CHAPTER 2
REVIEW OF LITERATURE

2.1 Geographical distribution, new species and new records

Family Atyidae is one of the primitive groups among the order Decapoda. De Haan (1849) was the first to use the term ‘Atyadea’ as a family containing the genus *Atya* Leach, 1816. Later Dana (1852) adopted the term ‘Atyidae’, a group characterized by spoon-like fingers of chela ending in tufts of bristles. The studies on Atyidae remained dormant during first half of last century but gained momentum only in the second half. Kemp, De Man and Holthuis had been the pioneers to study on atyids. In India a few detailed studies had been carried out on the taxonomy and population ecology of atyids (Pillai, 1958; Babu, 1963; Tiwari & Pillai, 1968; Thomas *et al*., 1973; Jalihal *et al*., 1984; Richard & Chandran, 1994; Mariappan & Richard, 2006 and Jayachandran *et al*., 2008).

Atyids are common inhabitants in the freshwater ecosystems of tropical and subtropical regions and their occurrence in brackish water can be considered as a readaptation (Ortmann, 1894). Henderson (1893) reported *C. wyckki* from Madras that formed the first report of an atyid shrimp in India. *Caridina nilotica* is reported from River Nile in Egypt as *Pelias niloticus* (Roux, 1833). De Man (1908a) studied *C. nilotica* (Roux) and described 3 new varieties namely, *Caridina nilotica* var. *bengalensis*, *Caridina nilotica* var. *natalensis* and *Caridina nilotica* var. *brachydactyla*, in addition to the five varieties already known to science; subsequently they were raised to subspecies and species level (Calman, 1906; Bouvier, 1925). Kemp (1913) made a study on the decapod crustaceans of Brahmaputra valley and reported two new species of *Caridina* namely, *Caridina*...
excavata and C. hodgarti. Two new species of Caridina namely, C. rajadhari and C. babaulti had been reported from central India (Bouvier, 1918). Roux (1931) reported Caridina carli as new species and C. cavaleriei industana as new subspecies from Tamil Nadu. Natarajan (1942) commented on the occurrence of Caridina in Travancore and reported C. gracilirostris, C. laevis, C. nilotica var. gracilipes and C. weberi var. sumatrensis. Holthuis (1955) in his paper on the recent genera of Caridean and Stenopodidean shrimps, described 19 genera of atyid shrimps and provided a key for their identification. Pillai (1958) made a detailed study on the biology of Caridina laevis.

Holthuis (1960) described a new atyid genus Stygiocaris from N. W. Australia and provided descriptions of two new species, Stygiocaris lancifera and S. stylifera. Hart, 1961 described seven atyid shrimps from Jamaica- Atya scabra, A. occidentalis, Jonga serrei, Micratya poeyi, Potimirim americana, P. mexicana and Xiphocaris elongata. Thakur (1961) reported cross breeding between Caridina weberi var. sumatrensis and Caridina rajadhari, the first successful attempt in Decapod Crustacea. Arudpragasam & Costa (1962) reported two genera of atyids from Ceylon- Caridina and Atya. Of the 6 species of Caridina two are new to science, Caridina fernandoi and C. nilotica var. zelanica. A new genus, Halocaridina was reported from tropical land-locked saltwater pools in Hawaii (Holthuis, 1963). While describing the Caridina of Travancore Pillai (1964) described a new variety namely, C. nilotica (Roux) var. veliensis. Williams (1964) gave an account of the subterranean freshwater prawns of Australia and reported two new species of Parisia, namely, P. gracilis and P. unguis. Smith (1967) studied the Arthropoda of Australian caves and reported three genera of atyids, namely,
Stygiocaris, Parisia and Paratya. Tiwari et al. (1968) described a new species from Museum Tank in Trivandrum, Caridina natarajani, which shows close affinity with Caridina laevis.

Tiwari & Pillai (1971) reported 5 species of Caridina from the Andaman Islands including one new species, C. prashadi. The collections made by the Smithsonian-Bredin expeditions (Chace, 1972) to the Lesser Antilles, Virgin Islands and Yucatan contain four genera of atyids namely, Atya, Jonga, Potimirim and Typhlatya (Chace, 1972). Chace & Manning (1972) recorded Typhlatya rogersi as new species from Ascension Island. Two species of atyid shrimps belonging to two genera, Antecaridina lauensis and Halocaridina rubra, had been reported from the Hawaiian Archipelago (Holthuis, 1973). Thomas et al. (1973) described a new species namely, C. pseudogracilirostris from the Cochin backwaters. Dutt & Ravindranath (1975) recorded Caridina brachydactyla peninsularis for the first time from India. Hunte (1975) made taxonomic description of Atya lanipes and described its first larval stage. Three species of troglobitic shrimps belonging to the genus Typhlatya were reported from Yucatan Peninsula in Mexico (Hobbs, 1976). Chace (1975) analyzed the cave shrimps of Dominican Republic and reported an atyid genus, Typhlatya. Of these, two species are new to science namely, Typhlatya mitchelli and T. campecheae. Kim (1976) reported C. denticulata keunbaei as new subspecies from Teju Island, Korea. While reviewing the troglobitic decapod crustaceans of the America Hobbs et al. (1977) found that the family Atyidae is represented by two genera namely, Palaemonias and Typhlatya. Holthuis (1978) assessed the cavernicolous shrimps of New Ireland and the Philippines and erected a new genus, Edoneus to accommodate E. atheatus.
and also described a new species, *Caridina troglodytes*. Holthuis (1978) described eight species under two genera, *Atya, Caridina*, from Lesser Sunda Islands, including a new species namely, *Caridina sundanella*. Ravindranath (1978) reported heteromorphosis in the atyid shrimp *Caridina weberi sumatrensis*, relatively a rare phenomenon in Crustacea. Williams & Smith (1979) revised the Australian atyid genus *Paratya* and examined its geographical variation.


