has been a major problem. However, in most cage cultures in India, seed of Pangasius or Tilapia are stocked. Another exotic fish called Pacu (Piaractus brachypomus) which has accessed to Indian aquaculture through illegal route, has gained popularity for its high growth potential, even in low saline pond culture systems, less occurrence of disease problems and appreciable meat quality. The fish produced in Indian freshwater aquaculture system are mostly consumed in domestic market because of high consumer demand and low market value at international market, nonetheless, some are also exported to neighbouring Asian countries as per the demand.

Potential of fish production from open-water resources: India is endowed with a vast expanse of open inland waters in the form of rivers, canals, estuaries, lagoons, reservoirs, lakes etc. In recent years traditional aquaculture has turned into a science based economic and commercial activity involving heavy inputs. Locally known as tal, jheel, maun, chaur, beel and pat in different states in India, floodplain wetland occupies an estimated area of over 354213 ha [21-23]. Although the vast and varied inland fishery resources of India have a rich production potential, this potential has not yet been utilized at optimum level. The production potential of river Ganga at its lower stretches is around 198 kg/ha/year, whereas the actual fish yield is only 30 kg/ha/year, indicating only 15% of the potential is harvested [21]. The reservoirs have been classified into three categories as small (<1000 ha), medium (1,000 to 5,000 ha) and large (>5000 ha) for the purpose of fisheries management [4,24]. The country has 19134 small reservoirs, 180 medium and 56 large reservoirs, with a total water surface area of 1485557 ha, 527541 and 1140268 ha, respectively, with a total area of 3153366 ha [21-23]. Although the vast and varied inland fishery resources of India have a rich production potential, this potential has not yet been utilized at optimum level. The production potential of river Ganga at its lower stretches is around 198 kg/ha/year, whereas the actual fish yield is only 30 kg/ha/year, indicating only 15% of the potential is harvested [21]. The reservoirs have been classified into three categories as small (<1000 ha), medium (1,000 to 5,000 ha) and large (>5000 ha) for the purpose of fisheries management [4,24]. The country has 19134 small reservoirs, 180 medium and 56 large reservoirs, with a total water surface area of 1485557 ha, 527541 and 1140268 ha, respectively, with a total area of 3153366 ha [25]. The State-wise area of reservoirs and fish production status and expected production potential have been presented in table 2. Prioritizing production of fish from reservoirs holds the key for increasing inland fish production in India. At the present level of management, the yield from Indian reservoirs is 50 kg/ha/year from small reservoirs, 20 kg/ha/year from medium-sized reservoirs and 8 kg/ha/year from large reservoirs, where as a production of 50-100kg/ha can be easily achieved from large reservoirs and 100-300 kg/ha from medium and small reservoirs, while still leaving scope for enhancing fish yield through capture fisheries, culture-based fisheries and cage culture [22,23].
Another typical open-water resource being employed in freshwater aquaculture is Sewage-fed fisheries. It is an important part of the productive activity being undertaken in the East Kolkata Wetlands. In these waste-fed fisheries, fish culture activity has been undertaken in nearly 4000 ha of water area [21]. Kolkata’s municipality, with the capacity to treat only 24% of the city’s 706 million litres of wastewater produced each day. The rest comes to the wetland and the city’s fishermen recycle it in their ponds using fish culture [27]. It is a unique and inexpensive system of rearing fish, without much input except fish seed. The uniqueness of these wetlands is that the sewage and wastewater of the city get treated in a natural way through the practice of sewage-fed fisheries. This helps the Kolkata Municipality to save almost INR 1,300 million per year for treating wastewater and for the fish farmers an expenditure of INR 60 million is averted every year for buying fish feed [28]. Majority of the sewage-fed fisheries in the East Kolkata wetlands area are under private ownership. The ecological condition limits the average production to only 1500 - 2000 kg/ ha [29]. The east Kolkata wetlands provide a living for some 50,000 cultivators and fish traders, most of them small-time private entrepreneurs who earn an income rearing 10,000 tonnes of wastewater-fed fish a year. Sewage which is of domestic origin is usually free from hazardous chemicals, however, microbial populations contained in sewage need to be checked regularly [27]. Despite occasional media scares about eating sewage-fed fish, Kolkata continues to depend on the practice for its food.

**Pen culture and cage culture:** Cage culture is being looked upon as an opportunity to utilize existing open-water resources to enhance production from inland open waters and posed as an answer to increased demand for animal protein in the country [4]. Fish production in wetlands and small reservoirs could also be enhanced through pen culture [22], specifically in raising fingerlings or fish seed material for stocking. There is enormous opportunity of fish production through cages with production potential of 4.5 tonnes/ cage [30]. Projecting that 1% of medium and large reservoir area would be utilized for cage culture in coming decades, would produce fish biomass in excess of the country’s requirement [30]. The cage aquaculture sector has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressures from globalization and growing demand for aquatic products in both developing and developed countries [4]. Currently there are
about 6000 cages of different dimensions installed in different wetlands in India. States like Jharkhand, Chhatisgarh, Odisha, Telangana, Maharashtra and Madhya Pradesh have made significant progress in cage culture in reservoirs. The predominant species being used in cage culture is Pangasius (Pangasiastodon hypophthalmus) or GIFT Tilapia. Trials with genetically improved variety of rohu called “Jayati Roohu”, Puntius javanicus, Labeo rohita, Lates calcarifer, Macrobrachium rosenbergii, besides air breathing fishes, ornamental fishes and Murrels are being undertaken to establish their success in cage culture [30]. A successful cage farming was initiated by the Jharkhand Government in Chandil reservoir during 2007, in a project mode ‘cage fish farming project to help address the problem of displacement of locals. This pilot project, was funded by the National Mission for Protein Supplement Scheme. With nearly 100% subsidy given by the State Government to the cooperative society, cage fish farming showed encouraging results. The state Fisheries Department provided the technical support and training to the farmers to manage and run these fish farms [31]. Presently there are more than 400 cages in operation with culture of Pangus and improved Tilapia.

Brackishwater aquaculture sector in India

India occupies fifth position amongst the major shrimp farming countries in the world [32]. Brackishwater aquaculture includes culture of shrimp varieties mainly, the native giant tiger prawn (Penaeus monodon) and exotic white leg shrimp (Penaeus vannamei). In addition to these culture of seabass (Lates calcarifer) and milkfish are largely practised in brackish water aquaculture. About 90% of the shrimp farmers in India are small scale farmers which own less than 2 ha of land [5,12]. Brackishwater shrimp farming sector in India has witnessed significant transformation over the last three decades. The development of hatchery technology for mass scale seed production of tiger shrimp Penaeus monodon along with involvement of farmers and timely intervention by agencies like Marine Products Export Development Authority (MPEDA) and ICAR Fisheries Research Institutes, paved the way for development of scientific shrimp farming in India in the 1980s [33].

Brackishwater shrimp aquaculture is mostly export oriented, considering high international value of the species cultured and demand at International market. Since late 1980s, the tiger shrimp culture saw many ups and downs due to high profitability and consumer demand. The most significant transformation in shrimp farming was the introduction of the non-native species, white leg shrimp P. vannamei, replacing the dominant native shrimp P. monodon during 2009-10. Between 1989 and 2007, the shrimp farming experienced a fivefold increase to 144.346 tonnes per year [33]. The details of Brackish water area developed for aquaculture different states in India has been presented in table 3.

| Sl No. | State/Union Territory | Estimated Potential (Ha) | Area Developed (Ha) | Area under Culture (Ha) | Production (MT) | Productivity (MT/Ha) |
|--------|------------------------|--------------------------|---------------------|------------------------|----------------|---------------------|
| 1      | Andhra Pradesh         | 150000                   | 84951               | 36123                  | 159083         | 4.40                |
| 2      | Goa                    | 185000                   | 340                 | 31                     | 63             | 2.03                |
| 3      | Gujarat                | 376000                   | 2371                | 2359                   | 9393           | 3.98                |
| 4      | Kerala                 | 65000                    | 14875               | 12917                  | 5175           | 0.40                |
| 5      | Karnataka              | 8000                     | 1945                | 394                    | 664            | 1.69                |
| 6      | Maharashtra            | 80000                    | 1330                | 1486                   | 3513           | 2.36                |
| 7      | Odisha                 | 31600                    | 13400               | 6302                   | 14532          | 2.31                |
| 8      | Tamil Nadu & Puducherry| 56800                    | 6248                | 7804                   | 25815          | 3.31                |
| 9      | West Bengal            | 405000                   | 50405               | 48410                  | 52581          | 1.09                |
| Total  |                        | 1190900                  | 175865              | 115826                 | 270819         | 2.34                |

Data indicates a total of 68846 ha area is under tiger shrimp culture in 9 maritime states producing 81452 MT with an average production of 1.18 MT/ha/year. The state of Gujarat records maximum productivity of 3.12 MT/ha/year followed by Tamil Nadu and Odisha with productivity of 2.70 and 2.02 MT/ha/year, respectively. Andhra Pradesh state has been the hub of modern aquaculture and the production trends in this state reflect directly in the country’s production [9,11]. Shrimp production data indicates nearly five times enhancement of shrimp production during last 15 years with a
mere production of less than 100,000 metric tonnes during 2000-
01 to around 500,000 metric tonnes during 2015-16 [35]. Figure
1 depicts progress of shrimp aquaculture development in India,
with variable composition of species during last 15. There has
been significant shift from primarily tiger shrimp *P. monodon*
production to predominant *P. vennamei* production to more than
80% of total shrimp production. Similarly, there has been signif-
icant foreign exchange earing through export of frozen shrimp
at International market with earning value of 2000 billion INR
during 2015-16.

Figure 1: Showing development of shrimp aquaculture production
in India, with variable composition of species during last 15 years
(Adapted with modification from: Aqua Aquaria India [6]).

Disease problems in freshwater aquaculture

Frequent occurrence of disease is one of the major constrains to
aquaculture and may eventually become a limiting factor for aq-
uaiculture development [36,37]. The increasing development of
aquaculture activities and with intensification of fish culture, has
led to increasing number of infectious diseases. It has been rec-
ognized that emerging infectious diseases have been rapidly in-
creasing in geographical range, host range with higher incidenc-
es of disease outbreaks in aquaculture, including those caused
by previously recognized and unrecognized pathogens [1,17].

A total loss of one billion US $ was reported due to diseases
in shrimps [34]. Fortunately, the disease problems in freshwater
aquaculture in India is minimal compared to its occurrence in
shrimp culture and their prevalence in neighboring Asian coun-
tries [38]. The disease occurrence pattern in India is variable in
culture methods like in pond culture, open-water culture and in
cage culture (Figure 2A-C). This may be due to types of culture
methods adopted by most farmers and comparatively higher re-
sistance status of IMCs, which are mostly grown in the region.

