

REVIEW OF LITERATURE

Systematic of Podostemaceae

The name of the family 'Podostemaceae' was proposed by Michaux (1803) after the type genus *Podostemum* (prominent stamen supported by pedicel). Sprague (1933) fixed the family name as Podostemaceae. The pioneering work on podostemaceae was that of Aublet (1775) who discovered the first member *Mourera fluviatilis*, of the family. Tulasne (1852) made an important contribution to the morphology and taxonomy of the Podostemaceae through his celebrated work '*Monographic Podostemacearum*'. Griffith (1838) reported Podostemaceae for the first time from India, and from Sri Lanka by Gardner in 1847. Willis (1902b, c, 1914, 1915b, c, 1926a, b) studied the Indian Podostemaceae in their natural habitat directing major attention to their morphology, taxonomy, ecology and phylogeny. Tulasne (1852) described several Indian Podostemaceae. Beddome (1865) described several podostemads from Annamalai. Weddell (1873) redefined the genus *Hydrobryum*. Warming (1882) provided illustrative account for many podostemads.

Hydrophytes are defined as those which grow in water (Arber, 1920). Muenscher (1944) considered aquatic plants as those germinate in water or any other substrate. Podostemaceae were classified as "rheophytes" as they were firmly attached to rocks, boulders or even submerged wood pieces in the running water of rivers, streams and waterfalls (Gardner, 1847). Sculthorpe (1967) in his "Biology of Aquatic Plants" opined that Podostemaceae were a strange group of angiosperms. Bentham and Hooker (1880-1883) placed the family in the series Multiovulate Aquaticae under subclass Monochlamydeae considering the presence of numerous ovules, apetalous flowers and aquatic habitat. Hooker (1885) again classified Podostemaceae into two tribes Hydrostachydaceae and Eupodostemoideae. Tulasne (1852) made subdivisions of the family on the basis of floral characters, where as Weddell (1873) classified it on the basis of staminal characters.

Willis (1914) suggested that Tristichaceae should be treated as a separate family. Rendle (1925) classified Podostemaceae in the order Rosales under Dialypetalae of dicotyledons. This family was closely linked with Saxifragaceae of order Rosales.

Due to the resemblance of floral characters, numerous anatropous ovules, bicarpellary gynoecium and free styles, Engler (1930) suggested that the family was linked to Saxifragaceae. Van Royen (1951) reviewed the different classifications of Podostemaceae and proposed the recognition of the two sub families Podostemoideae and Tristichoideae with tribes. The family Podostemaceae deserves a placement in the order Podostemales in division Herbbaceae under the sub-phylum Dicotyledonae and phylum Angiospermae as observed in Hutchinson's classification (1959). Takhtajan (1980) regarded the Podostemaceae as "related to and derived from" the order Saxifragales, and followed several authors (e.g. Mauritzon, 1933; Kapil, 1970; Maheshwari, 1945) who concluded that the family is derived from Crassulaceae. Thorne (1992) considered Tristichoideae and Podostemoideae as two subfamilies of Podostemaceae in the suborder Saxifragineae of Rosales under the super order Rosiflorae.

The Podostemaceae have been considered as phylogenetically isolated, because of its extremely peculiar vegetative morphology. There has been no established or usually accepted hypothesis on its systematic position. Especially, Cusset and Cusset (1988a) proposed the new class, Podostemopsida beside the Magnoliopsida and Liliopsida because of absence of double fertilization and the embryo without any histological zonations. Many authors, however, have agreed that they are related to the Saxifragaceae and the Crassulaceae (Warming 1882; Willis 1915a; Engler 1930; Dahlgren 1980; Cronquist 1981, 1988), and placed the Podostemaceae in the monotypic Podostemales.

In the phylogenetic classification of Cronquist (1981) the division Magnoliophyta and class Magnoliopsida had the subclass Rosidae with Podostemaceae family. Dahlgren's (1980) proposal also had the class Magnoliopsida and sub class Magnolidae. Podostemaceae was raised to the super order level Podostemiflorae with the order Podostemales. The family was placed in the Malpighiales clade belongs to eurosids I, perhaps related to Hypericaceae (Soltis et al., 1999).