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Choy (1984) described a new species with edentulous rostrum, *C. nudirostris*, from the Nadrau plateau in Fiji. Gurney (1984a) reported nine species of atyids belonging to two genera from Madagascar viz., *Caridina* and *Parisia*, including four new species, *C. crurispinata*, *C. parvocula*, *C. unca* and *Parisia dentata*. Gurney (1984b) reexamined the specimens collected from an anchialine habitat that had been previously placed in the genus *Parisia*. By examining the branchial formula and appendages it had been transferred to the genus *Halocaridinides*. Jalihal et al. (1984) described *C. williamsoni*, *C. shenoyi*, *C. kempi*, *C. gurneyi* and *C. panikkari* as new taxa from Dharwar in Karnataka. Liang et al. (1984) reported a new subspecies, *C. denticulata anhuiensis* from China. Ng (1985) reported *C. typus* from Pulau Tioman, West Malaysia that forms the first
record of the species from the island. Coetzee (1986) reported the south-western range extension of *C. nilotica* and *M. petersi* in S. Africa. Holthuis (1986) described the Atyidae of western Colombia and reported *Atya limnetes* as new species. Holthuis (1986) described the genus *Pycneus* from Western Australia. *Halocaridina palahemo* is a new atyid species from the Island of Hawaii (Kensley & Williams, 1986). Liang *et al.* (1986) reported seven species of *Caridina* from Guizhou Province, China, out of which four are new to science, *C. guizhouensis*, *C. cornuta*, *C. liui* and *C. brevispina*. Raman *et al.* (1986) in their study on the distribution and abundance of prawn fauna in the freshwater habitats of South India reported *M. lanchesteri* and three species of *Caridina* namely, *C. rajadhari*, *C. nilotica* var. *bengalensis* and *C. weberi* var. *sumatrensis*. Al-Adhub & Hamzah (1987) described a new subspecies for *Caridina babaulti* namely, *Caridina babaulti basrensis* from Iraq. Gurney (1987) described a new atyid genus *Puteonator* from southern Iraq. Abele & Kim (1989) while reporting the crustacean fauna of Panama Canal noticed the occurrence of three genera of atyids namely, *Atya*, *Micratya* and *Potimirim*.

De Silva (1990) described a new species, *Caridina kumariae* from Sri Lanka and provided some aspects of its population ecology. Ng & Choy (1990) reported *Atyopsis moluccensis* and three species of *Caridina*, *C. thambipillai*, *C. tonkinensis* and *C. propinqua*, from Peninsular Malaysia. Rabadà (1990) reported a new genus from Spain, *Delclosia*, which is regarded as the single fossil genus in the family Atyidae. Two species have been reported so far, of which *Delclosia martinelli* is new species. Fourteen species of shrimps belonging to four genera were reported from the Fiji Islands namely, *Antecaridina*, *Atyoida*, *Atyopsis* and *Caridina*, of
species of freshwater shrimp from Hunan province, China. Guo et al. (1996) described a new species of troglopic shrimp *Caridina semiblepsia* from Hunan Province, China.

atyids from Hunan, China namely, *Paracaridina, Mancicaris* and *Caridina*. The new species reported are *P. longispina, M. sinensis* and *Caridina spinosipes C. oligospina*. Yeo *et al.* (1999) documented the freshwater and terrestrial decapod crustacea of Pulau Tioman, Peninsular Malaysia and reported *Caridina celebensis* and *C. aff. brachydactyla* as new records from the region.

Cai & Ng (2000) recognized five species of *Caridina* from Myanmar, of these three are new to science, *Caridina williamsi, C. rangoona* and *C. burmensis*. Hamano *et al.* (2000) assessed the Atyidae of Tokushima Prefecture, Japan, and reported the occurrence of *Paratya compressa, C. typus, C. leucosticta, C. japonica, C. serratiostris* and *Neocaridina denticulata*. Liang & Cai (2000) described *Caridina shilinica* and *C. curta* as new species from Yunnan in China. Ng & Cai (2000) recorded *Caridina dentifrons* and *C. breviata* from southern China both are new additions to science. Buden *et al.* (2001) identified the decapod crustaceans of Pohnpei, Eastern Caroline Islands as *Atyoida pilipes, Caridina weberi* and *C. typus*. Cai & Ng (2001) assessed the freshwater decapod crustacea of Halmahera, Indonesia and reported to science five species of atyids belonging to two genera, *Atyopsis* and *Caridina*. Cai & Ng (2001) revised *Caridina yunnanensis* and its allied species and provided descriptions of a new species, *C. impensa* from Yunnan, southern China. Dutta (2001) studied the systematics and distribution of prawns in Assam and reported the occurrence of *Caridina weberi*. Martin & Davis (2001) provided the recent classification of Crustacea. Wang & Liang (2001) reported *Caridina kunmingensis* as new species from Yunnan, China. Choy & Marquet (2002) surveyed the atyid shrimps of New Caledonia and reported to science 21 species, of which four are new to science. Fossati *et al.* (2002) studied the