In pond/ tanks culture: Among all fish pathogens, parasitic
infestation has been the major cause of concern and causing
significant setback to freshwater aquaculture in India [39]. Fish
parasites multiply rapidly under poor water quality conditions,
there by affecting fishes, often leading to high morbidity. Fish
parasites, mostly, the protozoan ciliates (*Ichthyophthirius* sp.,
*Trichodina* sp.), monogenetic trematodes (*Dactylogyrus* sp.,
*Gy
-
rodactylus* sp.) and larger crustacean ectoparasites viz.
*Lernae*
spp., *Argulus* spp., *Ergasilus*, are the commonly reported from
cases of fish diseases. The *Ichthyophthirius*, cause “white spot”
or “Ich” in most freshwater fishes. *Trichodina* browse over gills
and skin, damaging the host tissue and consuming the resulting
dead tissues [40-42]. Parasites interfere with nutrition of hosts,
disrupts metabolism and secretary functions of alimentary canal
and damage nervous system [43], thereby reducing growth rate
and even mortality, which result in substantial economic loss in
fish culture system in India. It has been observed that in pond
cultures, parasitic infestations are major cause of concern flowed
by alteration in water quality (Figure 2A). Single or multiple
parasites are involved alone or along with bacterial infections
causing severe damage to host tissues [38]. Among all parasites
infestation with *Argulus* is maximum followed by *Dacylogy-
rous* sp. affecting gills. Occurrence of *Myxobolous*, *Trichodina*
and *Ergasilus* sp. are also reported but with less number of inci-
dences [38,39].

A wide variety of bacterial pathogens also cause major losses
to the freshwater aquaculture. These microorganisms are es-
sentially opportunistic pathogens which invade the tissues of a
fish host rendered susceptible to infection by stress factors [44].
Hence, poor or abnormal water quality is a predisposing factor
making the cultured fish susceptible to bacterial opportunistic

---

Figure (A-C): Showing variable disease patterns in cultured fish in different freshwater aquaculture systems, A.) Pond culture, B.) Open-water
culture, and C.) Cage culture systems, in India.
pathogens. Bacterial diseases like Motile *Aeromonas* septicaemia, *Edwardsiella*, *Pseudomonas* septicaemia, Flexibacteriosis, bacterial gill disease, streptococcal septicaemia, mycobacteriosis, columnaris disease etc. are often reported in various semi-intensive or intensive pond culture systems in India [45]. However, motile aeromonad septicaemia locally called as red disease, is considered to be the most common and troublesome among all bacterial diseases [38]. Contrary to number of bacterial and parasitic diseases, only a few number of fungi are shown to be pathogenic to fish. Mostly these are present in water and under unfavourable conditions, they attack the fish causing skin lesions. Most fungal infections recorded from fish are caused by species belonging to the oomycete fungi, *Saprolegnia*, *Achlya* and *Aphanomyces*. Diseases caused by these fungi are collectively called “saprolegniasis” [27]. Another important fungal induced disease in fish culture of high economic importance is Epizootic Ulcerative Syndrome (EUS). It is an important bacterial-fungal disease responsible high mortality in freshwater fishes [40]. It has been observed that in pond culture, bacterial induced infections like red disease, ulcerative disease, fin rot, eye disease are commonly reported in pond culture. Deterioration of water quality due to high stocking density, high organic load mostly due to accumulation of unused feed, less water exchange cause stress to animals making them prone to other microbial pathogens and parasitic infestations. Low Dissolved Oxygen (DO) level especially during winter or cloudy weather and high ammonia level are other factors responsible for fish kills. It has also been reported that when total alkalinity level falls below the optimum range (100 - 250 mg/L) in grow-out ponds, fishes become more susceptible to microbial infections. Occurrence of red spots, skin ulcerative disease and fin rot are reported in such conditions. Unless controlled at early stage, this may lead to secondary infections with other pathogens, causing mass mortality of cultured fish.

**In open water aquaculture:** The cases of fish mortalities in open-water ecosystems are very infrequent in India, considering low intensity fish culture practice being followed with low anthropogenic intervention in such systems. Since some of these open water resources serve as source for public supply and human consumption, there are restrictions of external inputs into the system, which otherwise make water unsuitable for human consumption. However, fish kills are sometimes reported in some reservoirs due to sudden change in water quality parameters of the system either due to weather changes or anthropogenic activities. Again, most of the floodplain wetlands (beels, bheries, lakes, and reservoirs) have either sub-optimal water quality or ecological condition that limit their production. Due to water extraction, siltation and in many cases due to influx of sewage or industrial effluents to the system, cause changes in water quality and degradation of aquatic environment causing fish kills [21]. Fish kills occur due to a number of reasons including abrupt change of temperatures (winter fish kills/summer fish kills), accidental spills, acid mine drainage, algal blooms (cyanobacteria, dinoflagellates), ammonia (NH₃) toxicity, hydrogen sulphide (H₂S) toxicity, hypoxia etc. There are several reports of fish kills in Indian lakes due to severe influx of domestic sewage, pesticides, tannery wastes, toxic and hazardous wastes, wastes from oil refinery, sugar mill effluents and microbial pathogens [21,42].

It has been observed that some of the wetlands are less managed and in various stages of eutrophication, majority of them are choked with submerged or floating vegetation and are having sub-optimal water quality [23]. This affect the general health condition of fish and most of the cultured animal are under stress and have retarded growth [21]. The DO level is sometimes reduced to less than 3.5 mg/L during night, causing stress to resident fish. More over un-ionized ammonia levels are in the range of 0.05-0.25 mg/L, which further add stress to animals [21]. In sewage fed bheries, the water quality point stress to cultured fish. Here the microbial consumption of DO (18mg/L/hour) indicate exhaustion of DO for few hours at night, creating stressful environmental condition for fish, that most fish swim on water surface gasping for air, often leading to mass mortality. Moreover, the un-ionized ammonia levels are very high (0.2-1.1 mg/L), causing a toxic environment for the fish [42]. Data on fish kills indicate that infectious disease problems in open-water system are very minimal. Most cases of fish kills in wetlands, beels or reservoirs occur mainly due to sudden change in water quality or water pollution either due to climatic change or human intervention (Figure 2B). Nonetheless some bacterial and parasitic problems have also been reported in some reservoirs in India, mainly due to induction of stressful environment [46]. Some cases of parasitic infestations, mainly by *Argulus* species and *Dactylogyrous* species are reported in some beels. Das MK [47] reported occurrence of EUS in some open-water bodies in India, causing variable mortalities in different geographical regions. However, incidence of bacterial or fungal diseases are very minimal in open-water systems in India.

**Disease problems in cage culture**

Management of fish disease in cage culture has been an area of concern and often responsible for catastrophic losses. Compared to pond culture, cage culture poses higher risk due to fish diseases, stress and growth limitations, vulnerability to natural disasters like storm etc. In cage culture, disease occurrence, morbidity and mortality are very high, because of high stocking density that favours disease transmission among the group [30]. Wild fish around the cage can transmit diseases to the caged fish [48,49]. The crowding in cages promotes stress and allows disease organisms to spread rapidly [4]. Localized water quality problems, particularly low dissolved oxygen, are common in cage culture. The high fish densities, along with the high feeding rates, often reduce dissolved oxygen and increase ammonia concentration in and around the cage, especially if there is no water movement through the cage [4]. Overwintering problems cause stress to animals. There is usually a high mortality rate because of bacterial and fungal diseases [50]. Different bacterial diseases...
like Motile Aeromonas septicaemia, Tail rot and Fin rot are commonly reported in cage culture [30]. Fungal diseases like Saprolegniasis, also called “Cotton wool disease” caused by Saprolegniasa parasitica and Achlya species are also commonly reported during winter months, when the cage nets are clogged with fouling agents. It has been observed that the incidences of fungal infections are maximum in cage culture systems, followed by infection with bacterial and parasitic infestations (Figure 2C). Presence of heavy load of organic matter from unutilized and decomposed feed, excreta, decaying biofouling organisms, promote rapid growth of fungi and trigger heavy mortality in cages.

Emerging diseases of fish in Indian aquaculture

There are no major emerging bacterial, fungal or parasitic pathogens so far been reported in freshwater aquaculture systems in India, except those commonly occurring bacterial, parasitic and fungal pathogens described above. Although prevalence of more than 125 different viruses have been reported in fish culture around the globe including many Asian countries and new viruses are being discovered every new date [1,51,52], Indian fishery sector has been fortunate in this regard that that occurrence of viral pathogens in fish culture has been very minimal. There are only few reports of viral diseases affecting food-fish in India only for a limited period without much economical loss to sector [53-56]. However, there are some reports of isolation of viral pathogens from ornamental fish in India [57,58] Viral pathogens like Cyprinid Herpesvirus-2 (CyHV-2), Koi Ranavirus (KIRV), Carp Edema Virus (CEV), Megalocytiviruses and Goldfish haematopoietic necrosis herps virus, have been reported in ornamental fish culture in India [52]. Recent reports indicated KIRV causing huge mortality of koi Cyprinus carpio in a farm in south India [52]. In addition to above, koi sleepy disease caused by CEV has been reported in Cyprinus carpio [58]. Viral Encephalopathy and Retinopathy (VER/VNN) or Betanodavirus was also reported for a period in seabass farming [53], although there was no subsequent major loss reported due to this disease in India. The details of emerging viral diseases in fin fish has been presented in table 4.

