INTRODUCTION

The first documented studies on fish nutrition date back to early Nineteen thirties. It was however, only after the second World War, the field attracted greater attention as an area of separate investigation or as part of the overall studies on the biology of fishes. In the earlier years, the methods commonly employed in animal husbandry studies were also applied to study the food and feeding habits of fishes. These methods though posed considerable difficulties in providing a comprehensive information on different aspects of nutrition in fishes that are poikilotherms and inhabit the dynamic aquatic environment unlike the homeothermic land animals, enabled to gather valuable data on the food and feeding habits, particularly of the commercially exploited fishes. In the capture fisheries, the implications of these studies thus helped to explain the distribution pattern, growth and fluctuations of the exploited fish resources.

With the advancement and standardisation of methods in nutritional and physiological investigations, introduction of biochemical analysis and exposition of the relation between the environment and the fish and the predator-prey relationship, a wealth of information on qualitative and quantitative aspects of food consumed by the fishes, the digestion process, energy utilisation at various trophic levels and nutrient requirements, was accumulated between 1950 and 1970, and formed the subject of excellent reviews by Winberg (1956), Cowey and Sargent (1972), Halver (1972) and others. Robertson (1945), Hynes (1950),

and later, Nose (1963, 1967a), Ogino and Chen (1973a,b), Ogino, Kakino and Chen (1973) and Schneider and Flatt (1975) perfected, standardised and developed new methodologies/techniques in fish nutrition studies.

Fish and shellfish nutrition received tremendous impetus with the active development of aquaculture all over the world during the past one and half decades. As a result, enormous literature is now available not only on the dietary requirements of fishes and shellfishes, digestion and bioenergetics, but also on the larval nutrition, feed formulation and feed technology. Synthesising these works, several reviews are also now available, the most important among these being the 'Bioenergetics and growth' in the series of 'Fish Physiology' edited by Hoar Randall (1978); National Research Council (1977, 1981, 1983); Castell et al. (1981); Millikin (1982) and Tytler and Calow (1985). Realising the importance of a comprehensive knowledge of fish nutrition, particularly in the context of development of aquaculture under controlled conditions, a series of Symposia, Workshops and Task Force have been organised during this period. The noteworthy of these are the EIFC - Symposium on Finfish Nutrition and Feed Technology held in Hamberg in 1978 (Halver and Tiews, 1979), World Mariculture Society Nutrition Task Force established in 1970 to 'co-ordinate the Society's role in nutritional Science' (Conklin and Beck, 1979) and the Asian Fish Nutrition Workshop held in Singapore in 1983 (Cho, et al., 1985). The publication and the Proceedings of these Symposia/ Workshops reviewed the different aspects of fish and shellfish nutrition, its status, constraints encountered, methodological approach and the strategies for future development.

Among shellfishes, crustaceans that include the familiar forms such as shrimps, prawns, lobsters and crabs, occupy an important place both in the capture and culture fisheries of many nations in the world. Inhabiting diversified ecosystems, crustaceans feed on a variety of material which vary from microorganisms in microcrustaceans, to detritus and a range of animal and plant matter in larger crustaceans. Armoured with a diversity of external appendages and mouth parts, but with a rather simple alimentary system, they are equipped to ingest, digest and assimilate protein, lipids, carbohydrates and other nutrients required for their growth, survival and reproduction. Since, crustaceans excrete nitrogenous waste products in the form of ammonia, they are known as 'ammonotelic' animals.

A perusal of literature on crustacean nutrition reveals that the bulk of the information on food and feeding habits, nutritional requirements and digestive physiology is derived from the larger crustaceans belonging to Decapoda, although appreciable data are also available on the lower crustacean groups such as amphipods, isopods and cirripedes. Marshall and Orr (1960), Vonk (1960) and Fisher (1960) reviewed the available works upto 1960 on feeding and nutrition, digestion and metabolism and vitamins respectively in the 'Physiology of Crustacea' volumes edited by Waterman (1960). Over the last 20 years which paralleled the growth and development of aquaculture of decopod crustaceans, the nutritional science of Crustacea has grown considerably and reviewed by New (1976, 1980); Zein-Eldin and Meyers (1973); Kinne (1977); Conklin (1980); Dall and Moriarty (1983) and by Grahame (1983).