Davie & Suzuki (2003) described a new species of *Pycnisia* from northwestern Queensland, namely, *Pycnisia bunyip*. Guo & Liang (2003) reported *Caridina angustipes* and *C. clavipes* as new species from Hunan Province, China. Leberer & Cai (2003) reported the occurrence of five genera of atyids in Guam, Mariana Islands, namely, *Atyopsis*, *Atyoida*, *Caridina*, *Antecaridina* and *Halocaridinides*. Naruse *et al.* (2003) reported *Halocaridinides trigonophthalma* that forms the first record of the species from Hatoma Island. Yam & Cai (2003) described a new species *Caridina trifasciata* from Hong Kong. Anastasiadou *et al.* (2004) examined the morphological variations within the species *Atyaephyra desmarestii* and confirmed the presence of many ecophenotypes. The collections made by an Italian Speleological expedition contained three genera of atyids namely, *Atyopsis*, *Caridina* and *Parisia*. Of the seven species of *Caridina* three were previously undescribed, *C. samar*, *C. gortio* and *C. minidentata*, and two are new records, *C. rubella* and *C. peninsularis*. The genus *Parisia* was represented by a new species, *P. macrophora* (Cai & Anker, 2004). Guo & Grave (2004) studied the *Paracaridina* of Hunan Province, China and reported *P. chenxiensis* as new and synonimized *Caridina guizhouensis* with *P. guizhouensis*. Martin & Wicksten (2004) reviewed the genus *Syncaris* and provided redescriptions for *Syncaris pasadenae* and *S. pacifica*. Three species of *Typhlatya* namely, *Typhlatya*

Cai & Ng (2007) while revising Caridina gracilirostris provided descriptions for two new species, C. neglecta and C. longifrons. Cai et al. (2007) reviewed the family Atyidae from Peninsular Malasia and Singapore and reported the occurrence of two genera, Caridina and Atyopsis. Of the 14 species of Caridina examined two are new to science, namely, Caridina johnsoni and C. malayensis and two are new records C. thambipilai and C. excavatoides. Klotz et al. (2007) provided redescriptions of Caridina buehleri and C. appendiculata from central Sulawesi, Indonesia. Magalhães & Pereira (2007) assessed the decapod fauna of Guayana Shield region and reported Atya gabonensis. Shih & Cai (2007) described two new species of Neocaridina from Taiwan, Neocaridina saccam and Neocaridina ketagalan and proposed a speciation model based on geological events and molecular clock estimates. Thomas & Jayachandran (2007) reported Caridina jalihali for the first time from Kerala. De Almeida et al. (2008) studied the decapod crustaceans in the freshwaters of southeastern Bahia, Brazil and found that the family Atyidae is represented by two genera namely, Atya scabra and Potimirim potimirim. Marquet & Keith (2008) gave details about the taxonomy and distribution of Caridina similis from the Seychelles Islands. Jayachandran et al. (2008) studied the caridinian shrimp resources of Kerala and reported eleven
species of *Caridina*. Rintelen *et al.* (2008) described a new species, *Caridina thomasi* from Banggai Islands, Indonesia. Wang *et al.* (2008) described four new species of *Caridina* from Guangdong Province, China namely, *C. maculata*, *C. venusta*, *C. tumida* and *C. meridionalis*. Among these *C. maculata* and *C. venusta* are popular in the pet market as ornamental shrimps.

Cai & Husana (2009) reported three new species of *Edoneus* from Luzon, namely *E. erwini*, *E. sketi* and *E. marulas*. Cai *et al.* (2009) assessed the Atyidae of Bohol Island, Central Philippines and reported that the family is represented by sixteen species belonging to four genera, namely, *Antecaridina*, *Halocaridinides*, *Atyopsis* and *Caridina*. Thirteen species of *Caridina* are reported, of which seven are new to science, *C. lobocensis*, *C. liaoi*, *C. boholensis*, *C. valencia*, *C. batuan*, *C. anislaq* and *C. camaro*. Cai *et al.* (2009) partially revised the freshwater shrimps from Central Sulawesi, Indonesia along with descriptions for two new species, *Caridina woltereckae* and *C. mahalona*. De Grave *et al.* (2009) while classifying the living and fossil genera of decapod crustaceans reported 42 genera under the family Atyidae. Marquet *et al.* (2009) reported a new species, *Caridina gueryi* from Santo Island. Richard & Clark (2009) in their study on African *Caridina* redescribed *C. africana* and *C. togoensis* and given species status to *C. africana natalensis* and *C. africana var. roubaudi*. They also described fourteen new species of *Caridina* from specimens previously assigned as *C. africana*, *C. nilotica* and *Caridina* spp. namely, *C. evae*, *C. belazoniensis*, *C. ghanensis*, *C. ebuneus*, *C. sodenensis*, *C. amnicolizambezi*, *C. congoensis*, *C. lineorostris*, *C. okiamnis*, *C. gaesumi*, *C. susuroflabra*, *C. umtatensis*, *C. messofluminis* and *C. malawensis*. Rintelen & Cai (2009) revised the endemic *Caridina* of Sulawesi and described eight