| Disease                                      | Virus                                      | Species Affected                                      | Known Geographic Distribution | OIE Listed | Whether Reported in India | References |
|----------------------------------------------|--------------------------------------------|------------------------------------------------------|-----------------------------|------------|---------------------------|------------|
| Koi Herpes Virus Disease (KHV)               | Koi Herpes Virus                           | Common carp (Cyprinus carpio) and Koi carp            | Asia, Europe, North America, Israel, Africa | Yes        | Reported in Koi carp but not in common carp (food-fish) | [54,59]    |
| Spring Viraeemia of Carp Virus (SVC)         | Spring Viraemia of Carp Virus (SVCV), (+)ssRNA, Mononegavirale Family: Rhabdoviridae, Vesiculovirus | Common carp (Cyprinus carpio) and Koi carp            | Europe, Asia, North and South America | Yes        | No                        | [3,60]     |
| Epizootic Haematopoietic Necrosis Virus Disease and other Ranaviruses | EHNV, dsDNA, Iridoviridae, Ranavirus       | Rainbow trout (Oncorhynchus mykiss), and redfin perch | Australia, Europe, Asia, North America, Africa | Yes        | No                        | [61]       |
| Red Sea Bream Irido Virus Disease (RSID)     | RSIV, dsDNA, Iridoviridae, Megalocytivirus | Chinese perch, red drum, Mugil cephalus and Epinephelus spp. | Japan, China Korea Malaysia, Philippines, Singapore, and Thailand | Yes        | No                        | [62]       |
| Viral Nervous Necrosis Virus                 | VNNV, (+)ssRNA, Nodaviridae, Betanodavirus | Seabass (Lates calcarifer)                            | Australia, Asia, Europe, North America, Africa        | No         | Yes                       | [10,52,63] |
Koi herpes virus disease: Common carp (Cyprinus carpio) is a widely cultivated freshwater fish for human consumption, while koi carp, a farmed colored sub species of common carp used for ornamental purposes. Since 1998, both common carp and koi carp were severely affected by Koi Herpes Virus (KHV) disease [57]. This disease is caused by Koi Herpes Virus (KHV), also known as cyprinid herpes virus-3, which is amongst the most common examples of an emerging disease of ornamental fish. CyHV-3 is a highly contagious pathogen, resulting up to 100% mortality in affected populations [65]. KHV is a member of the genus Cyprinivirus in the family Alloherpesviridae [12]. The virus causes interstitial nephritis and gill necrosis in carp, so it is also termed as carp interstitial nephritis and gill necrosis virus. KHV was reported be present in England from 1996, as evident by analysis of preserved tissue samples [66]. However, Hedrick et al., [56] reported occurrence of KHD, which subsequently spread globally by uncontrolled international trade of apparently healthy but sub-clinically infected koi carp [67]. Since then, outbreaks of KHDV are being regularly reported from Europe, South Africa, USA and Asia. It also affected the carp aquaculture industry resulting in heavy losses in common carp, Cyprinus carpio [68]. In view of its significance on fish trade, KHV is designated as OIE listed pathogen for finfish. In Asia, KHV has been reported from Israel, Indonesia, Taiwan, China, Thailand, Japan and Malaysia [57]. However, incidence of this disease is so far not reported in common carp (Cyprinus carpio) from India, in spite of its occurrence in neighbouring South East Asian countries [69]. This may be due to the fact that Indian Major Carps (IMC) are the major chunk of carps being cultured in India, which are so far shown not to be susceptible to KHV. However, there is every possibility that unregulated import of ornamental fish can lead to LHV host range expansion, thus adversely affecting other carp species. Hence strict surveillance and monitoring of KHV has been taken up in India to assess impact of KHV in carp culture.

Spring viraemia of carp: Spring Viraemia of Carp Virus (SVCV) is a fish Rhabdovirus in the genus Vesiculovirus. Initially believed to be endemic among common carp (Cyprinus carpio) in Eastern and Western Europe, the disease appeared in the spring to cause large losses among farm-reared carp [11,69,70]. Subsequently, SVCV has emerged in several regions of the world where it has been associated with heavy losses in common carp, both in food-fish and its ornamental variety, the koi carp. These outbreaks have also been reported in both farmed and wild fish, suggesting host range expansion [12]. Non-piscine carriers may include herons, leeches and parasitic copepods [51,71]. The young survivors are more susceptible to disease at water temperature up to 20°C. The survivors of this infection act as carrier of the virus. The virus enters the water through faeces, urine and spawning fluids as well as external mucous, skin secretion and infected eggs. Blood-sucking parasites such as copepods and leeches can transmit the virus from carp to carp [51]. Detailed survey carried out under ICAR-surveillance programme have indicated that SVC is not prevalent in Indian carp culture [69], while there are some reports of occurrence SVCV in ornamental fishes.

Viral nervous necrosis diseases: The first report of viral infection in Asian sea bass, Lates calcarifer was made by Glazebrook et al., [52] who described a picorna-like virus associated with mortalities of 15 to 20-day old larvae. This disease was also investigated by Munday et al., [72] in Asian sea bass and is known as Viral Nervous Necrosis Virus (VNNV) or Viral Encephalopathy and Retinopathy (VER) disease [73]. It is being caused by a piscine Nodavirus, which belongs to the genus Betanodavirus of the family Nodaviridae [74]. The disease has been reported in Australia, Indonesia and Singapore [72,75], and India. This disease is characterized by the development of a vacuolating encephalopathy and retinopathy of larval and juvenile marine fish [73]. VNN has been identified in a wide range of cultured marine fish and responsible for massive mortalities in affected stocks [72]. In India, the disease was first reported in hatchery produced larvae of Asian seabass, Lates calcarifer [53,56] and subsequently in some freshwater ornamental fish [55]. The disease affects the neuronal tissues of brain, spinal cord and eye [54,55]. Azad et al., [10] reported VNN in larvae of the Asian sea bass Lates calcarifer (Bloch) which suffered heavy mortalities (60 to 90%) during the hatchery-rearing phase. Parameswaran et al., [63] isolated VNN Virus from infected Asian sea bass (Lates calcarifer) larvae during the massive outbreak in sea bass hatcheries located in Chennai and Nagapattinam of Tamil Nadu, India. The present status indicate low prevalence status of the disease, may be due to selective culture of Asian sea bass in few locations of coastal districts.

Tilapia Lake Virus (TiLV): Tilapia farmers around the world are growing increasingly concerned about the growing number of incidences of Tilapia Lake Virus (TiLV), an emerging disease affecting farmed tilapia (Oreochromis niloticus) and another Tilapia (Oreochromis spp.) in the Asia-Pacific region [76-78]. TiLV is an Orthomyxo-like RNA virus and originally observed...
and reported in Israel, Ecuador, Colombia and Egypt [79]. The virus affected tilapia culture in Thailand, causing mortality up to 90 percent of stocks [77,79,80]. TiLV is thought to represents a significant threat to the global tilapia industry, which recorded a production in 2015 of 6.4 million tons with a value in excess of USD 9.8 billion. Global tilapia industry of US$7.5 billion per annum, is at stake as the top tilapia-producing countries in the region including China, the Philippines, Thailand, Indonesia, Lao PDR and Bangladesh are prone to this virus [79]. Hence, active TiLV surveillance is being conducted in China, India, Indonesia and it is planned to start in the Philippines [76]. According to a “Special Alert” released today by FAO’s Global Information and Early Warnings System, advisory have been issued that the outbreak should be treated with concern and countries importing tilapias should take appropriate risk-management measures - intensifying diagnostics testing, enforcing health certificates, deploying quarantine measures and developing contingency plans [76]. TiLV has caused about 80 per cent loss in countries of Israel, Latin America, Ecuador and Colombia. In India, although there are some reports of tilapia kills in some ponds, suspected to be TiLV, it has not yet be confirmed [81]. Hence Marine Products Exports Development Authority (MPEDA) have warned the aqua farmers about probable invasion of TiLV to aquaculture sector in India, so as to take suitable preventive measures to prevent production loss. Alert has also been issued to aqua farmers on the spread of TiLV and the Indian Council of Agricultural Research (ICAR) has sounded a caution to farmers on the outbreak of the virus in India [82]. However, no large-scale mortality due to this virus have been reported in India so far.

**Emerging diseases of shellfish in Indian aquaculture**

Viral diseases are a major problem in the shrimp aquaculture industry worldwide and several viral outbreaks often cause catastrophic losses in shrimp farming around the globe [83]. Shrimp are arthropods and most shrimp viruses are either related to those previously known to infect insects (e.g., densovirusues, dicistroviruses, baculoviruses, nodaviruses, luteoviruses) or are completely new to science and have been assigned to new taxa [12]. In India, during initial phase of commercial shrimp farming development in some coastal states during late 1980s, there were emergence of different diseases in shrimp culture which included luminescent bacterial disease, Vibriosis, Bacterial septicaemia and Larval mycosis, mostly due to poor pond management. However, the losses were minimal. However, with growth of shrimp aquaculture sector in India during last two decades, the proportion of disease occurrence has significantly increased and the shrimp aquaculture in India is at stake. The details of emerging diseases of shrimp which have been prevalent in South East Asian (SE) Countries and are concern to Indian aquaculture have been presented in table 5.

| Sl No. | Disease | Etiological agent | Geographical location of disease | Present Status in India | References |
|-------|---------|-------------------|----------------------------------|-------------------------|------------|
| 1.    | White tail disease/ White Muscle Disease of freshwater prawn | *Macrobrachium rosenbergii Nodavirus* (MrNV), non-enveloped virus 26–27 nm, ssRNA (RNA1 and RNA2) | China, Taiwan Thailand and another SE Countries & Australia | Reported in India during 2004. Presently there are no reports of MrNV induced mortality in India | [7,84,85] |
| 2.    | Monodon Baculovirus (MBV) Disease | Monodon Baculo Virus (MBV), dsDNA, size 75X300 nm, Baculovirus, occluded | Thailand, Indonesia, Taiwan and Philippine and other SE countries, | Large scale loss during 1993 in South India, became less virulent, presently no MBV incidences | [68,86-88] |
| 3.    | Yellow Head Disease (YHD) | Yellow Head Virus (YHV), (+)ssRNA virus, genus: *Okavirus*, family: *Roniviridae*, order *Nidovirales*, Size: (40-50 X 150-170) nm | Thailand in 1990, India, China, Indonesia, Malaysia, Philippines, Sri Lanka, Vietnam and Taiwan, reported in Mexico | After first report of occurrence during 1993-94, the disease has not been reported in Indian aquaculture | [21,89,90] |
| 4.    | White Spot Disease (WSD) | White Spot Syndrome Virus (WSSV), Baculovirus, dsDNA, enveloped, (100-140 X 270-420 nanomicrons, Family: *Nimiviridae*, Genus: *Whispovirus* | China, Taiwan Japan. Asian pandemic, 1999, reported in Latin America, presently panzootic throughout shrimp farming regions of Asia and the Americas | Initially reported during 1994-95, caused wide spread damage, continuing problem reported but virulence comparatively reduced | [4,22,58,87] |
White tail disease/White muscle disease of freshwater prawn:

Freshwater prawn, Macrobrachium rosenbergii is an economically important crustacean that is cultured on a large scale in many countries including India [106] as it has been considered as a moderately disease resistant aquaculture species with high economic value. However, occurrence of White Tail Disease (WTD) or White Muscle Disease (WMD) cause severe loss to prawn industry in many SE countries including India. The causative organisms were identified as M. rosenbergii Nodavirus (MrNV) and its associated Extra Small Virus (XSV) [107]. The disease was first reported in 1995 from the island of Guadeloupe and then reported by Martinique in the French West Indies, and has since been reported from China, [94] Taiwan [94,108], Thailand [50], India [107] and Australia [109]. Affected prawns show signs of whitish tails to milky-white muscles, leading to up to 100% mortality. In India, this disease was reported towards the later part of 2001 and most of the hatcheries and nursery ponds in Andhra Pradesh and Tamil Nadu states suffered major losses due to this disease [99]. MrNV is a small, icosahedral, non-enveloped virus 26-27 nm in diameter. The genome is formed by two pieces of ssRNA (RNA1 and RNA2) of 2.9 and 1.26 kb, respectively, and there is a single polypeptide of 43 kDa in the capsid [110]. Qian et al., [111] reported the occurrence of an additional Extra Small Virus (XSV) in prawns with WTD collected from China. Sahul Hameed et al., [112] reported presence of these two viruses in WTD-infected prawns in India. The interest in M. rosenbergii culture gradually declined in India because of disease outbreak in hatchery and culture ponds with large scale mortality of prawn larvae. Subsequently, there has been low rate of M. rosenbergii since last 10 years in many parts, specifically due to this pathogen and other factors like non-availability of quality prawn seed, long duration of culture and low profitability. Consequently, the incidences of MrNV has gradually declined to zero incidence level. Recent reports indicate that MrNV is still prevalent in Andhra Pradesh [113] but mortality and loss due to this pathogen has been non-significant.