Nagendran et al., (1981), Cusset and Cusset (1988b-d) recognized Tristichaceae as an independent family. Cusset and Cusset (1988c, 1989) strongly suggested that Podostemaceae and Tristichaceae belong to a third class within angiosperms – Podostemopsida. This proposal was based on the prominent characters of the group

i.e. lack of double fertilization and extra ordinary vegetative construction (Kapil, 1970; Nagendran, 1975).

In contrast to the above proposal, Willis (1902b, 1914), Subramanyam and Sreemadhavan (1969), Cook (1990), Rutishauser and Huber (1991), and Thorne (1992) had recognized Podostemoideae and Tristichoideae as two sub families of Podostemaceae under dicotyledonae. This was well supported by characters of the seedlings and the presence of two cotyledons. Mathew and Raveendran (1995) also favoured the above placement. Analysing the nucleotide sequence, Ueda et al., (1997), supported the views of Takhtajan (1980) and Cronquist (1981) that Podostemaceae was closely related to Crassulaceae and Saxifragaceae. Mathew et al., (2001) favoured Cusset's (1992) view of raising the family to a separate class status.

Habitat characteristics and Ecology

Sioli (1986) has stated that rivers are the most pollutant among tropical aquatic ecosystems. Philbrick and Crow (1983), Philbrick and Novelo (1995) and Novelo and Philbrick (1997) have reported on the possible loss of podostemaceae species in North America (USA and Mexico) due to human impacts on the rivers in which the species are found. Cross Bell (1990) has provided evidence that the disappearance of three Podostemaceae species downstream of a rubber factory in India was due to acid discharge from factory into the river. Data on water quality at the sites where Podostemaceae occur are scanty except for work done, e.g by Grubert (1975) in South America, Noro et al., (1994) in Japan and Quiroz et al., (1997) in Mexico.

Willis (1902b) recorded the qualitative characters of water in the spots of Podostemaceae in India. Studies on river hydrobiology in Indian rivers had been done. Adyar river by Chako and Ganapathi (1949), Cauvery by Sreenivasan et al., (1980) and Yamuna by Chakrabarty et al., (1959); and Ganga by Rai (1978). Vijayakumar (1995) studied on water chemistry of rivers. Works of Bhimachar and David (1946), and Venkateshwarulu (1969) on the ecology of algal flora of Moosi river at Hyderabad were with special reference to pollution. Gopinathan et al., (1984) published their work on the quantitative ecology of Phytoplankton in Cochin

backwaters. Joy (1989) studied growth response of phytoplankton exposed to industrial effluents in Periyar river. The above studies were done with respect to algal population in the rivers. Grubert (1975) pointed out the detrimental impact of siltation on the seed germination stage of podostemads. Meijer (1976) opined that podostemaceae were indicators of water pollution.

River biotas are highly threatened by anthropogenic factors (Allan and Flecher, 1993). Anthropogenic impacts on tropical rivers can have devastating impacts on populations of Podostemaceae. For instance, three species *Marathrum schiedeanum* (V. Cham.) Tul., *Oserya coulteriana* Tul., and *Tristicha trifaria* (Bory ex Willd. Sprengel) in the Refilion River, Nayarit, Mexico, are abundant upstream of a coffee-bean processing plant but sparse downstream of the outflow from the plant, despite the abundance of otherwise suitable habitat (Philbrick and Novelo, 1995). Pollution is correlated with the loss of population of *Podostemum ricciiforme* (Liebm.) P. Royen at the type locality for the species (Novelo and Philbrick, 1997), and the extirpation of *Marathrum tenue* Liebm. (Philbrick and Novelo, 1995) in the Mexican states of Puebla and Morelos, respectively. Moreover, populations of the temperate *Podostemum ceratophyllum* Michx. in New Hampshire (USA) were decimated after apparent industrial waste disposal in the early 1970's (Philbrick and Crow, 1983). Crossbell (1990) reported the detrimental impact to rubber factor effluents on Podostemaceae population in the hill streams of Kanyakumari district. Empirical data on the water chemistry in rivers where Podostemaceae occur are lacking, although Grubert (1975) reported pH, conductivity and temperature values for one river in South America where several species were found. A significant parameter reflecting a physical and biological process in water was the dissolved oxygen content (Michael, 1984). Butcher (1947) observed that the water polluted by organic waste showed decline in dissolved oxygen. Pannier (1960) after a physiological study of *Tristicha* spp. concluded that Podostemaceae were plants of high oxygen uptake.