*Caridina atyoides* Nobili, 1900 is transferred to a new genus *Atydina*, so far it is reported from two islands in Indonesia (Cai, 2010a). By noticing specific differences from *C. typus*, Cai (2010b) redescribed *Caridina typus* var. *brevirostris* and proposed a replacement name, *C. jeani*. Jingchun & Shuqiang (2010) described *C. alba* as new species from Hubei Province, China. Kargae *et al.* (2010) reported *Caridina buergersi* and *C. elisabethae* as new species from Papua New Guinea. Richard & Clark (2010) provided redescriptions for four species of *Caridina*, namely, *C. serratiostris*, *C. angulata*, *C. brachydactyla* and *C. moeri* from eastern and southern Africa. Silas & Jayachandran (2010) described *C. mathiassi* as new species from the hill streams of southern Western Ghats.

### 2.2 Factors affecting shrimp distribution

Hunte (1978) observed that oxygen, temperature, and current speed were the physical factors influencing shrimp distribution. De Silva (1987) after studying the salinity tolerances of three species of atyids commented that the synergetic action of temperature and salinity must be taken into consideration while studying the geographic distribution of atyids. Shrimps may undertake dial vertical migration to
escape from variations in temperature (McLeod, 1982; Hart, 1983; Lehman, 1996). The limitations in physiological tolerance, human interference in habitat and the introduction of carnivorous culture fishes may have contributed significantly to the present day isolation of some atyids (De Silva & De Silva, 1988; Benzie & De Silva, 1988). De Silva (1989) studied the temperature tolerance of *C. fernandoi*, *C. simoni* and *C. pristis*. Walsh & Mitchell (1995) opined that salinity tolerance may help in the dispersal of the larvae of atyids. Temperature and flow dynamics (Hancock & Bunn., 1997; Woolschot et al. 1999), environmental factors and faunal interactions (Leberer & Nelson 2001), natural barriers like water falls and cascades (Hughes et al., 1996; Yam & Dudgeon, 2005) influence the distribution of species. Fossati et al. (2002) while studying the distribution and habitat utilization of atyid shrimps observed that *Atyoida pilipes* was abundant in lotic habitats whereas *C. weberi* was found among plants in lentic habitats.

### 2.3 Molecular taxonomy and Barcode analysis

The vast diversity of organisms and the occurrence of intraspecific variations sometimes make traditional taxonomy confusing. The limitations of traditional morphology based taxonomy have been surpassed by a comparatively new approach called molecular taxonomy and it exploits diversity among DNA sequences to identify organisms (Santamaria et al., 2007). It may help in reliable and fast identification of organisms, discovering cryptic, new species (Knowlton, 1993; Herbert et al., 2004; Hebert & Gregory, 2005; Dinca et al., 2010), greater understanding of community structure (Baird et al., 2011), identifying damaged or incomplete specimens, identifying species from diapausing eggs (Briski et al., 2010), linking adults with larvae, juveniles (Greenstone et al., 2005; Thomas et al.,
By assisting species delineation and identification DNA barcoding will enhance the effectiveness and efficiency of conservation planning and research activities (Francis et al., 2010). Dasmahapatra et al. (2006) and Bravo et al. (2008) opined that taxonomic approaches integrating morphological, molecular and distributional data allows better understanding of biodiversity. Page et al. (2005) commented that morphological taxonomy and molecular taxonomy are inseparably linked. However, there are criticisms regarding the use of mtDNA as a potential bio-identification code. Since nuclear and mitochondrial genomes have different patterns of evolution and modes of inheritance, they result in different assessments of biodiversity (Rubinoff, 2005; Rubinoff, et al., 2006). The co-amplification of pseudogenes, the occurrence of heteroplasmy and maternally inherited symbionts over estimate the number of species determined by DNA barcoding (Song et al., 2008).