Monodon Baculovirus (MBV): Penaeus monodon-type Baculovirus (MBV) was the first reported virus of P. monodon and the second virus of penaeid shrimp, which is a Nuclear Polyhedrosis Virus (NPV) of the family Baculoviridae [114]. After the first report of MBV in Taiwanese P. monodon [114] MBV became wide spread in several penaeid prawns in different geographical regions [115]. Incidence of MBV was reported to be present in 70-100% in various hatcheries and ponds in Thailand, Indonesia, Taiwan and Philippines [116,117]. In India, outbreak

### Table 5: Status of Emerging Diseases of shellfish prevalent in South East Asian (SE) Countries and concern to India [97].

| Pathogen                                      | Country                           | Description                                                                 | Mortality/Impact                                                                 |
|-----------------------------------------------|-----------------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Taura Syndrome Virus (TSV)                    | Ecuador, China, Taiwan, Thailand | Mainly affecting Indian and South East Asian (SE) countries                 | New TSV strains emerging?                                                       |
| Infectious Hypodermal and Hematopoietic       | Western Hemisphere, Americas, China, Taiwan, Thailand, Malaysia, Indonesia & others SE countries | Status of Emerging Diseases of shellfish prevalent in South East Asian (SE) Countries and concern to India [97]. |
| Hepatopancreatic Parovirus (HPV) disease       | Asia, Africa, Australia and north and South America | Reported in India during 2002-03, no wide spread, no significant loss reported |
| Infectious Myonecrosis Virus (IMNV) disease    | Brazil, spread to Indonesia, China, Made its way into SE Asia | Reported in India (Andhra Pradesh, West Bengal), so far, no serious outbreaks or loss reported |
| Acute Hepatopancreatic Nercrosis Disease / Early Mortality Syndrome (AHPND/EMS) | Southern China, Vietnam, Thailand and Malaysia. Devastating loss in Thailand other SE Countries | Reported in India in 2015-16 (in Andhra Pradesh and Tamil Nadu), low-level mortalities, |
| Hepatopancreatic Microsporidiosis (HPM)       | First seen in 2001 in Thailand, Widespread in China, Vietnam, Thailand, Indonesia and Malaysia | Reported in South India shrimp farms, “slow growth syndrome” |

Citation: Mishra SS, Das R, Choudhary P, Debbarma J, Sahoo SN, et al. (2017) Present status of Fisheries and Impact of Emerging Diseases of Fish and Shellfish in Indian Aquaculture. J Aquat Res Mar Sci 2017: 5-26.
of MBV was reported from 1994-1999, causing serious mortalities within populations of cultured giant tiger prawn, *Peneaus monodon* (Fabricious) and Indian white shrimp, *Peneaus indicus*, leading to severe economic losses and virtual collapse of prawn farming in maritime states in India [75,118-121]. It was reported that the virus was carried to the region with imported shrimp-seed consignment by some farmers in south India, subsequently spreading to other regions [119]. As with all NPVs, MBV it has a double stranded circular DNA genome of 80-100 x 10^6 Da within a rod shaped, enveloped particle often found occluded within proteinaceous bodies [122]. Transmission of MBV usually occurs horizontally through faecal oral route. MBV in the faecal matter of brood stock, infect eggs and larvae in hatcheries. The prevalence of MBV in the hatchery can be substantially reduced by washing the eggs or nauplii before they are transferred to rearing tanks [123]. In India, MBV was found to be established in the region. However, within two - three years of onset of disease, MBV was observed in low virulent state and many farmers obtained shrimp harvest in spite of stock being infected with MBV. Subsequently, it was noted that *P. monodon*, well tolerated this pathogen and MBV has not been a problem for shrimp culture in India.

**Yellow head disease:** Yellow Head Disease (YHD) caused by Yellow Head Virus (YHV) was the first major viral that caused extensive loss to tiger shrimp farms in Thailand during 1990-91. YHV was first detected in central Thailand in 1990 in pond reared black tiger prawns *Peneaus monodon* [16]. YHV was widespread in cultured stocks of *P. monodon* in Thailand and others SE countries. Shrimps infected with YHV died within a few hours of developing color and the whole crop was lost within 3-5 days after the first appearance of affected shrimp [124,125]. It was the most virulent of shrimp pathogens, commonly causing total crop loss within several days of the first signs of disease in a pond [96]. Besides *P. monodon*, YHV was also been shown to infect *P. vannamei* and *P. stylirostris* [125]. *Palaemon syliferus* and *Acetes* sp. have been recorded as carriers of YHV. Occurrence of YHV was reported in major shrimp farming countries including India, Indonesia, Malaysia, the Philippines, Sri Lanka, Vietnam, Taiwan and Mexico [12,16,126]. In India, YHD was first noticed in different semi-intensive shrimp farms along Kangaluru creek in Nellore district of Andhra Pradesh during 1994 [119,127]. Mass mortality up to 100% was reported within 3-4 days on onset of disease. Moribund shrimp showed yellowish discoloration and swelling of hepatopancreas. The yellow color in the cephalothorax region was due to the underlying yellow hepatopancreas visible through the translucent carapace in moribund shrimp [16]. Histopathological analysis revealed severe necrosis of hepatopancreatic tubules with presence of cosinophilic bodies in lumen and inter/intra cellular spaces [92]. The disease outbreak was found to be localized, might be due to transmission of pathogen in imported shrimp-seed. However, due to awareness campaign and efforts by the local farmers, the spread of YHV could be controlled [119]. After that one outbreak, no cases of YHV outbreak has so far been reported in India. YHV is an enveloped, rod-shaped (+)ssRNA virus with a helical nucleocapsid and prominent glycoprotein projections on the virion surface [63]. It has been classified within the order *Nidovirales* in the family *Roniviridae*, genus *Olakavirus* [128]. YHV is known to exist as at least 3 different genotypic clades [126]. The original YHV clade reported from Thailand differs from Gill Associated Virus (GAV) clade of Australia by approximately 15% in nucleic acid sequence. Third intermediate clade has been found in Thailand and Vietnam and have been included in a YHV-complex [126].

**White spot disease:** The most striking emerging disease in shrimp farming which has caused serious havoc in aquaculture industry around the globe is White Spot Disease (WSD), caused by WSSV. This virus was first reported in 1992 in *P. japonicus* cultured in north-eastern Taiwan [129]. It was soon after reported in Taiwan and Japan and became panzootic throughout shrimp farming regions of Asia and the Americas [11,111]. Incidence of WSD was reported to be 70-100% in various hatcheries and ponds in Thailand, Indonesia, Taiwan and Philippines [116]. Considering its virulent nature, wide host range, wide geographic distribution, high mortality, catastrophic economic losses, WSSV has become the single most dangerous virus to the penaeid shrimp farming industry [111].

In India, culture of tiger shrimp, *Peneaus monodon*, was in steady progress globally, until 1992-1993, when it was struck by WSSV, the third viral disease in the series. Within a short span of time, the disease became pandemic and the farmers suffered severe loss as most of the farms were virtually wiped out because of this disease [118]. This led the farmers to adopt alternate farming system like extensive, modified extensive culture instead of semi-intensive culture and replacement of *P. monodon* with giant freshwater prawn *Macrobrachium rosenbergii* (de man) in order to minimize loss. However subsequent reports indicated occurrence of WSSV in many farms, specifically along south-east coast and south-west coast of India [117], even in ponds with *M. rosenbergii* culture [130] virtually collapsing shrimp aquaculture in India. Subsequently, SPF stock of *L. vannamei* was introduced to India, which showed tremendous potential of growth and market value till WSSV and other pathogens impacted production of *P. vannamei* in India [39]. Thus, WSSV is continuing a serious viral problem in India as in other SE countries, warranting urgent attention to control this viral problem.

WSSV is a large, enveloped, ovaloid DNA virus with a flagellum-like tail and helical nucleocapsid that has been classified as the only member of the new family *Nimaviridae*, genus *Whis povirus* [104]. WSSV has a very broad susceptible host range in decapod crustaceans [1]. The WSSV has been considered as a serious threat to prawn culture because it infects a wide spectrum of crustaceans like crabs, lobsters and shrimp, some of which act as potent carriers [131]. It is now observed that WSSV occurs commonly as a low level persistent infection. However, rapid increase in virus load, precipitated by physiological stress, salinity changes or temperature variation can aggravate disease,
resulting in heavy mortality and significant production loss to aquaculture [1]. Despite these difficulties, fisheries managers and aquaculturists are still retaining an optimistic outlook for India’s shrimp aquaculture industry [132].

**Taura syndrome:** Taura syndrome was reported as a new disease in 1992 in commercial penaeid shrimp farms located near the mouth of river Taura in the Gulf of Guayaquil, Ecuador [133]. The disease spread rapidly throughout most shrimp farming regions of Central and South America [59]. In 1998, it was detected in Taiwan and subsequently spread throughout much of Asia [134]. This disease represents a serious problem in the culture of *P. vannamei* due to the high level of mortality and the economic losses [135]. TSV causes 3 distinct disease phases in infected shrimp. The per acute/acute phase of the disease is characterized by moribund shrimp displaying an overall pale reddish coloration caused by the expansion of the red chromatophores. Shrimp in this phase usually die during the process of moulting. If the shrimp survive through the per acute/acute phase, the recovery phase begins. Multifocal, melanized cuticular lesions are the major distinguishing characteristics of the recovery phase [59]. In the chronic phase of TSV infection, infected shrimp appear and behave normally, but remain persistently infected perhaps for life [55]. Rapid spread of the TSV in pond populations occurs through cannibalization of infected moribund and dead shrimp by healthy members of the same population [136]. The susceptible host range of TSV is far more restricted than that of WSSV but includes most farmed marine shrimp species [12]. However, susceptibility to disease varies and virulence varies for different strains of the virus. Other crustaceans including freshwater shrimp and crabs appear to be resistant to disease but may be potential carriers [137]. Taura Syndrome Virus (TSV) is a small, naked (+)ssRNA virus that is currently classified as an unassigned species in the family *Dicistroviridae*, order *Picornavirales* [138]. Although prevalent in neighbouring Asian countries, TSV has not yet been reported in Indian aquaculture. Hence stringent quarantine measures and surveillance programmes have been undertaken to control its access to Indian aquaculture.