Another important parameter of aquatic ecosystem was free carbondioxide (Welch, 1952). As podostemads were not able to utilize dissolved bicarbonates directly, the value of free CO₂ was a limiting factor in their growth. The CO₂ content in the water might be restricting waterfalls and rapid streams (Pannier, 1960; Gessner and Hammer, 1962; Grubert 1975).

Alkalinity was another parameter closely related to the above parameters, so it had a role in the distribution of aquatic flora (Philipose, 1967). Chloride content of water varied in different seasons (Michael, 1984). Quiroz et al., (1997) examined the relation between chemical variables of water and their relation with occurrence of podostemaceae in Mexican rivers.

Ameka (2000) studied the relationship between water chemistry and distribution of podostemads in 21 rivers in Ghana. He concluded that the availability of appropriate substrata, in addition to adequate light, was more important than the water chemistry in limiting the distribution of species.

Associations with plants and animals

Macrophytes of riverine systems provide to a large number of other biota (Westlake, 1975). They furnish substratum or shelter for epiphytic algae, invertebrates, insects larvae, fish and their eggs. Leppik (1953, 1956), and Levin (1971) studied the close relation between animal and plant population. Stebbins (1973) related organism with its physical environment. The diversity of biota was maintained in erratic ecosystems by the microhabitats maintained by these macrophytes (Fox, 1992). Water current and light were the major controlling factors of this microenvironment (Dodds, 1991). Filamentous algal communities form favourable epiphytic algal cover of macrophytes. Sand- Jensen et al., (1989), Gopal and Goel (1993) and Dobson and Frid (1998) had contributed on the inter relations in this microenvironment.

Hosmani and Nagendran (1980) had reported an intimate association between *Griffithella hookeriana* cyanobacteria *Rivularia aquatica*. Kondratieff and Voshell Jr. (1981) had studied the relationship between *Podostemum* and the mayfly *Heterocloeon curiosum* in the river North Anna.

Connelly et al., (1999) describe the riverweed darter (*Etheostoma podostemonae*), a small fresh water fish of the perch family, as being closely associated with the habitats of *Podostemum ceratophyllum* in North America. Hutchens et al., (2004) found a strong positive relationship between surface area of *Podostemum ceratophyllum* and macroinvertebrate abundance and biomass. Léonard and Dessart (1994) reported that some species of the Torridincolidae (Myxophaga, Cleoptera) possibly have a symbiotic relationship, pollinating the flowers of riverweeds

(Podostemaceae) like *Ledermanniella*, *Leiothylax* and *Macropodiella* in Central Africa. Lechleitner and Kondratieff (1983) observed nymphs of stonely *Ptenonarcys dorsata* in Tamery the population of *Podostemum ceratophyllum* vegetation in southwestern Virginia. Grimm (1994), Bijl et al., (1989) viewed that Podostemaceae provided a “biotic structure” in unstatic river environment by altering stream biota. Quiroz et al., (1997) viewed that changes in the associated algal flora might be detrimental to podostemads population. Nileena (2001) studied the curious interrelationships of genera and species in Podostemaceae, with special reference to polymorphism. Geetha (2002) reported occurrence of algae and some water insects in association with the podostemads.