Ivey & Santos (2007) presented the complete mitochondrial genome of 
*Halocaridina rubra*. It is a circular molecule of 16,065 base pairs and encodes 37 mitochondrial genes (13 protein coding genes, 22 tRNAs and 2 rRNAs). Past phylogenetic work has focused on mitochondrial genes encoding ribosomal RNA (12S, 16S), but the prevalence of insertions and deletions (indels) restrict their use as barcodes (Doyle & Gaut, 2000). The 13 protein coding genes in the mitochondrial genome are preferred for phylogenetic analysis because of the absence of indels (Saccone et al., 1999). But, Murphy & Austin (2003) opined that 16S mtDNA has both fast and slow evolving genes and can provide useful information across a broad taxonomic spectrum. A short 648 base pair region of
mitochondrial CO1 gene is commonly used as barcode for the identification of animals (Herbert et al., 2003a, b). An ideal barcode should be relatively short in length, more variable between than within species and easily amplifiable with universal primer (Cowan et al., 2006). Smaller fragments of the mitochondrial CO1 gene (‘mini barcodes’ up to 100 base pairs) also provide information about sequence variability and divergence at intraspecific and intrageneric levels (Hajibabaei et al., 2006; 2007). The accuracy in DNA barcoding depends on the extent of intra and interspecific divergence (Meyer et al., 2005). Min et al., (2007) opined that mitochondrial barcodes have gained prominence as a tool for species identification and it reflects several important attributes of the complete mitochondrial genome. According to Hudson & Coyne (2002) evidence from 16S and 18S rDNA are also essential for arriving at taxonomic conclusions.

However, CO1 is unsuitable for barcoding in plants because of its low substitution rates and rapidly changing gene content and structure. Nitta (2008) sequenced chloroplast DNA from three different regions (rbcL, trnSGG, trnH-psbA) for biocoding the filmy ferns Hymenophyllaceae and found that trnH-psbA has greatest potential as a biomarker because of its high interspecific variability and high degree of amplification success. Vijayan et al. (2010) in a review article provides information about 12 different loci suitable as barcodes in plants.

The origin and evolution of a species can be known by phylogenetic analysis. The mtDNA has been used for analyzing phylogenetic relationships due to its peculiar properties like the presence of orthologous genes, the lack of recombination and an appropriate substitution rate (Gissi et al., 2000). The DNA
sequences are used for phylogenetic analysis of closely related species whereas aminoacid sequences are preferable for more distant relationships (Michu, 2007).

Lefèbure et al. (2006) described molecular taxonomy as an effective tool to differentiate crustacean species. Kim & Abele (1990) studied the molecular phylogeny of some selected decapod crustaceans based on 18S rRNA nucleotide sequences. Hurwood & Hughes (2001) analyzed mitochondrial DNA data to determine whether the observed genetic structure in Caridina zebra was a result of historical processes or due to low levels of terrestrial dispersal. Benzie et al. (2002) analyzed the mitochondrial DNA variation in Indo-Pacific populations of Penaeus monodon and provided evidence that the Indo-west Pacific region is a site of accumulation of genetic diversity. Mitochondrial DNA studies by Rintelen et al. (2007) suggested that colour play a role in species recognition and speciation in Caridina. Cook et al. (2008) described the importance of cryptic species for identifying representative units of biodiversity for freshwater conservation. Benzie & De Silva (1984) studied the taxonomic relations among atyids by electrophoretic technique.

The barcode concept has particularly been useful for identifying the least morphologically tractable species such as protists, bacteria and viruses (Allander et al., 2001; Hamels et al., 2001). Mitochondrial CO1 analysis has been performed successfully in a variety of genera for delineating species, revealing cryptic species and phylogenetic, phylogeographic studies, which includes Anaspides tasmaniae (Jarman & Elliott, 2000), the rodent genus Clethrionomys (Matson et al., 2001), freshwater crustaceans (Cox & Hebert, 2001), Antarctic krill Euphausia crystallorophias (Jarman et al., 2002), Ponto-Caspian crustaceans (Cristescu et al.,
Ranjanee (2010) proved the reliability of RAPD markers in identifying species of *Macrobrachium* and *Caridina*. Rintelen *et al.* (2010) while studying the molecular phylogeny of *Caridina* commented that ecological specialization and allopatric speciation are the driving forces for species diversification.

In spite of the success reports, there are criticisms regarding DNA based identification, Meier *et al.* (2006) reported low success rates in identifying members of the order Diptera. Hickerson *et al.* (2006) opined that single gene thresholds sometimes result in incorrect species discovery and make substantial error between recently isolated populations and reproductively isolated lineages. Because of the limited performance of DNA barcoding in a diverse community of tropical butterflies Elias *et al.* (2007) recommended the analysis of nuclear sequence data along with mtDNA barcode. According to Brower (2006) the trouble arises when DNA barcoding is marketed as a substitute for evidence from morphology and biogeography. This will accelerate the loss of systematic expertise, systematic training and research programmes in conventional taxonomy.

The extraction of DNA from small specimens requires crushing of the entire sample, precluding the deposition of the carcass as a museum voucher (Whitfield & Cameron, 1994). Rowley *et al.* (2007) developed a protocol for nondestructive DNA extraction from terrestrial arthropods. According to them linking MorphBank images and GenBank sequences will improve the reliability and utility of barcoding by making it possible to view all important attributes of a specimen such as morphology, taxonomy, DNA sequence, voucher identity and collection data. This proves true in some species of *Caridina* during the present study and has been discussed in the concerned chapter.
DNA was isolated from ethanol preserved shrimp samples following the Salt precipitation method (Crandall et al., 1999). DNA sequencing of the PCR products was performed using the di-deoxy chain termination method (Sanger et al., 1977) modified by Chen and Seeburg (1985). 648 base pairs of COI gene sequences from the samples were aligned with homologous sequences using the program CLUSTAL X (Thompson et al., 1997) and subsequently checked by visual inspection. Numbers of nucleotide frequencies, estimating evolutionary divergence between species and nucleotide divergence were calculated by MEGA 5.0 (Kumar et al., 2004). The robustness of the ML tree was evaluated by bootstrap analysis (Felsenstein, 1985) with 1000 replicates.