**Infectious hypodermal and hematopoietic necrosis virus:** Infectious hypodermal and Hematopoietic Necrosis Virus (IHHNV) like White Spot Virus (WSV) has been an important DNA virus infecting penaeid shrimp in the Western Hemisphere and Asian counties [83]. Natural infection by IHHNV has been reported for most shrimp (*Penaeus* sp.) species [83]. IHHNV was discovered as early as 1981 when it was highly virulent to *Penaeus stylirostris* resulting in high mortality [83]. It has been reported that *P. vannamei* and *P. monodon* infected with IHHNV do not show mortality. However, infection by this virus results in a disease called Runt-Deformity Syndrome (RDS) in both species [98], and this can also cause substantial economic losses. The genome organization revealed that IHHNV belongs to the family *Parvoviridae* and is closely related to mosquito *brevi- densovirus* [112]. In India, Sheela et al., [93] detected IHHNV in cultured *P. monodon* in Tamil Nadu. Presence of this virus in cultured *L. vannamei* as a single agent or co-infection of this virus either with WSSV and other viruses have been reported [139]. However, the virus does not cause lethal infection in *P. vannamei*, instead, it causes reduction in growth and a variety of cuticular deformities of the rostrum, antenna, and other thoracic and abdominal areas [93]. Losses of revenue due to runt deformity syndrome range from 10 to 50% depending on the level of infection. Although present is some pockets, IHHNV has not been a serious problem for Indian aquaculture.

**Hepatopancreatic Parovirus (HPV):** Hepatopancreatic Parovirus (HPV) was first reported by Lightner and Redman [79] in cultured populations of 4 different penaeid shrimp species from 4 separate culture facilities in China (*Penaeus chinensis*), Singapore (*P. merguensis*), the Philippines (*P. monodon*) and Kuwait (*P. semisulcatus*). In Thailand, HPV was first reported during 1992 in the black tiger shrimp, *P. monodon* [140] this virus infects several penaeid species and is widely distributed in many parts of the world, including Asia, Africa, Australia and North and South America [59,141]. A number of cultured and wild penaeids have been reported as hosts for HPV [100]. High levels of HPV infection have been reported especially in early juvenile stages [73] and the transmission of HPV is believed to be both vertical and horizontal [78]. Shrimp affected by HPV show non-specific gross signs, including atrophy of the hepatopancreas, anorexia, poor growth rate, reduced preening activities and a consequent increased tendency for surface and gill fouling by epimennosal organisms [100]. Currently, HPV is considered a member of the *Paroviridae* [15] but its position within the family still remains uncertain. In India, Presence of HPV in *P. monodon* post larvae in India was reported by Manivannan et al., [94] and Umesha et al., [95]. However, there have been no reports of large scale mortality or production losses in Indian aquaculture due to HPV.

**Infectious myonecrosis:** Infectious Myonecrosis Virus (IMNV) is a viral pathogen of shrimp and is responsible for causing an infection, namely Infectious Myonecrosis (IMN) in *L. vannamei*, this virus causes severe mortality in grow-out system. The IMNV was first reported in cultured *L. vannamei* in Brazil in 2003-04 [142] loss of ~$20 million [96]. The disease was subsequently reported in Indonesia during 2006 [143]. In Indonesia and Hainan, China, the disease also caused heavy production loss cultured shrimp [96]. To date IMNV was detected in East Java, Bali, and West Nusa Tenggara provinces [96,124]. In India, IMNV was detected in East Godavari district in Andhra Pradesh [99] and in Purba Medinipur District, West Bengal [98]. Seed sourced from Kakinada probably contained this virus. The disease was confirmed during 55-70 days of culture and mortality was 15%. Clinical signs observed were lethargic, slow growth with growth variation, whitish abdominal muscle, muscle cramp and full gut [99]. However, mortality due to this virus was not so significant. More work is in progress to confirm the pathogen. IMNV is a Totivirus and closely related to *Giardia lamblia* virus and belongs to the family *Totiviridae* [76]. IMNV is an unenveloped virus which isicosahedral in shape and measures 40 nm in
diameter. The viral genome consists of a single double-stranded RNA molecule of 8,230 bp [98].

Other emerging diseases in shrimp culture

4.7.1 Acute hepatopancreatic necrosis disease/Early mortality syndrome: Acute Hepatopancreatic Necrosis Disease (AH-PND) also commonly called Early Mortality Syndrome (EMS) is currently the most important non-viral disease threat for cultured shrimp *P. vannamei*. It is usually characterized by mass mortality during the first 35 days of culture. The disease has been severely impacting shrimp production since 2010 in Southern China, Vietnam, Thailand and Malaysia [1]. EMS devastated shrimp farms in Thailand and other countries in Southeast Asia during 2014-15, triggering a global shortage of shrimps [101]. This disease is caused by certain strains of ubiquitous in marine and brackishwater bacteria called *Vibrio parahaemolyticus* [101]. In India, EMS in *P. vannamei* culture was reported in Andhra Pradesh and Tamil Nadu during 2015-16, which caused significant production loss in *P. vannamei* culture. Affected farms suffered continuous low-level mortalities, low survival and reduced productions [101,113]. Mortality rate was relatively more in low saline ponds. White or yellow faecal matter noticed in the gut. The mortality percentage was very high in most of the cases. Several farmers have lost their crops. In the beginning, the farmers managed the situation by immediately removing the dead shrimps. Some farmers reduced the stocking densities and were able to harvest the crop successfully without EMS [113]. In India, the disease has been apparently not as destructive as that reported in other SE countries.

Microsporidiosis due to *Enterocytozoon Hepatopanumaei* (EHP): Hepatopancreatic Microsporidiosis (HPM) is caused by *Enterocytozoon Hepatopanumaei* (EHP) [105]. The microsporidian parasite was reported to affect black tiger shrimp *Penaeus monodon* in Thailand in the year 2009. Since then, EHP has spread to other countries. The disease is widespread in China, Vietnam, Thailand, Indonesia, India and probably Malaysia [82,110]. In India, with increasing intensive shrimp farming with imported SPF *P. vannamei* in Asia, this parasite has transmitted to *P. vannamei*, causing huge loss to Indian shrimp industry [1,104]. During October 2015, India’s Marine Products Export Development Authority (MPEDA) gave warnings about the spread of EHP in India’s shrimp farms [132]. Low level prevalence of EHP associated with “slow growth syndrome” in tiger shrimp was reported. EHP sometimes found along with White Feces Syndrome (WFS). It caused retarded growth when copies above 10^7/ng total HP DNA and Copy of >10^9 was reported to cause mortality [82]. Observations on EHP infected samples of *P. vannamei* causes retarded growth observed after 90 days of culture with white/empty gut and discoloration of hepatopancreas and floating white faeces in the pond water. EHP, a spore forming parasite finds a suitable host in a shrimp, starts hatching and continues to seize the growth of the shrimp [104]. The fungus does not appear to be directly fatal, but it severely slows down growth by infecting the hepatopancreas which can lead to starvation [132]. The economic losses to aquaculture seem to be substantial, mainly due to slow growth and overall reduction in farm production. Severe infections by EHP can increase the susceptibility to other bacterial infections like *Vibrio* spp. in shrimp farms and could manifest mortality.

White gut disease or White faeces syndrome: White Gut Disease (WGD) also called White Faece Syndrome (WFS) was observed in *L. vannamei* culture ponds in India [113]. Incidences of WFS is normally observed after 50-60 days of stocking of the PLs [144]. WFS in shrimp arises from transformation, sloughing and aggregation of hepatopancreatic microvilli into verniform bodies, which superficially resembles like with protozoan Gregarines. White faecal matter floats on the water surface in the culture ponds. Gregarine protozoans along with huge amount of pathogenic *Vibrio* bacteria may be responsible for WFS. *Vibrio* species have been found in the faecal analysis from infected shrimps [41,81]. Early disease indications appear in feed trays and at water surface, where abundant floating white faeces are normally observed. Poor water quality, unhealthy seed, high loads *Vibrio* spp. and presence protozoa gregarines like organisms in the intestine and hepatopancreas are some of reasons for causes of the disease [109,113]. However, the actual cause of disease is debated. Some farmers reported use of some organic preparations like mixture of garlic and tamarind extract, applied directly to water or mixed with feed when applied for 3-4 days, was very effective in controlling EMS.

Factors Responsible for Disease Emergence

Emerging diseases of fish and shrimp are mainly of two categories, i) those which were present in dormant state either in the host or in the environment but subsequently acquired virulent status mainly due to stressful condition of the host and ii) those pathogens which have acquired broad host range and geographical adaptability, causing disease in new host or in new environment. Virus infections may occur commonly in wild fish and shrimp but these often pass undetected in the environment [1,111]. This may be due to the process of natural selection in which the susceptible individuals are lost and resistant varieties grow in the natural environment. Hence the wild fish or shrimp may carry viruses in carrier state which may under favourable environment get expressed causing large scale mortality. There are many factors responsible for emergence of pathogens in Indian aquaculture which have been broadly classified in to three categories i) International factors ii) National factors and iii) Regional factors.