Morphology and Anatomy

A preliminary study on hydrophytes of south India is believed to have been done by Henrick Van Rheede in the 17th century (Manilal, 1980). Contribution by Subramanyam (1962), Vartak and Bhadbhade (1973), Mohan Ram and Kakkar (1983), Mohan Ram and Sehgal (1997), Cook et al., (1974), Manilal and Sivarajan (1975) were some of the further attempts in the study area. In this family, structural studies are mainly related to the vegetative regions (Schnell, 1967; Rutishauser, 1997; Cusset and Cusset 1988a; Ancibor, 1990; Imaichi et al., 1999; Hiyama et al., 2002; Suzuki et al., 2002; Fujinami and Imaichi, 2009). The development and structure of vegetative and reproductive shoots were recently studied in the Neotropical species *Diamantina lombardii* Novelo, Philbrick and Irgang (Rutishauser et al., 2005) and the African species *Stonesia ghoguei* E. Pfeifer and Rutishauser (Pfeifer et al., 2009) and *Djinga felicis* C. Cusset (Ghogue et al., 2009)

The morphological nature of dorsally flattened plant body has been debated since the discovery of the first podostemads. It has been interpreted as a root (Tulasne, 1852; Willis, 1902b; Philbrick, 1984; Jäger-Zürn, 1997a, 2000; Rutishauser, 1997; Imaichi et al., 1999; Rutishauser et al., 1999; Jäger-Zürn and Grubert 2000; Ota et al., 2001), or as a stem (Warming, 1882, 1891; Novelo and Philbrick, 1993; Rutishauser and Grubert, 1994; Philbrick and Novelo, 1995; Rutishauser, 1997; Tur, 1997; Jäger-Zürn and Grubert, 2000) or as a combined shoot (leaf and stem structure, Willis, 1902c) or

thallus (Vidyashankari and Mohan Ram, 1987; Vidyashankari, 1988b, c; Mohan Ram and Sehgal, 1992, 1997; Khosla and Mohan Ram, 1993; Sehgal et al., 1993; Uniyal and Mohan Ram, 1996; Khosla, 1996, Khosla et al., 2000).

The vegetative morphology and anatomy of the Podostemaceae have been studied by a number of workers including Willis (1902b, c), Engler (1930), Van Royen 1951, 1953, 1954), Cusset (1987), Rutishauser and Grubert (1999), Ameka (2000a) and Ameka et al., (2002). The root or thallus vary in form from thread-like, ribbon-shaped to thalloid or foliose and are usually green (Cook, 1996a; Rutishauser, 1997; Ameka, 2000a). A primary root is absent (Schnell and Cusset, 1963; Rutishauser, 1997; Jäger-Zürn, 2000a). A root cap may be absent or present (Rutishauser, 1997). From the root margin and surface arise endogenous buds from which shoots and flowering stems develop (Cusset, 1997; Rutishauser, 1997). Adhesive hairs (rhizoids / root hairs) are present by which the roots are attached to rocks or other solid substratum (Rutishauser, 1997; Ameka, 2000a). Silica bodies occur in the epidermis of some species (Hammond, 1937; Dahlgren, 1980; Ameka, 2000a). If xylem is present it is represented only by a few tracheids with annular or spiral thickenings (Takhtajan, 1997; Uniyal, 1999; Uniyal and Mohan Ram, 2001). Typical phloem elements are not observed in the Podostemaceae but sieve plates have been observed in a few genera such as *Marathrum* sp. (Romano and Dwyer, 1971) and *Indotristicha tirunelveliana* (Uniyal, 1999)

Leaves are either absent or present and can then be reduced. They are extremely reduced in size and shape; linear to filiform or reduced and scale-like (Rutishauser, 1997). Linear leaves are entire, dichotomously, pinnately or laciniately divided (Cook, 1996a; Cusset, 1997). Scale-like leaves are tristichous or distichous (Cusset, 1997) the leaves when present lack auxiliary buds. Stipules may be absent or present (Taylor, 1954; Rutishauser, 1997). Stomata have not been demonstrated in the family and the epidermis, typical of submerged aquatic plants, contains chlorophyll (Metcalf and Chalk, 1950). Large air spaces or lacunae are usually absent in the podostemaceae, quite unlike true aquatic plants (Arber, 1920; Metcalfe and Chalk, 1950; Rutishauser, 1997).