2.4 Population ecology

Atyid shrimps are components of the littoral fauna and they play an important role in the ecology of freshwater habitats in the tropics (De Silva, 1988b). They are important in the stream food web because of their omnivorous habit and their role as a food source for predators (March & Pringle, 2003; Mantel & Dudgeon, 2004). Atyid shrimps play an important role in stream recovery after heavy discharges of sediments over benthic substrata (Pringle et al., 1993). Atyids can influence algal production, detritus processing and benthic community structure in streams but, their effects vary and depend on the presence of other biota (Pringle, 1996; Crowl et al., 2001; March et al., 2002). But Williams (2002) opined that atyid shrimps had no role in leaf litter decomposition.

Environmental factors like temperature and rainfall influence the population size and reproductive pattern of atyids (De Silva 1982; Dudgeon, 1985; De Silva

Tropical and subtropical atyids are perennial breeders (Nair, 1949; Hart, 1981) whereas temperate atyids breed only during summer (Williams, 1977; Shokita, 1979). *C. rajadhari* exhibited a continuous breeding cycle with two distinct spawning seasons (Victor, 1987). In *C. serrata* and *C. cantonensis* breeding was restricted to the wet season and the incidence of berried females rose at the start of the summer monsoon (Yam & Dudgeon, 2003). Richardson *et al.* (2004) while studying the distribution of caridean shrimps in southern Australia commented on the possibility of dams and weirs influencing shrimp abundance and timing of breeding. The timing and extend of the breeding season may vary with respect to geographic location and this may be due to variations in temperature. *Caridina typus* breeds throughout the year in Sri Lanka (De Silva, 1989) whereas in Japan its breeding season is reported from July-September (Kamita, 1959) and March-December (Soomro *et al.*, 2011).

Hart (1981) studied the seasonal changes in the population structure of *C. nilotica* and reported that higher birth rates during summer did not make corresponding increase in the population density due to high mortality. De Silva & De Silva (1989) reported enhanced breeding during the rainy season in *Caridina fernandoi*. Negative correlation between population density and rainfall was observed in *C. kunnathurensis* (Valarmathi, 2009). The seasonal difference in population density may be due to food limitation by the reduction of algal blooms (Dudgeon, 1992); the interference in feeding due to turbidity during heavy foods (Covich *et al.*, 2000); dispersal of the species to freshly inundated areas (Oh *et al.*, 2011).
2003) or spate-induced disturbances (Yam & Dudgeon, 2006). Goudswaard et al. (2006) opined that high predation pressure sometimes play the role of a limiting factor in population density.

2.5 Colour

Shrimps are gaining popularity in the pet market as ornamental species. Jayachandran et al. (2005) listed a few species of Macrobrachium and Caridina are species having potentials in the ornamental pet market. Vasantha (1973) studied the effect of temperature on red and white chromatophores of C. weberi. The red chromatophores aggregated and white chromatophores dispersed at high temperature. The chromatophores of C. weberi underwent small but significant cyclic changes in degree of expansion during various stages of the moult cycle (Nagabhushanam & Vasantha, 1971).

2.6 Food and Feeding

Stomach content analysis may be helpful in assessing the trophic position of a species within the ecosystem and in framing sustainable management strategies (Richardson et al., 2000). The family Atyidae is unique among the Malacostraca in having representatives that filter passively by means of the chelifeds (Fryer, 1977). The propodus and dactylus of feeding appendages bear setae which are of three types, chemoreceptors, scrapers and filtering setae (Felgenhauer & Abele, 1983). The feeding structures of Atya innocous and Potimirim glabra showed modifications for handling fine particles of food (Felgenhauer & Abele, 1985).

2.7 Live Feed

Natural foods play an important role in the nutrition of shrimps. Unlike penaeid prawns freshwater prawns grow on low protein and relatively inexpensive
diets (Mitra et al., 2005). Munuswamy (2005) reported that live feed can be used as colour enhancers and its nutritional quality can be improved by bioencapsulation. Jalihal et al. (1982) suggested C. kempi as a prospective species for culture both in inland and coastal low saline waters because of its hardiness, tolerance to fluctuations in temperature and salinity. Alam et al. (1991) suggested Moina as a substitute for Artemia nauplii while culturing Macrobrachium rosenbergii. The calanoid copepod Bestiolina similis is ideal as live food because of its growth rate and nutritional composition (McKinnon et al., 2003). Indulkar & Belsare (2004) reported higher weight, length gain and specific growth rate when post larvae of Macrobrachium rosenbergii were fed with Moina. Boonyaratpalin & Chittiwan (2007) worked out the importance of animal feed in the culture of Macrobrachium rosenbergii.