Among decapods, prawns are of vital economic importance, being intensively exploited from the wild by over 20 countries including India and widely cultivated in tropical and subtropical regions. The warm-water penaeid prawns (Order, Decapoda, Sub-order, Dendrobranchiata; Superfamily, Penaeiodea; Family, Penaeidae) constitute the most commercially important group. Most of the penaeid prawns breed in the sea and the eggs hatch out as free swimming planktonic naupliar larvae. Passing through different larval stages such as protozoea and mysis, the postlarvae enter into shallow inshore waters or estuaries wherever available, and develop further into juvenile stage. The juveniles or sub-adults after certain period of growth in these ecosystems, migrate offshore for further growth and spawning. The food, feeding mechanism and behaviour of penaeid prawns are found to vary with the different life stages. Thus the first larval stage, namely the nauplius, does not feed and lives by utilising the internal yolk. The protozoea larvae feed mainly on the available phytoplankton of approximately 3 to 10 micron size. In the mysis stage, the particulate food of about ten times the size of the food of protozoea and in the postlarval stage, still larger size particulate food available in the water table are ingested. As the prawn grows, it gradually changes to different modes of feeding described as omnivorous, scavanger, detritus or carnivorous feeders, depending on the species by different workers. The structure of the mouth parts and feeding appendages play a significant role in the food selection, collection and feeding behaviour.

As in the case of fishes, most of the earlier works on food and feeding habits of penaeid prawns were based on the gut

content analysis which provided information on the qualitative and quantitative aspects of the food constituents of the species studied (Gopalakrishnan,1952; Williams,1955, 1958; Ikematsu, 1955; George,1959, 1974; Hall,1962; Dall,1967; Thomas,1972,1980; Kuttyamma,1973; and Wickins,1976). These studies by and large, related to juvenile and adult prawns feeding in the wild on a community level and found much application in their capture fisheries rather than in the culture. Similarly, the knowledge on larval nutrition at that time had been grossly inadequate. The successful rearing of Penaeus japonicus by Hudinaga (Fujinaga) in 1942, the technological advancements made in the physiological and biochemical studies and the realisation of great growth potential of aquaculture of prawns,stimulated intensive interest in penaeid prawn nutrition and a good deal of work cameforth during the past 20 years from several laboratories in the world. Compiling these information, New in 1976 presented an excellent review of the literature available on dietary studies with prawns and shrimps. This was followed by another comprehensive review by Kinne (1977). Biddle (1977) described the various aspects of nutrition in freshwater prawns. Besides, the books published by Shigueno (1975 and 1978), Chen (1976) Imai (1977), Hanson and Goodwin (1977) and Stickney (1979) treated some aspects of nutrition of the candidate species dealt with by them. Subsequently, New (1980) compiled a bibliography of prawn and shrimp nutrition and Pruder et al. (1983) compiled studies on penaeid nutrition. More recently, Kanazawa (1984) presented the recent advances made in penaeid prawn nutrition at the First International Conference on the .

Culture of Penaeid prawns/shrimps held at Iloilocity, Philippines.

One of the areas which received considerable attention, ever since the report of Hudinaga (1942) on rearing of P. japonicus on the diatom, Skeletonema costatum, has been the search for suitable live food organisms to rear the larval stages. The works carried out by Fujinaga and Miyamura (1962), Cook and Murphy (1969), Liao and Huang (1972), Thomas et al. (1976a , 1976b), AQUACOP (1978), Platon (1978), Beard et al. (1977), New (1979), Kurata and Shigueno (1979) and Muthu (1982) identified several species of diatoms and other live food organisms which could be advantageously employed for feeding penaeid larvae and postlarvae. Parallel to these studies, attempts were also made on large scale culture of microalgae and zooplankton by several investigations (Ukeles, 1976; Shaw Watson, 1979; Kinne, 1977; Kahan, 1982; DePauw and Pruder 1981; Sorgeloos, 1981 ; Nellen, 1981) to meet the requirements of hatchery production of larvae.