Developmental Biology: *In-vitro* seed germination and seedling development

Seeds in Podostemaceae were termed unique since they lack endosperm (Maheshwari, 1945; Stace, 1989). Several workers have investigated the attachment mechanisms of seeds and seedlings of Podostemaceae (Grubert, 1970, 1980; Nagendran, 1983; Philbrick, 1984). Grubert, based on studies of *Mourera fluviatilis* Aublet, reported that the adhesive strength of the mucilage far exceeds the shearing forces of the water current. Interpretation of basic plant form has been hindered by a lack of knowledge of how seedlings develop into mature plants. Early observations were based on study of field collected seedlings (Warming, 1891; Willis, 1902a; Hammond, 1937; Schnell and Cusset, 1963). Nagendran (1975) succeeded in germinating seeds of nine Indian podostemads in petri-plates, but was unable to sustain their growth beyond 30 days. Grubert (1976) observed germination in Venezuelan podostemads. Philbrick and Novelo (1994) recorded a high percentage of germination in laboratory studies of five Mexican species and discussed issues such as dormancy, viability and role of seed biology in population dynamics. Detailed studies of the sequence of events during seed germination, thallus formation and secondary shoot development in *Griffithella hookeriana* was studied by Vidyashankari and Mohan Ram, 1987; Vidyashankari, 1988b), *Polypleurum stylosum* (Wight) Hall (Sehgal et al., 1993) and *Dalzellia ceylanica* (Gardn.) Wight (Uniyal and Mohan Ram, 1996). Mohan Ram and Sehgal (1997) studied the *in-vitro* seed germination and developmental morphology of some Indian Podostemaceae. The events of seed germination in Indian Podostemaceae were also studied by Uniyal (1999, 2001). Uniyal (2001) studied the early stages of *in-vitro* seed germination in *Willisia selaginoides*. Sanavar et al., (2008) studied the *in-vitro* germination of seed in *Zeylanidium lichenoides*. Reyes-Ortega I. et al., (2009) studied the seed germination in *Marathrum schiedeanum* and *M. rubrum*.

Reproductive Biology

Embryological data are increasingly included in phylogenetic studies, especially at the family level (Simpson, 2006). In the podostemaceae, such data, mainly embryo sac development, are used in the infrafamiliar classification (Razi, 1949; Mukkada 1969; Battaglia 1971; Nagendran et al. 1977, 1980; Jäger-Zürn, 1997b Murguía-Sánchez et al., 2002; Sikolia and Ochora 2008; Sikolia and Onyango 2009). Nagendran et al., (1976, 1980, 1981) studied the embryology of Podostemads. Histotaxonomic study by Raveendran (1995) and studies on the vegetative and reproductive features of Podostemaceae in Kerala by Mathew and Satheesh (1997) are noteworthy.

According to Cook (1996a), Novelo and Philbrick (1997) and Mathew and Sateesh (1997), flowers of the family Podostemaceae are small, solitary or in Cymose inflorescences, hermaphrodite, actinomorphic or zygomorphic, apetalous, anemophilous, entomophilous or cleistogamous. Spathella if present encloses the flower during development and is ruptured by elongation of the pedicel prior to anthesis (Graham and Wood, 1975). The tepals (perianth) if present comprise of three or five free or connate members or are reduced to linear or subulate, scale-like structures which are usually 2-20 in number (Graham and Wood, 1975; Cook, 1996b). Stamen number varies from one to many. They are free or connate. pollen grains are in monad or dyads and are from three-colpate and five-colpate to pantoporate, sometimes inaperturate (Bezuidenhout, 1964; Rutishauser and Huber, 1991; O'Neill et al., 1997) the ovary may be on a gynophores or it is sessile, and globose to ellipsoid (Taylor, 1954). The ovary is superior with one, two or three locules (Hutchinson, 1959); the locules are ellipsoid to fusiform or subglobose and may be equal or unequal in size (Cusset, 1997). The ovary contains numerous or rarely two-four (as in *Farmeria* sp.) ovules on free-central or axile placenta (Takhtajan, 1997). The ovules are anatropous (Went, 1909). The stigmas are one, two or three, sessile or subsessile, usually free, and variable in shape (Cook, 1996a). The female gametophyte is monosporic or bisporic, four-celled; it contains an egg, one or two synergids, and one or two chalazal cells (Razi, 1949; Maheshwari, 1955; Mukkada, 1964; Arekal and

Nagendran, 1975; Battaglia, 1971, 1987; Jäger-Zürn, 1997b). Polar nuclei are absent and therefore, there is no triple fusion (Mukkada, 1969).