International factors

The main International factor includes increased international trade of live animals and animal food with increased chances of transmission of pathogens to different geographical locations. With the growth in aquaculture around the globe, there have
been increasing international trade in fish/shrimp and fish-food, which has resulted in increased trans-boundary movement, thus resulting in spread of pathogens through in live aquatic animals and their products [145]. Considering high local demand, cheaper source of shrimp seed, often low quality and contaminated with infectious agents, reach the region through legal and illegal route and porous international boundaries. Similarly, legal or illegal trans-boundary movement of infected or carrier ornamental fish by individuals or companies involved in global ornamental fish trade are also an important driver of viral disease emergence [11,146]. The international trade in frozen commodity of shrimp or shrimp products have also been recognised as a potential mechanism of trans-boundary spread of disease [83]. Several reports have indicated the presence of infectious WSSV and YHV in frozen commodity shrimp imported to the USA and Australia [12], thus spreading the pathogen to other regions. International movement has also resulted expression of latent or avirulent pathogen to get reverted to virulent state under suitable environmental, geographical and host conditions. As was observed in shrimp, IHHNV, Yellow-Head-Complex Viruses (YHV) and MrNV in Macrobrachium rosenbergii, which were appear to be naturally endemic in healthy wild populations, have become emerged as significant pathogens only as a consequence of stringent aquaculture practices, translocation of hosts and under stressful environments [11,147]. Again, emergence of IHHNV in Hawaii and the Americas, was reported due to translocation of the natural host, *P. monodon*, from the Philippines to Hawaii, where these were used in breeding programs, thereby allowing transmission of pathogen into susceptible shrimp species in western hemisphere [12]. In India, occurrence of IHHNV, TSV and MRNV was reportedly introduced through susceptible host *P. vannamei*, which were not earlier reported in tiger shrimp *P. monodon* culture. Amongst ornamental fish viruses, occurrence of Cyprinid Herpesvius-2 (CyHV-2), KHV, Koi Ranavirus (KIRV), Carp Edema Virus (CEV), *Megalocytivirus* and Goldfish haematopoietic necrosis herpes virus were reportedly introduced from wild and stocked in culture ponds for raising. With the development of hatchery breeding technologies, matured brood-stocks were collected from wild and used for seed production. Traditionally, shrimp seed were collected from wild and stocked in culture ponds for raising. With the development of hatchery breeding technologies, matured *P. monodon* brood-stocks were collected from wild and used for production of Post Larvae (PLs) and raided for stocking, as was the practice in many Asian countries. This method of use of wild shrimp seed were collected from wild and stocked in culture ponds for raising. With the development of hatchery breeding technologies, matured *P. monodon* brood-stocks were collected from wild and used for production of Post Larvae (PLs) and raided for stocking, as was the practice in many Asian countries. This method of use of wild brood-stock worked well for nearly a decade, till shrimp virus struck the region. The wild brood-stock which was once the basis involving various ICAR Research Institutes and Universities, which resulted in increased discovery/ reporting of fish and shrimp viruses in the region. Since India is signatory to OIE and Network of Aquaculture Centres in Asia-Pacific (NACA), Bangkok and occurrence of any disease in aquaculture is immediately reported to NACA. This led to reporting of new fish viruses like CyHV-2, KHV, Koi Ranavirus (KIRV), Carp Edema Virus (CEV), *Megalocytivirus* and indicated that Indian freshwater aquaculture sector is still free from Koi Herpes Virus (KHV) and Spring Viremia of Carp Virus (SVCV), which have caused havoc in most SE counties. Similarly, occurrence of WSSV, IHHNV, TSV, IMNV, AHPND/EMS and *Enterocytozoon Hepatopenaei* (EHP) microsporidian parasite etc. were reported by the researchers in various culture facilities, because of active surveillance. On the other hand, without a specific “National Aquaculture Policy” and “National Aqua Drug Use Policy”, there has been wide business especially, fish seed across the states, even use of exotic species in aquaculture in India and rampant use of aqua-medicines, drugs and chemicals in aquaculture sector [116]. Although some Indian states have State specific aquaculture policy, these are not strictly enforced and not properly implemented. This has led to spread of pathogen transmission to various aquatic resources across the country, enhancing incidences of disease outbreaks. To control disease and production loss, farmers are in habit of using various aqua-drugs, chemicals and formulations (most of which are imported and packed locally) to protect their crop. This has led to deterioration of aquatic environment, further making cultured animals susceptible to pathogens.

**Regional factors**

Strict enforcement of regulations and adoption of better management practices are essential to be adopted at each farm level for sustainable growth of aquaculture sector. The most important regional factor has been i) Regional development of aquaculture sector with involvement of higher economic class of entrepreneurs controlling aquaculture sector. The aquaculture activities in India is complicated as various categories and economically able farmers have been involved in aquaculture activities in various regions adopting different culture practices. While most involved are small and marginal farmers with small land holds, maximum aquaculture farms belong to few economically strong entrepreneurs, which control aquaculture activities in the zone. So, any step taken by a section of entrepreneurs, impact the entire section of aquaculture farmers. Again, while some marginal farmers adopted moderately extensive and semi-intensive culture methods, with IMC/Tilapia or Pangasius culture, even without much external inputs like application aqua-drugs and chemicals. Another regional factor was ii) dependency of farmers on wild stock for seed production. Traditionally, shrimp seed were collected from wild and stocked in culture ponds for raising. With the development of hatchery breeding technologies, matured *P. monodon* brood-stocks were collected from wild and used for production of Post Larvae (PLs) and raised for stocking, as was the practice in many Asian countries. This method of use of wild brood-stock worked well for nearly a decade, till shrimp virus struck the region. The wild brood-stock which was once the source of PLs production, became the source of pathogen, and ultimately responsible for the major shrimp disease pandemics in the region. The other factors include iii) Increasing anthropo-
genic activities causing stress to animals. The increasing rate of emergence of diseases of fish and shrimp has been driven primarily by anthropogenic activities. The environmental impacts of increasing loads of pollutants, contaminants and toxins in aquatic habitats also threaten the health and disease-resistance of both native and farmed fish populations. Increasing application of various aqua-medicines, drugs and chemicals on the advice of so-called “fish-health consultants” or representatives of chemical manufacturers, have led to increasing load of contaminants in culture systems. Although such practice has helped temporary protection against fish diseases, the aquatic environment gets polluted, causing stress to animals, thereby making cultured animals prone to microbial diseases. Survey also revealed that most farmers did not have proper knowledge about the chemicals and they use such aqua drugs as per the advice of fish-consultants or chemical suppliers in the region [116]. Indiscriminate use of such antibiotics and chemicals may lead to development and spread of antimicrobial resistant bacteria and resistance genes and occurrence of antimicrobial residues. All that may induce a negative impact on human, fish and the environment.

**Future of Indian Aquaculture**

The future of aquaculture in India lies in the hands of the aquaculturists or fish farmers who think of fish as the source of food and nutrition but not for higher income in a short span. While fishery sector has seen not much adverse impact because of domestic consumption of the produce, shrimp aquaculture has been a risky business as the produce is totally exported with high economic gain. Hence there is an urgent need for implementation of “National Aquaculture policy” to control sustainable growth of aquaculture sector, prohibiting unwarranted activities in terms of seed, brood-stock use and application of antibiotics and chemicals in aquaculture sector. To mitigate the concern, Government of India is seriously taking steps in this regard. The Coastal Aquaculture Authority and MPEDA have been actively monitoring aquaculture activities in India. Again, to control emergence of viral pathogens in to Indian sector, the Department of Animal Husbandry, Dairying and Fisheries (DAHDF), Ministry of Agriculture, Government of India is seriously taking steps in this regard. The National emphasis has been to doubling the farmer’s income. This could be achieved through fish production enhancement from inland open water bodies, specifically employing selective stocking and harvesting of suitable fish species [22]. Again, cage culture is being looked upon as an opportunity to utilize existing reservoirs with great production potential to enhance production from inland open waters and posed as an answer to increased demand for animal protein in the country.

Realizing the immense scope for development of fisheries and aquaculture, the Government of India has restructured the Central Plan Scheme under an umbrella of “Blue Revolution” [35]. Under this scheme, specific target has been made to enhance the fish production from present level of 107.95 lakh tonnes to about 150 lakh tonnes by 2020. It would lead to augmentation of export earnings, which would directly and indirectly benefit the fishers and fish farmers, with nearly doubling their income [14,15]. The Department of Animal Husbandry Dairying and Fisheries (DAHDF), Ministry of Agriculture, Government of India, has prepared a detailed proposal called “National Fisheries Action Plan-2020” (NFAP) for the next 5 years with sole objective of enhancing fish production by 8 percent annual growth rate, to achieve the concept of Blue Revolution. The mission would be operated through National Fisheries Development Board (NFDB) in collaboration with State Governments and ICAR Research Institutes, for their specific components [8].

Besides modern culture practices, research on disease surveillance, pathogen zoning and disease forecasting would help to take up suitable preventive and control measures to protect the
crops against eventualities. The development and export of Specific Pathogen Free (SPF) stocks of *Peneaus vannamei* (the Pacific white shrimp) from the USA to the major shrimp farming countries of Latin America and SE Asia is cited by FAO as being the main contributor to the industry’s recovery and subsequent expansion following the viral pandemics of the early 1990’s [76]. Due emphasis now to be given for local development of SPF brood-stock of *P. monodon*, *P. indicus* and *P. vannamei*, on the lines of step being taken by National fisheries Development Board for carp culture. Due emphasis need to be given on disease control strategies. As in other countries, there are so far, no preventive or prophylactic vaccines are made available for protection against emerging bacterial and viral pathogens of fish and shrimp. Besides development of rapid diagnostics, suitable surveillance and early warning system need to be developed for aquaculture sector in India. The biosecurity programme need to be tightened up to produce SPF or SPR stocks for use in aquaculture. Implementation of proper national regulations and collaboration with other regional, national and international agencies is the need of the hour for sustainable development of aquaculture sector in India.

Acknowledgments

The authors are grateful to Director ICAR-CIFA, Bhubaneswar for all kind of necessary support and encouragement for the present work. The cooperation and assistance provided by all State Fisheries Department for providing necessary information, is duly acknowledged. Authors are also thankful to Indian Council of Agricultural Research (ICAR), New Delhi, for financial support in form of “ICAR- All India Network Project on Fish Health” and to the Project Coordinator, ICAR-Central Institute of Brackishwater Aquaculture, Chennai, for necessary support.

References

1. AGDAFF-NACA (2007) Aquatic animal diseases significant to Asia-Pacific: Identification field guide. Australian Government, Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

2. Āhameda K, SAARC Agricultural Information Centre (2005) Handbook on Fish and crustacean diseases in the SAARC region. (1st edn), SAARC Agricultural Information Centre, Bangladesh.

3. Ahn W, Bjorklund HV, Essbauer S, Fijian N, Kurath G, et al. (2002) Spring Viremia of Carp (SVC). Dis Aquat Organ 52: 261-272.

4. Algarswami K (1995) Status report on shrimp disease outbreak in coastal aquaculture farms on the east coast of India during 1994-1995, for the Technical Committee, Government of India, Ministry of Agriculture, New Delhi, India.

5. Andrews S (2015) India’s Shrimp Aquaculture Industry Remains Hopeful Despite Onset of Disease. The Fish Site, 5m Publishing, Sheffield, England.

6. Aqua Aquaria India (2017) Aquaculture Production in India. Aqua Aquaria India, Kerala, India.
53. Haenen O, Hedrick R (2006) Koi herpesvirus workshop. Bull Eur Ass Fish Pathol 26: 26-37.

54. Haenen OLM, Way K, Bergmann SM, Ariel E (2004) The emergence of koi herpesvirus and its significance to European aquaculture. Bull Eur Ass Fish Pathol 24: 293-307.

55. Hasson KW, Lightner DV, Poulos BT, Redman RM, White BL, et al. (1995) Taura syndrome in Penaeus vannamei: demonstration of a viral etiology. Dis Aquat Org 113: 125-162.

56. Hedrick RP, Gilad O, Yun S, Spangenberg JV, Marty GD, et al. (2000) A herpesvirus associated with mass mortality of juvenile and adult koi, a strain of common carp. J Aquat Anim Health 12: 44-57.

57. Holmyard N (2017) Tilapia virus, spreading rapidly, poses threat to global food security. SeafoodSource, USA.

58. Ignatius B (2016) Cage Aquaculture. Training Manual on Thera-naiypuna - Equipping Fisherwomen Youth for Future. Ch. 31, ICR-AR-Central Marine Fisheries Research Institute, Kochi, India. Pg no: 175-178.