2.8 Moulting

Moultng is a periodic phenomenon associated with growth in Crustaceans. Temperature, quality and quantity of food, sex, physiological condition and developmental stage influence the frequency of moulting. Nagabhushanam & Chinnayya (1972) studied the moulting behaviour of C. weberi and observed that the animals moult throughout the year with two moulting peaks which coincided with high temperatures. Ponnuchamy et al. (1983) studied the effects of different ration levels in two freshwater prawns and reported that moulting is a metabolic necessity and occurs even at the expense of the organic reserves of starving prawns. Ponnuchamy et al. (1984) observed that population density stress affects moult production and growth in Macrobrachium lanchesteri and C. weberi.
2.9 Sexual dimorphism

Except differences in the morphology of 1st and 2nd pereiopods sexual dimorphism is not prominent in *Caridina*. But it has been proved that *Caridina* exhibits sexual dimorphism with regard to the number of aesthetasc bearing segments in the outer flagellum of antennular peduncle (Shenoy *et al*., 1993).

2.10 Morphometrics

Growth and reproduction are important aspects in the life history of a species. Growth may be quantified as an increase in total length (TL), carapace length (CL), telson length (TL), rostral length (RL) and body weight (W). Enin (1994) while studying the length-weight parameters of West African prawns reported isometric growth in *Nematopalaemon hastatus* and allometric growth in *Macrobrachium macrobrachion*. De Silva (1988a, b) reported positive relationship between length and weight in males and non-ovigerous females of *C. simoni* and *C. pristis*. The males and females of *C. kumariae* showed somewhat different length-weight relationship (De Silva, 1990). Bello-Olusoji *et al*. (2004) reported positive correlation between length and weight in *Caridina* spp.

2.11 Fecundity

Reproductive performance and abundance of a species is usually measured in terms of fecundity. Fecundity has different aspects such as, potential fecundity, realized fecundity and actual fecundity (Anger & Moreira, 1998). The parameters such as total body length (Valenti *et al*., 1989; Müller & Carpes, 1991), length and volume of the abdomen (Corey & Reid, 1991), length of pleopods and mortality rate of eggs (Annala, 1991) influence fecundity. Caridean females carry eggs in a brood pouch formed by the growth of the abdominal pleura and the bristles of the
pleopods (Charniaux-Cotton & Payen, 1992). The strategy of carrying eggs enhances the survival of the embryos, optimising the reproductive success of the species (Shakuntala, 1977; Nazari, et al., 2003).

Rao et al. (1981) observed a linear relationship between egg number and volume of the female in *C. weberi*. Weerakkody (1984) established a linear relationship between the logarithmic values of fecundity and body length in *C. simoni*. Mashiko et al. (1991) studied the reproductive characteristics of *Limnocaridina tanganyikae* from Lake Tanganyika, East Africa. Galvão & Bueno (2000) reported positive correlation between fecundity and female body size in *Atya scabra*. Nazari et al. (2003) compared the fecundity, egg size and egg mass volume of *Macrobrachium potiuna* and *Macrobrachium olfersi*. Bello-Olusoji (2004) analyzed the weight-fecundity and length-fecundity relationship of *Caridina* spp. and showed that the relationship between fecundity and weight is weak ($R^2 = 0.382$) and that between fecundity and length is relatively strong ($R^2 = 0.64$). Bhuiyan et al. (2007) reported positive correlation between the number of eggs and the length of female body in *Macrobrachium dayanum*.

The increase in fecundity with regard to length and weight of the animal is not consistent. Lobão et al. (1985) and Oh & Hartnoll (1999) related the disproportionally large number of eggs in some smaller females to the physiological condition of the parent.

Vorstman (1955); Smith & Williams (1980); Mayen & Contreras (2000); Galvão & Bueno (2000); Bhuiyan et al. (2007); Kim et al. (2008) reported positive correlation between fecundity and total length in *Atyaephyra desmaresti, Paratya*
australiensis, Atya margaritacea, Atya scabra, Macrobrachium dayanum and Palaemon paucidens respectively.

2.12 Larval development

Based on diameters of eggs Shokita (1981) classified the eggs of atyids in to 3 types namely, small, medium and large. Hancock et al. (1998) suggested that egg size is under strong genetic control while clutch size is influenced by environment. Hancock (1998) reported that embryonic duration was not dependent on egg size but was a function of temperature. Based on the number of larval stages three types of larval development have been recognized in palaemonids and atyids namely, common or prolonged type, abbreviated type and completely suppressed type (Sollaud, 1923; Benzie, 1982; Jalihal et al., 1993; Shy et al., 2001). The completely suppressed development is further divided into complete suppression type- A and complete suppression type- B (Lai & Shy, 2009). The studies on reproductive biology may be helpful in assessing larval release and survival rates that have important implications in structuring adult populations. The early developmental stages of shrimps are more susceptible to environmental stresses, so shrimps having abbreviated development can be successfully cultured than those with prolonged development (Dobkin, 1969).