Fruits are septicidal or septifragal capsules usually with numerous seeds (Taylor, 1954; Philbrick, 1984). The capsule is usually brown, spherical or ellipsoid or fusiform, smooth or ribbed (Cusset, 1997) with equal or unequal valves. In some Neotropical species, e.g. *Apinagia* and *Mourera*, flowering to maturation of capsule takes only 2-3 weeks (Grubert, 1974).

Seeds of Podostemaceae are usually reddish-brown to blackish, minute, ellipsoid to ovoid, slightly flattened (Cusset, 1997; Ameka, 2000a). Many seeds are with reticulate testa (Cusset, 1983, 1984; Ameka, 2000a). The seeds when initially shed from the capsule, have dry and collapsed outer integuments. When wetting takes place, however, these cells absorb water quickly, expand and become mucilaginous (Philbrick and Novelo, 1997; Ameka, 2000a). The embryo is straight with massive cotyledons and a large suspensor (Mukkada, 1969). Since the embryo sac lacks polar nuclei, endosperm is absent (Went, 1909; Mukkada, 1969; Takhtajan, 1997). Seeds number per capsule varies among the Podostemaceae. Rutishauser and Grubert (1994) found 2000-2400 seeds per capsule in *Mourera fluviatilis*. *Hydrobryum griffithii* (Wallich ex Griffith) Tul., on the other hand, was found to contain about 30 seeds only per capsule. According to Vidyashankari and Mohan Ram (1987) and Philbrick and Novelo (1994), the seeds can remain viable for period upto 18 months when stored dry at room temperature ($25\pm 2^{\circ}\text{C}$).

Reproductive phase has been defined as the time when half of the population had produced flowers. The pattern of flowering was fixed by its timing and frequency. Bawa (1983) viewed that these represented as sequences called phenograms. He has stressed the need for complete phenological observation of plants in its ecological study.

According to Rutishauser (1997) many Neotropical species, especially from the genera *Apinagia*, *Mourera* and *Rhyncholocis*, have entomophilous characteristics: Variable number of stamens, brightly colored filaments and pedicel, floral odour and

visitor insects. However, inferences on the pollination mode based on flower morphology, number and arrangement of floral parts (e.g. Philbrick, 1981; Philbrick and Bogle, 1988; Khosla and Mohan Ram, 1993), dimensions, structure of pollen grains and pollen-ovule ratio (Bezuidenhout, 1964; Lobreau-Callen et al., 1998; Okada and Kato, 2002; Cook and Rutishauser, 2007), as well as case studies (Philbrick, 1984; Philbrick and Novelo, 1998; Khosla et al., 2000,2001; Khosla and Sehgal, 2009), suggest the predominance of autogamy, and anemophily as the main pollination system. There are records of bees visiting flowers of Podostemaceae, including *Mourera fluviatilis* (Went, 1926a; Gessner and Hammer, 1962; Grubert, 1974; Tavares, 1997; Okada and Kato, 2002), suggesting a possible allogamy by biotic factors. Mukkada (1969) suggested for *Dalzellia zeylanica* (Gardner) Wight (Podostemaceae) the occurrence of a pollination system including insects and wind as pollen vectors.