59. Rathore G, Kumar G, Swaminathan TR, Swain P (2012) Koi Herpes Virus: A Review and Risk Assessment of Indian Aquaculture. Indian J Virol 23: 124-133.

60. Walker PJ, Winton JR (2010) Emerging viral diseases of fish and shrimp. Vet Res 41: 51.

61. OIE (World Organisation For Animal Health) (2017) Tilapia lake virus (Tilv)-A novel Orthomyxo-like virus, OIE, Paris.

62. OIE (The World Organisation for Animal Health) (2009) Manual of Diagnostic Tests for Aquatic Animals. OIE, Paris.

63. Parameswaran V, Rajesh Kumar S, Ishaq Ahmed VP, Sahul Hameed AS (2008) A fish nodavirus associated with mass mortality in hatchery-reared Asian Sea bass, Lates calcarifer. Aquaculture 276: 366-369.

64. Surachetpong W, Janetanakit T, Nonthabenjawarn N, Tattiypong P, Sirkananchana K, et al. (2017) Outbreaks of Tilapia Lake Virus Infection, Thailand, 2015-2016. Emerg Infect Dis 6: 1031-1033.

65. Jimenez R (1992) Sindrome de Taura (Resumen). In: Acuicultura del Ecuador, Camara Nacional de Acuicultura, Guayaquil, Ecuador. Pg no: 1-16.

66. Jithendran KP, Shekhar MS, Kannappan S, Azad IS (2011) Nodavirus infection in freshwater ornamental fishes in India: diagnostic histopathology and nested RT-PCR*. Asian Fish Sci 24: 12-19.

67. Kalaimani, N, Ravisankar T, Chakravarthy N, Raja S, Santiago TC, et al. (2013) Economic Losses due to Disease Incidences in Shrimp Farms of India. Fishery Technology 50: 80-86.

68. Karnataka G, Kumar V (2014) Potential of cage aquaculture in Indian reservoirs. International Journal of Fisheries and Aquatic Studies 1: 108-112.

69. Karunasagar I, Otta SK, Karunasagar I (1997) Histopathological and bacteriological study of white spot syndrome of Penaeus monodon along the west coast of India. Aquaculture 153: 9-13.

70. Kalagayan H, Godin D, Kanna R, Hagingo G, Sweeney J (1991) IHNV virus as an etiological factor in Runt-Deformity Syndrome (RDS) of Juvenile Penaeus vannamei cultured in Hawaii. J World Aquaculture Soc 22: 235-243.

71. Katicha PK, Jena JK, Pillai NGK, Chakraborty C, Dey MM (2005) Inland Aquaculture in India: Past Trend, Present Status and Future Prospects. Aquaculture Economics & Management 9: 237-264.

72. Munday BL, Langdon JS, Hyatt AD, Humphrey JD (1992) Mass mortality associated with a viral-induced vacuolating encephalopathy and retinopathy of larval and juvenile barramundi, Lates calcarifer Bloch. Aquaculture 103: 197-211.

73. Prem K, Sanjay K, Sudhakar D, Shiv Kumar S, Himabindu (2015) An Overview of Fisheries and Aquaculture in India. Agro-Economist 2: 1-6.

74. Lightner DV (1996) A Handbook of Pathology and Diagnostic Procedures for Diseases of Penaeid Shrimps. World Aquaculture Society, Baton Rouge, LA, USA.

75. Kiatpathomchai W, Jaroenram W, Arunrut N, Gangnonngiw W, Boonyawiwat V (2008) Experimental infections reveal that common Thai crustaceans are potential carriers for spread of exotic Taura syndrome virus. Dis Aquat Organ 79: 183-190.

76. Lightner DV (2011) Status of shrimp diseases and advances in shrimp health management. In: Bondad-Reantaso MG, Jones JB, Corsin F, Aoki T (eds.), Diseases in Asian Aquaculture VII. Fish Health Section, Asian Fisheries Society, Selangor, Malaysia. Pg no: 385.

77. Lightner DV, Redman RM (1981) A baculovirus-caused disease of the penaeid shrimp, Penaeus monodon. Journal of Invertebrate Pathology 38: 299-302.

78. Lightner DV Redman RM (1992) Penaeid virus diseases of the shrimp culture industry of the Americas. In: Fast AW, Lester J (eds.). Marine Shrimp Culture: Principles and Practices. Elsevier, Amsterdam, USA. Pg no: 569-588.

79. Lightner DV, Redman RM (1985) A parvo-like virus disease of penaeid shrimp. J Invertebr Pathol 45: 47-53.

80. Lightner DV, Redman RM, Poulos BT, Nunam LM, Marie JL, et al. (1997) Risk of spread of penaeid shrimp viruses in the Americas by the international movement of live and frozen shrimp. Rev Sci Tech 16: 146-160.

81. Limsuwan C (2010) White Feces Disease in Thailand. Boletines Nicolas magazine 2010: 2-4.

82. Liu Z, Zhang QL, Wan XY, Huang J (2016) Development of real-time PCR assay for detection of microsporidian Enterocytozoon hepatopenaei and detection in shrimp samples under different growth rates. Progress in Fishery Science 37: 119-126.

83. Lu Y, Tapay LM, Brock JA, Loh PC (1994) Infection of the Yellow head Baculo-like Virus (YBV) in two species of penaeid shrimp, Penaeus stylirostris (Stimpson) and Penaeus vannamei (Boone). J Fish Dis 17: 649-656.

84. Sahul Hameed AS, Yoganandhan K, Sri Widada J, Bonami JR (2004) Experimental transmission and tissue tropism of Macrobrachium rosenbergii Nodavirus (MVN) and its associated Extra Small Virus (XS V). Dis Aquat Organ 62: 191-196.

85. Tripathy S, Sahoo PK, Kumar J, Mishra BK, Sarangi N (2006) Multiplex RT-PCR detection and sequence comparison of viruses MrNV and XSV associated with white tail disease in Macrobrachium rosenbergii. Aquaculture 258: 134-139.

86. Mishra SS (1996) Prawn disease epizootics in India and its remedial measures. In: Proceedings of National Workshop on fish and prawn
disease epizootics and quarantine adoption in India, Central Inland Fisheries Research Institute, Barrack pore, West Bengal. Pg no: 16.

87. Monohar BM, Sundararaj A, Selvaraj D, Sheela PRR, Chidambaram P, et al. (1996) An outbreak of SEMBV and MVB infections in cultured Penaeus monodon in Tamil Nadu. Indian J Fish 43: 403-496.

88. Vijayan KK, Alavandi SV, Rajendran KV, Alagarswami K (1995) Prevalence and histopathology of Monodon Baculovirus (MBV) infection in Penaeus monodon and P.indicus in shrimp farms in the south-east coast of India. Asian Fisheries Science 8: 267-72.

89. Cowley JA, Dimmock CM, Spann KM, Walker PJ (2000). Detection of Australian Gill-Associated Virus (GAV) and Lymphoid Organ Virus (LOV) of Penaeus monodon by RT- nested PCR. Dis Aquat Org 39: 159-167.

90. Walker PJ, Cowley JA, Spann KM, Hodgson RAJ, Hall MR, et al., (2001) Yellow head complex viruses; transmission cycles and topographical distribution in the Asia-Pacific region. In: Brodwy CL, Jory DJ (eds.). The new wave: Proceedings of the Special Session on Sustainable Shrimp Culture. Aquaculture World Aquaculture Society, Baton Rouge, USA. Pg no: 292-302.

91. Lightner DV, Redman RM, Bell TA (1983) Infectious hypodermal and hematopoietic necrosis, a newly recognized virus disease of penaeid shrimp. J Invertebr Pathol 42: 62-70.

92. Otta SK, Anuraj R, Ezhil Praveena P, Manivel R, Panigrahi A, et al. (2014) Association of dual viral infection with mortality of Pacific white shrimp (Litopenaeus vannamei) in culture ponds in India. J Virodisese 25: 63-68.

93. Sheela RR, Muralimohanbor A, Sundarraj A, Selvaraj D, Chidambaram P, et al. (1998) Infectious Hypodermal and Haemato poetic Neerosis Virus (IHHNV) in cultured Penaeus monodon in Tamil Nadu. India, Indian J Fish. 45: 183-186.

94. Manivannan S, Otta SK, Karunasagar I, Karunasagar I (2002) Multiple viral infection in Penaeus monodon shrimp postlarvae in an Indian hatchery. Dis Aquat Org 48: 233-236.

95. Umesha KR, Uma A, Otta SK, Karunasagar I, Karunasagar I (2003) Detection by PCR of Hepatopancreatic Parvovirus (HPV) and other viruses in hatchery-reared Penaeus monodon postlarvae. Dis Aquat Org 57: 141-145.

96. OIE (World Organisation for Animal Health) (2007) Infectious Myonecrosis. OIE Aquatic Animal Disease Cards, Paris, France.

97. Pantoja CR, Lightner DV, Poulos BT, Nuan L, Tang KFJ, et al. (2008) Paper Presented on Overview of Diseases and Health Management Issues Related to Farmed Shrimp, OIE Reference Laboratory for Shrimp Diseases Department of Veterinary Science & Microbiology, University of Arizona, Tucson, USA.

98. Sahul Hameed AS, Abdul Majeed S, Vimal S, Madan N, Rajkumar T, et al. (2017) Studies on the occurrence of infectious myonecrosis virus in pond-reared Litopenaeus vannamei (Boone, 1931) in India. J Fish Dis 40: 1823-1830.

99. Mastan SA (2017) Incidences of Running Mortality (RM) in Litopenaeus vannamei culture system of Andhra Pradesh.

100. Srinivas D, Venkatrayal Ch, Laxmappa B (2016) Identifying diseases affecting farmed Litopenaeus vannamei in different areas of Nellore district in Andhra Pradesh, India. International Journal of Fisheries and Aquatic Studies 4: 447-451.

101. Towers L (2015) New shrimp disease effecting India’s shrimp production. The Fish Site, 5m Publishing, England, UK.

102. Vijayan KK, Kumar S, Alavandi SV (2017) Emerging pathogens in Brackishwater aquaculture and challenges in aquatic health management. In: Proceedings of International Symposium on aquatic Animal Health and Epidemiology for sustainable Asian Aquaculture, ICAR-National Bureau of Fish Genetic Resources, Lucknow, India. Pg no: 140-144.

103. Chayaburarakul1 K, Nash G, Pratapanipat P, Srirurairatana S, Witthychummarunk1 B (2004) Multiple pathogens found in growth-retarded black tiger shrimp Penaeus monodon cultivated in Thailand. Dis Aquat Org 60: 89-96.

104. Rajendran KV, Shivram S, Ezhil Praveena P, Joseph Sahaya Rajan J, Sathish Kumar T, et al. (2016) Emergence of Enterocytocozoon Hepatopneumoniae (EHP) in farmed Penaeus (Litopenaeus) vannamei in India. Aquaculture 454: 272-280.