While the endeavours in the selection and mass production of live food organisms have been progressing in one front, attempts have been made in the other front to replace the live food organisms, as their large scale production posed constraints due to wide fluctuation in the yield, contamination by unwanted species and considerable cost of production, with artificial diet (Subrahmanyam and Oppenheimer, 1969; Kanazawa et al.,1970; Forster and Gabbott, 1971; Cowey and Forster, 1971; Hirata et al., 1975; Shigueno, 1975; Sick et al., 1972; Kitabhayashi et al., 1971 a,b,c,d; AQUACOP, 1978; Villegas and Kanazawa,1980; Villegas et al.,1980; Alikunhi et al., 1980, 1982; Usha Goswami and

Goswami, 1979, 1982; Raman et al.,1982; Mohammed Sultan et al., 1982; Ahamad Ali,1982a ; Mohamed et al., 1983, Ahamad Ali and Mohamed, 1985). The results of these investigations have shown the feasibility of using different types of artificial diets to rear the larvae in the hatchery, postlarvae in the nursery and juveniles in the grow out systems with varying survival and growth performance depending on the qualities of diets,experimental design and water quality management.

One of the noteworthy advancements of nutritional research in the mid-seventies, has been the development and use of microencapsulated diet for the filter feeding crustacean larvae (Jones et al., 1974). Jones et al.(1976) and Moller et al. (1979)reared the larvae of P.merquiensis upto postlarvae II with micro-encapsulated diet. Subsequently, Jones et al. (1979a) employed the encapsulated diet consisting of chicken egg, short necked clam (Tapes philippinarum), Soybean cake and the purified diet-B of Kanazawa et al.(1977a), having particulate size ranging from 10 to 100 micron, to rear P.japonicus with encouraging results. Successful rearing of Penaeid Prawn larvae with micro-particulate and micro-encapsulated diets was demonstrated in P. japonicus (Kanazawa,1985), P.monodon, P.stylirostris and P.vannamei (Jones et al.,1987)and more recently by Galagani and AQUACOP (1988) in zoeal stages of some penaeid prawns.

The development of micro-encapsulated diets also helped to study the nutritional requirement of larvae. Thus, Jones et al. (1979b) studied the fatty acid requirement of the larvae of P. japonicus; Kanazawa (1982, 1983), Teshima and Kanazawa (1984) and Kanazawa et al. (1985) on protein, lipid, carbohydrate, phospholipid and vitamin requirements.

Studies on nutritional requirements of prawns and shrimps received considerable impetus in the recent years. Greater emphasis was given for understanding the protein requirement and determining optimum protein levels in the diet for different species (Kanazawa et al., 1970; Lee, 1970; Kitabhayashi et al., 1971 a, b, c; Deshimaru and Shigueno, 1972; Andrews et al., 1972; Balazs et al., 1973; Forster and Beard, 1973; Deshimaru and Kuroki, 1975a; Venkataramaiah, et al.,1975a; Colvin, 1976a; AQUACOP, 1977; Khannapa, 1979; Bages and Sloane, 1981; Kanazawa et al., 1981; Ahamad Ali, 1982 a; Charles John Bhasker and Ahamad Ali, 1984). In these investigations, a protein requirement ranging from 15% to 80% was reported for different species of penaeid prawns. The variations in the protein requirement among the different species were thought to be due to different factors such as the aminoacid profile of the protein source used, the carbohydrate level in the diet and factors such as differences in feeding habits and age of experimental animals. The amino acid requirements of penaeid prawns (Cowey and Forster, 1971; Kanazawa and Teshima, 1981) and also the Caridean prawns(Watanabe, 1975; Miyajima et al., 1976), were investigated and found that the same number of amino acids which were found to be essential for land animals were also found to be essential for these prawns.