The mechanism of pollination has been studied in very few podostemads (Philbrick, 1984; Philbrick and Novelo, 1997) although autogamy is believed to be common. Pollination biology of *Indotristicha ramosissima* of sub-family Tristichoideae was studied by Khosla and Sehgal (2009). In general diverse pollination mechanisms ranging from anemophily (Cook, 1988) to entomophily (Philbrick, 1984) have been reported in Podostemaceae. The breeding system in Podostemaceae varies from allogamy to autogamy and was studied by Willis (1902a); Philbrick, (1984); Philbrick and Novelo (1997); Rutishauser and Grubert (2000); Khosla et al., (2000, 2001); Ameka et al., (2002); Okada and Kato (2002). Importantly, podostemads have generally high seed numbers as compare to other aquatic plants (Philbrick and Novelo, 1997; Rutishauser, 1997). Sexual reproduction is quite well established in podostemads unlike other aquatic angiosperms which show a high propensity for vegetative propagation (Khosla and Mohan Ram, 1993; Jäger-Zürn, 1997a; O'Neill et al., 1997; Philbrick and Novelo, 1997). Philbrick and Novelo (1994, 1997) have carried out investigations on ovule number, seed number, seed germination and seed size in species of North American podostemads.

The embryological studies of Went (1908, 1910, 1912, 1926a), Magnus (1913), Chiarugi (1933) and Razi (1949, 1955) were confined chiefly to the development of the female gametophyte. Mukkada (1962a, b, 1964) investigated the morphology and embryology of *Dicrea stylosa* while Chopra and Mukkada (1966) studied gametogenesis in *Indotristicha ramosissima*. Considerable work has been done on the embryology of the Podostemaceae (Kapil, 1970; Mohan Ram and Sehgal, 1992; Jäger-Zürn, 1997b). Philbrick (1984) investigated the reproductive biology of *Podostemum ceratophyllum* in detail.

Embryological studies in Podostemaceae were initiated by Went (1908) and described the embryo development in *Apinagia imthurni* and *Mourera fluviatilis*. He also reported *Allium* type of embryo sac in several taxa of four nucleated embryo sac with egg apparatus and polar nucleus. Chiarugi (1933) reported tetra nucleate embryo sac in *Weddelina squamulosa*. The embryology of these plants was further studied by several workers (Razi, 1949; Chopra and Mukkada, 1962; Kapil, 1970; Battaglia, 1971). The occurrence of single fertilization (i.e. syngamy), was reported by Mukkada, 1962a; Mukkada and Chopra, 1973. Absence of antipodals, triple fusion and endosperm; presence of a four-nucleate mature gametophyte, pseudo-megagametophyte, single fertilization and suspensor haustoria were reported by Razi, (1949); Mukkada, (1962a); Chopra and Mukkada, (1966); Kapil, (1970); Battaglia, (1971); Mukkada and Chopra, (1973); Nagendran, (1975); Sehgal et al., (2002). Khosla et al., (2000) have reported on the reproductive biology of *Polypleurum stylosum*. Sehgal et al., (2010) reported the occurrence of unique three-celled megagametophyte and single fertilization in *Dalzellia zeylanica*.

The flowering phenology and pollen-ovule ratio of *Marathrum rubrum* was calculated by Philbrick and Novelo (1997). They followed the procedure outline by Philbrick and Anderson (1987). The systematic relevance of pollen-ovule ratio was described by Cruden (1977). Philbrick and Novelo (1987) and Khosla et al., (2000) had reported pollen-ovule ratio of selected aquatic plants including the varieties of *Polypleurum*. Kita and Kato (2001) inferred pollination systems of some Podostemads from pollen-ovule ratios.

Ecological Niche Modeling (ENM)

The term 'niche' was first coined by Sir Joseph Grinnell (1917) in his paper 'The niche relationships of the California Thrasher'. He emphasized that niche of a species is the sum of the ecological conditions that allows a species to persist and produce offspring. Elton (1927) proposed that ecological niche of a species is characterized by the functional role it plays in an ecosystem. Hutchinson (1957) theorized ecological niche to be the activity range of a species defined by an n-dimensional hyper volume of all the environmental conditions. The foundation of ecological niche modeling is based on Grinnell's ecological niche concept which has a single focus i.e. the environmental factors and permits model development. Elton's, Hutchinson's and MacArthur's concept however are more process based which include species functions and biotic interactions, and hence are difficult to fit in a modelling framework. Ecological niche in the light of ENM can be defined as '.....the set of ecological conditions within which the species is able to maintain its population without immigration' (Grinnell, 1917).