105. Tourti S, Wongtripop S, Stentiford GD, Bateman KS, Srirurairatana S, et al. (2009) Enterocytocozoon hepatopneumoniae sp. nov. (Micromysopora: Enterocytocozoonidae), a parasite of the black tiger shrimp Penaeus monodon (Decapoda: Penaeidae): Fine structure and phylo genetic relationships. J Invertebr Pathol 102: 21-29.

106. Sahul Hameed AS, Jean-Robert Bonami (2012) White Tail Disease of Freshwater Prawn, Macrobrachium rosenbergii. Indian J Virol 23: 134-140.

107. Mana SK, Das BK (2017) Fish Health Management in Freshwater Cage Culture. In: Souvenir-National Seminar on Strategies, innovations and sustainable management for enhancing coldwater fisheries and Aquaculture, ICAR- Directorate of Cold Water Fisheries Management Institute. Bengaluru. Pg no: 31-36.

108. Manohar BM, Sundararaj A, Selvaraj D, Sheela PRR, Chidambaram P, Mohan AC, Ravishankar B (1996) An outbreak of SEMBV and MBV infections in cultured Penaeus monodon in Tamil Nadu. Indian J Fish 43: 403-406.

109. Mastan SA, (2015) Incidence of White Feces Syndrome (WFS) in farm reared shrimp, Litopenaeus vannamei, Andhra Pradesh. Indo American Journal of Pharmaceutical Research 5: 3044-3047.

110. Matrix Sea Foods (2017) EHP - A New Scourge for Indian Shrimp Farmers. Matrix Sea Foods India Pvt Ltd, India.

111. Qian D, Shi Z, Zhang S, Cao Z, Liu W, et al. (2003) Extra Small Virus-like particles (XSV) and Novadivirus associated with whitish muscle disease in the giant freshwater prawn, Macrobrachium rosenbergii. J Fish Dis 26: 521-527.

112. Sahul Hameed AS, Yogananthand K, Widada JS, Bonami JR (2004) Studies on the occurrence of Macrobrachium rosenbergii novadivirus and extra small virus-like particles associated with white tail disease of M. rosenbergii in India by RT-PCR detection. Aquaculture 238: 127-133.

113. Mishra SS (1996) Prawn disease epizootics in India and its remedial measures. In: Proceedings of National workshop on fish and prawn disease epizootics and quarantine adoption in India, Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal. Pg no: 16-25.

114. Mishra SS (2000) Shrimp Viruses: Their pathogenicity, diagnosis and control. In: Advances in Aquaculture, Natarajan P, Jayaprakash V (eds.). Department of Aquatic Biology and Fisheries, University of Kerala, Thiruvananthapuram. Pg no: 239-246.
Citation: Mishra SS, Das R, Choudhary P, Debbarma J, Sahoo SN, et al. (2017) Present status of Fisheries and Impact of Emerging Diseases of Fish and Shellfish in Indian Aquaculture. J Aquat Res Mar Sci 2017: 5-26.

115. Mishra SS, Rakesh D, Dhiman M, Choudhary P, Debbarma J, et al. (2017a) Present Status of Fish Disease Management in Freshwater Aquaculture in India: State-of-the- Art-Review. Journal of Aquaculture & Fisheries 1: 003.

116. Mishra SS, Das R, Das BK, Choudhary P, Rathod R, et al. (2017b) Status of Aqua-medicines, Drugs and Chemicals Use in India: A Survey Report. Journal of Aquaculture and Fisheries 1: 004.

117. Mishra SS, Swain P, Rakesh D, Pani KC, Sarkar S (2017) Investigation of Mass mortality in Derjiang Reservoir in Angul District, Odisha, India, during April -2017. Report submitted to ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, India.

118. Mohan CV, Bhatta R (2002) Social and economic impacts of aquatic animal health problems on aquaculture in India. In: Arthur JR, Phillips MJ, Subasinghe RP, Reantaso MB, MacRae IH (eds.). Primary Aquatic Animal Health Care in Rural, Small-Scale, Aquaculture Development, FAO Fish Tech. Pg no: 63-75.

119. Mohanty BR, Sahoo PK (2007) Edwardsieliosis in fish: a brief review. J BioSci 32: 1331-1344.

120. Mori K, Nakai T, Muroga K, Arimoto M, Mushiake K, et al. (1992) Properties of a new virus belonging to nodaviridae found in larval striped jack (Pseudocaranx dentex) with nervous necrosis. Virology 187: 368-371.

121. MPEDA (2016) State-wise aqua culture productivity: Area utilized and production of tiger Shrimp during 2015-16, The Marine Products Export Development Authority, Ministry of Commerce & Industry, Government of India, Kochi, Kerala.

122. NACA (Network of Aquaculture Centres in Asia-Pacific) (2017) Tilapia Lake Virus (TLV) - an Emerging Threat to Farmed Tilapia in the Asia-Pacific Region. Disease Advisory. Asia Regional Aquatic Animal Health Care in Rural, India. In: Proceedings of International Symposium on aquatic Animal Health and Epidemiology for sustainable Asian Aquaculture, ICAR-National Bureau of Fish Genetic Resources, Lucknow, India. Pg no: 27-29.

123. NFDB (National Fisheries Development Board) (2016) Guidelines for Cage culture in inland open water Bodies of India, National Fisheries Development Board, Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi. Pg no: 14.

124. Nunes AJP, Martins PCC, Gesteira TCV (2004) Carcinicultura ameçada. Rev Panoram Aquic 83: 37-51.

125. OIE (Office International des Epizooties) (1997) Viral encephalopathy and retinopathy or viral nervous necrosis. In: Diagnostic manual for aquatic animal diseases, OIE, Paris. Pg no: 99-107.

126. Owens L, La Fauce K, Juntunen K, Hayakikjosol O, Zeng C (2009) Macrobrachium rosenbergii nodavirus disease (white tail disease) in Australia. Dis Aquat Org 85: 175-180.

127. Otta SK, Karunasagar I, Karunasagar I (2003) Detection of Monodon Baculo Virus (MBV) and White Spot Syndrome Virus (WSSV) in apparently healthy Penaeus monodon from India by polymerase chain reaction. Aquaculture 220: 59-69.

128. Patnaik AK (1990) An action plan for the development of Cultu- ta seafarmed ponds systems: In L Waste water fed aquaculture. In: Edwards P, Pullin RSV (eds.), Proceedings of the International seminar on Waste Water Reclamation and reuse for aquaculture. Calcutta, India. Pg no: 223-235.

129. Purohit M (2014) Their land lost to a dam, 2,000 farmers take to fishing – in cages. India Water portal, Bangalore, India.

130. Rajendran KV (2017) Health Management and Biosecurity in shrimp aquaculture in India-a review. In: Proceedings of International Symposium on aquatic Animal Health and Epidemiology for sustainable Asian Aquaculture, ICAR-National Bureau of Fish Genetic Resources, Lucknow, India. Pg no: 19-21.

131. Rajendran, KV, Vijayan KK, Santiago TC, Krol RM (1999) Experimental host range and histopathology of White Spot Syndrome Vi- rus (WSSV) infection in shrimp, prawns, crabs and lobsters from India. J Fish Dis 22: 183-191.

132. Rakus K, Ouyang P, Boutlier M, Ronsmans M, Reschner A, et al. (2013) Cyprinid herpesvirus 3: an interesting virus for applied and fundamental research. Vet Res 44: 85.

133. Ramasamy P, Brennan G, Jayakumar R (1995) A record and prevale- nce of Monodon baculovirus from post-larval Penaeus monodon, in Mardas, India. Aquaculture 130: 129-135.

134. Rohrmann GF (1986) Polyhedrin structure. J Gen Virol 67: 1499-1513.

135. Romestand B, Bonami JR (2003) A Sandwich Enzyme Linked Im- munosorbent Assay (S-ELISA) for detection of MnNV in the giant shrimp freshwater, Macrobrachium rosenbergii (de Man). J Fish Dis 26: 71-75.

136. Sahoo PK, Pradhan PK, Sundaray JK, Lal KK, Swaminathan TR (2017) Present Status of freshwater fish and shellfish diseases in India. In: Proceedings of International Symposium on aquatic Animal Health and Epidemiology for sustainable Asian Aquaculture, ICAR-National Bureau of Fish Genetic Resources, Lucknow, India. Pg no: 27-29.

137. Sahoo PK, Goodwin AE (2012) Viruses of Freshwater Finfish in the Asian-Pacific Region. Indian J Virol 23: 99-105.

138. Sahoo PK, Mohanty J, Gamayak SK, Mohanty BR, Kar B, et al. (2013) Estimation of loss due to argulosis in carp culture ponds in India. Indian J Fish 60: 99-102.

139. Shike H, Dhar AK, Burns JC, Shimizu C, Jousset FX, et al. (2000) Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) of shrimp is related to mosquito brevidensoviruses. Virology 277: 167-177.

140. Flegel TW, Srirairatana S (1994) Shrimp health management: an environmental approach. In: Subasinghe RP, Shariff M (eds.). Diseases in aquaculture: The Current Issues. Malaysian Fisheries Society Publication No. 8. Kuala Lumpur, University Pertanian Malaysia, Malaysia. Pg no: 1-48

141. Siddick A, Girigan G, Mishra CS, Oliver King EDI, Goddard E (2014) Home gardens and fish ponds for nourishment and empowerment. IDRC Stories of Change.

142. Tang KF, Pantoja CR, Poulou BT, Redman RM, Lightner DV (2005) In situ hybridization demonstrates that Lipoenaviruses vannelami, L. styliostis and Penaeus monodon are susceptible to experimental infection with Infectious Myonecrosis Virus (IMNV). Dis Aquat Organ 63: 261-265.

143. Senapin S, Pheuwaiai K, Briggs M, Flegel TW (2007) Outbreaks of Infectious Myonecrosis Virus (IMNV) in Indonesia confirmed by genome sequencing and use of an alternative RT-PCR detection method. Aquaculture 266: 32-38.

144. Srirairatana S, Boonyawiwat V, Gangnonngiw W, Laosutthipong S, Senapin S, Phewsaiya (2013) Cyprinid herpesvirus 3: an interesting virus for applied and fundamental research. Vet Res 44: 85.
145. Subasinghe RP, Bondad-Reantaso MG (2008) The FAO/NACA Asia regional technical guidelines for the responsible movement of live aquatic animals: lessons learned from their development and implementation. Rev Sci Tech 27: 54-63.

146. Whittington RJ, Chong R (2007) Global trade in ornamental fish from an Australian perspective: the case for revised import risk analysis and management strategies. Prev Vet Med 81: 92-116.

147. Tang KF, Lightner DV (2002) Low sequence variation among isolates of Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV) originating from Hawaii and the Americas. Dis Aquat Org 49: 93-97.