Prawns have specific qualitative requirement of lipids rather than their quantity. Eventhough a lipid level of below 10% was found to be adequate in the prawn diet (Andrews et al., 1972; Forster and Beard, 1973), the fatty acid composition of the lipid source used is found to be more important for growth and survival. Employing radioisotope tracer technique, Kanazawa

et al. (1979b) and Kanazawa and Teshima (1977) have shown that prawns are not capable of synthesising polyunsaturated fatty acids (PUFA) such as linoleic acid (18:2 W6), linolenic acid (18: 3 W 3), eicosapentaenoic acid (20: 5 W 3) and docosahexaenoic acid(22: 6 W 3). These fatty acids are essential for prawns and should be supplied in their diet. Infact Kanazawa et al.(1977b, 1978, 1979d, 1979f) have demonstrated that the diets containing the fatty acids 18: 2 W 6, 18: 3 W 3, 20: 5 W 3 and 22: 6 W 3 produced faster growth in P. japonicus. Similar results have been obtained by Shewbart and Mies (1973) in P. aztecus. The optimum levels of the fatty acids, 20: 5 W 3 and 22: 6 W 3 were found to be 1.0% in the diet of P. japonicus (Kanazawa et al., 1979a).

Prawns are also found to require cholesterol at 0.5% in the diet (Teshima and Kanazawa, 1971; Teshima, 1982; Kanazawa et al., 1971a; Shudo et al., 1971). Further, Kanazawa et al. (1971b) demonstrated that P. japonicus could utilize ergosterol, sitosterol and stigmasterol to some extent as substitute for cholesterol. Based on the dietary value of different steroids, Teshima et al,(1982) suggested the metabolic pathway for the conversion of C 28 and C 29 sterols to cholesterol in prawns. Subsequently Teshima et al. (1983, 1986a,b,c,d) investigated the role of phospholipids in the diet of prawn.

The nutritive value of carbohydrates in the diet of prawns was investigated (Cowey and Forster, 1971; Forster and Gabbott, 1971; Sick and Andrews, 1973; Deshimaru and Yone,1978b; Abdel Rahman et al., 1979; Ahamad Ali, 1982b; Pascual et al., 1983; Alava and Pascual, 1987) and found that penaeid prawns

generally utilize disaccharides and polysaccharides better than monosaccharides. A carbohydrate level of 5 to 40% has been suggested in the diets of penaeid prawns. The role of amino sugar, N-acetylglucosamine in the diet of prawn has also been investigated, reporting conflicting results on the role of glucosamine in the diet. While Kitabhayashi et al, (1971a) have demonstrated that addition of 0.52% of glucosamine in the diet improved the growth of P. japonicus, Deshimaru and Kuroki (1974b) have pointed out that it is not necessary in the diet of the same prawn. However, Vaitheeswaran and Ahamad Ali (1986) observed positive growth promoting effect of glucosamine in the diet of P. indicus. Addition of cellulose to the diet is found to help better utilisation of nutrients by prawns (Venkataramaiah et al., 1975a; Fair et al., 1980).

Requirement of vitamins and minerals in the diet of prawn was investigated by several workers. Deshimaru and Kuroki (1976, 1979) have shown that the juveniles of P. japonicus require 300-1000 mg of ascorbic acid, 60 mg of choline, 200-400 mg of inositol, 6-12 mg of thiamine and 12 mg of pyridoxine per 100 g diet. Lightner et al. (1977, 1979) found that ascorbic acid deficiency could lead to abnormal symptoms (black death) in P. californiensis and P. stylirostris. Kitabhayashi et al. (1971b) found accelerated growth in P. japonicus fed with the diet having Vitamin C. Reviewing the metabolic functions of vitamins in crustaceans, Fisher (1960) reported that most of the B group vitamins were required in the diets of prawns. Although the vitamin D would be partly ingested, it could also be synthesised by the animals from ergosterol. The role of vitamin K was noted

to be antagonistic in some species of crustaceans. While the vitamin A might not be essential in prawn diets, its precursor β-carotene was required in the diet. The presence of β-carotene, astaxanthin, and canthaxanthin were demonstrated in P. japonicus (Kitayama et al., 1972). The importance of carotenoids in the prawn diets for the pigmentation had been demonstrated by Joseph and Williams (1975) and Sandifer and Joseph (1976).