C. propinquua common in north-eastern India is a perennial spawner and Babu (1963) made a detailed study on its breeding, fecundity, moulting, growth and attainment of maturity. Macrobrachium idella shows prolonged development that passes through 10 well defined zoeal stages before metamorphosing into the first post-larva (Pillai & Mohamed, 1973). Caridina pseudogracilirostris reported from the backwaters of Kerala, shows prolonged development and its life history is
completed in 6 larval and 1 post larval stage at a salinity of 15 ppt. (Pillai, 1975). Lakshmi (1975) studied the early larval development of Caridina species and commented that intra and interspecific differences are common in the larval development of shrimps belonging to the family Atyidae. The post embryonic growth and development of Caridina nilotica aruensis shows partially abbreviated development that passes through 4 larval and 1 post larval stage before reaching juvenile stage (Glaister, 1976). Atkinson (1977) reported 11 zoeal stages in the larval development of Macrobrachium lar. Couret & Wong (1978) described the larval development of Halocaridina rubra and observed that its development proceeds through four zoeal stages and one megalopal stage before reaching the first juvenile stage. Jiansen & Xiaoyi (1979) described the larval development of six freshwater prawns namely, C. nilotica gracilipes, Neocaridina denticulata sinensis, Exopalaemon modestus, Palaemonetes sinensis, Macrobrachium nipponense and M. asperulum. Guest (1979) provided information about the larval stages, growth and sexual maturity of Macrobrachium amazonicum. Shy et al. (1980) observed that the larvae of Neocaridina brevirostris were hatched at an advanced stage.

While studying the post-embryonic growth rates in C. nilotica Hart (1980) observed that males grew faster than females during the first two months of life. Under laboratory conditions, the growth rate of males increased with temperature, but temperature related differences were not marked in females. Ravindranath (1981) described 8 zoeal stages in the larval development of C. rajadhari. The incubation period of Paratya curvirostris is 28 days at 14-18°C (Carpenter, 1983). Benzie (1982) described the larval development of Caridina mccullochi and
observed an increase in the duration of larval stages with age. *Caridina singhalensis* endemic to the island of Sri Lanka shows abbreviated larval development (Benzie & De Silva, 1983). Hayashi & Hamano (1984) studied the larval development of *C. japonica* and reported 9 zoeal stages in its life history. Ponnuchamy *et al.* (1987) reported nocturnal hatching rhythm in the larval release of *Macrobrachium lanchesteri*. Salman (1987) studied the larval life history of *C. babaulti basrensis*. Chong & Khoo (1987) studied the larval development of *Macrobrachium malayanum* and observed to complete development in 2 zoeal stages and one megalopal stage. Chong & Khoo (1988) provided larval descriptions for the 1st zoea of *Macrobrachium lanchesteri*. Wong (1989) described the abbreviated larval development of *Macrobrachium hainanense*. Walsh (1993) studied the larval development of *Paratya australiensis* and compared the fecundity, egg and larval size between forms inhabiting estuarine and riverine environments. Though there were no differences in development, the specimens collected from riverine locations possessed larger eggs and smaller brood sizes than those from estuarine habitats.

Mayén & Contreras (2000) discussed different aspects of the reproduction of *Atya margaritacea* in a population from the Mexican pacific. *Caridina kempi* completes its larval life cycle in 6 zoeal and 1 post larval stage and the successful completion of larval development in freshwater as well as seawater provides experimental evidence for the marine ancestry of atyids (Jalihal *et al.*, 2000). The salinity dependence during the larval phase also indicates that the process of freshwaterization is not yet complete in atyids (Kadrekar & Sankolli, 1987). Shy *et al.* (2001) reported direct larval development in *Caridina formosae*. Pillai (2002)
reported the larval history of *Caridina longirostris* in 8 zoeal stages at a salinity of 6-10‰. The 1st zoea of most of the atyid shrimps moult in less than one day regardless of temperature and according to Idrisi & Salman (2005) this is an adaptation to develop beyond the 1st critical stage. According to Heerbrandt & Lin (2006) *C. gracilirostris* has great potential for aquaculture as a candidate species in aquarium and they described the optimum conditions needed for its survival and larval development. Jalihal et al. (2007) provided larval descriptions for *Caridina gurneyi* and *Caridina shenoyi*. Almelkar et al. (2007) studied the larval development of *Macrobrachium bombayense*, *M. kulkarnii*, *M. sankollii* and *M. tiwarii*.

Besides the above mentioned species larval descriptions were available for several species of *atyids* viz., *C. wyckii* (Daday, 1907); *C. nilotica* var. *typica* (Gurney, 1927); *C. denticulata* (Shen, 1939); *C. brevirostris* (Shokita, 1973); *C. weberi* (Chinnaya, 1974); *C. denticulata ishigakiensis* (Shokita, 1976), *Neocaridina denticulata* (Shy et al., 1992), *C. gracilipes*; *C. bengalensis*; *C. williamsoni*; *C. kunnathurensis*, *C. gurneyi* and *C. jalihali* (Mariappan & Richard, 2007).