In the case of minerals, the requirement of calcium and phosphorous in the diet of P. japonicus (Deshimaru and Yone, 1978a; Deshimaru et al., 1978; Kitabhayashi et al., 1971a) and P. aztecus (Hysmith et al., 1972; Shewbart et al., 1973; Huner and Colvin, 1977) was studied and varying results were obtained. It was demonstrated that prawns could absorb calcium from sea water. Recently Kanazawa et al. (1984) reported the requirement of calcium, phosphorous, magnesium, potassium, copper, iron and manganese in the diet of P. japonicus.

In India, the information on prawn nutrition is relatively less as compared to those available on finfish nutrition. Most of the observations on the food and feeding habits of prawns have been made during the course of biological investigation of the species (Rai, 1933; Panikkar, 1952; Gopalakrishnan, 1952; Panikkar and Menon, 1956; George, 1959; 1974; Subrahmanyam 1963; Bhimachar, 1965; Rao, 1967; Kuttyamma, 1973; Thomas, 1972, 1980). Although these studies have shown that the penaeids feed on a variety of plant and animal organisms and other detritus indicating their opportunistic omnivorous feeding behaviour, Rao (1967) discussed the relative importance of food in their diet. Selective feeding by different size groups in P. indicus

and Metapenaeus monoceros (George, 1974) and food species differences related to habitat preference of prawns (Kuttyamma, 1973) have been observed.

A series of investigations were carried out in recent years on the energy conversion, energy metabolism and food conversion in some of the penaeid prawns of India (Qasim and Easterson, 1974; Laxminarayana and Kutty, 1982; Sumitra Vijayaraghavan and Ramdhas, 1982; Thomas et al. 1984). Ravichandra Reddy and Katre Shakuntala (1982) investigated the use of Moina for the juveniles of M. affinis while Usha Goswami and Goswami (1979, 1982) formulated certain artificial diets and evaluated them for feeding the penaeid prawns.

As witnessed elsewhere in the world, nutritional studies on penaeid prawns received greater thrust in the country with the propagation and promotion of aquaculture of prawns. Hameed Ali (1980) and Hameed Ali et al. (1982)reported successful rearing of larvae of P. monodon, P. indicus, P. merguiensis, and Parapenaeopsis stylifera on crustacean tissue particles maintained in a suspension state. Microparticulate artificial diet prepared from mantis shrimp, prawn waste, groundnut cake, fishmeal and tapioca, fortified with vitamins and minerals was used by Mohamed et al. (1983) to rear P. indicus larvae. Silas et al. (1985) discussed the hatchery techniques of mass rearing of this species.

Studies on nutritional requirements of penaeid prawns particularly on P. indicus were carried out by several workers in recent years (Ahamad Ali, 1982a, 1982b, 1986; Udayaram

Jyothy 1983; Ahamad Ali and Sivadas, 1983; Charles John Bhaskar and Ahamad Ali, 1984; Ahamad Ali and Mohamed, 1985; Sally Anne Thomas, 1985; Vaitheeswaran, 1983). Gopal (1986) studied certain aspects of protein and vitamin requirements, while Chandge (1987) investigated the lipid requirements of larvae and juvenile P. indicus.

Some observations are also available on the culture of prawns in the grow out systems by feeding with compounded diets (Raman et al., 1982; Mohamed Sultan et al., 1982; Sambasivam et al., 1982). These diets were mainly used to supplement the natural food available in the pond and related to growth and production performance of prawns.

Although the above studies have considerably contributed to the information on the food and feeding habits and nutritional requirements of penaeid prawns of India, there are still very large gaps in our knowledge and much remains to be done. The studies available now are neither comprehensive nor exhaustive. Since nutrition is basic to aquaculture and since penaeid prawns offer great potential for large scale aquaculture in the vast coastal waters of the country, the present study to evaluate the feed sources of purified and natural proteins and carbohydrates and on the mineral requirements was taken up with a view to develop a balanced prepared diet and a practical feed for feeding penaeid prawns, particularly for P. indicus.