The review for the present studies has been dealt under the following heads:

Fish fauna

Stream fish occur in discrete stream zones or parts of distinct fish assemblage in Europe (Huet, 1949, 1959; Penczak et al., 1991), southern Asia (Hutchinson, 1939; Edds, 1993) and western-north America (Gard and Flitner, 1974; Rahel and Hubert, 1991). Though, Vannote et al. (1980) described little about the functional roles of fish in streams, stream fish have since that time been increasingly integrated in paradigms of stream ecology (Power et al., 1985; Minshall, 1988; Grimm, 1988; Gelwick and Matthews, 1992; Allan, 1995).

The primary factors affecting fish populations in streams include physical structure of stream, flow, water quality, temperature and watershed which in combination affect the physical habitat along with the primary and secondary productivity of streams (Stainaker, 1979) (Fig. 3).

Horwitz (1978) observed strong positive correlation between fish diversity and variability in stream discharge (Schlosser, 1985; Poff and Allan, 1995; Power et al., 1995a). The number of species increases downstream either by addition (Lotrich, 1973; Morin and Naiman, 1990) or by replacement (Tramer and Rogers, 1973; Gard and Flitner, 1974; Maturakis et al., 1987). Longitudinal increase in number of fish species coincides with the habitat complexity downstream (Maturakis et al., 1987), however, observations contrary to this do exist (Rahel and Hubert, 1991).
Biotic factors that influence fish assemblage structure include competition (Echelle and Schnell, 1976; Page and Schemske, 1978), scale of food availability (Power, 1984), predator-prey interactions (Moyle and Li, 1979; Zaret, 1979; Fraser and Cerri, 1982; Fraser et al., 1995), resource partitioning (Zaret and Rand, 1971; Werner and Hall, 1976; Mendelson, 1975; Baker and Ross, 1981; Paine et al., 1982; Wynes and Wissing, 1982; Ross, 1986) and morphological adaptations (Gatz, 1981; Welcomme, 1985).

Contrary to this, other researchers have shown abiotic regulation of fish assemblage structure (Starret, 1951; Smith and Powell, 1971; Kushlan, 1976; Gorman and Karr, 1978; Matthews and Maness, 1979; Matthews and Hill, 1978; Matthews and Styron, 1981; Matthews et al., 1982b; Capone and Kushlan, 1991).

**Abiotic-biotic factors**

Owing to the close correlation between abiotic and biotic variables, it is often seldom possible to assess the impact of these variables separately, so the review of these factors has been dealt together.

The earliest investigations on the physical and chemical factors in
streams include Stehr and Branson (1938), Neel (1951) and the classic work of Minckley (1963) followed by Hynes (1970), ‘Ecology of running waters’ which remains the benchmark for studies on lotic waters. More recently, Allan (1995) has produced a comprehensive volume on stream ecology.

Water temperature strongly influences the composition of aquatic communities and is probably the most commonly recorded habitat attribute (Bain and Stevenson, 1999). The great Himalayan streams have comparatively low water temperature during summer (Badola and Singh, 1981; Sharma, 1984; Nautiyal, 1986) because of melting of snow. Altitude exerts a primary influence on thermal regimes of running waters through its influence on air temperature. Diatoms grow best at low temperatures (Roy, 1955; Vass et al., 1978). Water temperature has been found to be inversely proportional to zoobenthos density (Nautiyal, 1994). Temperature influences virtually all physiological and behavioural processes in fish (Hutchinson, 1975). It greatly influences the distribution and abundance of fish species (Johal et al., 2001a). McCauley and Huggins (1979) found that young fish tend to select higher temperature than the older fish.

An inverse relationship between dissolved oxygen and carbon dioxide was observed in freshwater bodies (Badola and Singh, 1981). Dissolved oxygen is positively correlated with zoobenthos density (Nautiyal, 1994) contrary to the observations of Hynes (1970). Tait et al. (1984) found that variations in dissolved oxygen had little impact on zooplanktons.

Alkalinity has been observed to be positively correlated with benthic density (Kumar, 1987). A strong inverse relationship between alkalinity and rainfall was observed by Daborn and Clifford (1974).

pH exerts important influence on the biological communities (Spigarelli et al., 1982; Serafy and Harrell, 1993) and markedly effect the community compositions (Sprules, 1975; Tait et al., 1984). pH has been directly related to zoobenthos density (Nautiyal, 1994). A higher level of phosphates has been observed in winters primarily due to agricultural runoff and sewage (King, 1981). Wetzel (1983) found degradation of sedimentary rocks to be the main source of phosphates. Squires and Saoud (1986) observed runoff to be the major source of chlorides.

Silicates are of immense significance as a major nutrient for diatoms
(Edward and Liss, 1973), a dominant constituent of phytobenthos (Vass et al., 1978). Their concentration tends to be uniform throughout the year (McIntire, 1966; Dor, 1978). Silicate concentration was in no-way related to development and decline of diatoms (Marker, 1976).

Conductivity has been found to be inversely related to discharge (Walling, 1980; Horned, 1982). Ward et al. (1978) found a positive correlation between conductance and density/mass of the macro invertebrates. King (1981) observed higher discharge to be related to higher water current leading to increased sedimentation which inturn decreases the substrate heterogeneity because of the blanketing effect of silt, resulting in reduced algal populations affecting benthos (Ward et al., 1978; Dutta and Malhotra, 1980).

The substrate has been recognized as an important factor related inversely to phytobenthos (Crayton and Sommerfield, 1979; Holmes and Whitton, 1981; Negi and Singh, 1990). Hynes (1970) attributed current to be the most significant characteristic of the running waters leading to the difference of stream animals from their stillwater relatives. Heavy stream flow accompanied by high turbidity has been observed to be the primary factor governing plankton population size especially in rivers of Himalayan region (Badola and Singh, 1981; Sharma, 1984; Nautiyal, 1985). A good crop of planktonic population results in higher benthic density (Sharma, 1985; Nautiyal, 1986). The mountain streams show very little plankton in their lower course and the true plankton were almost absent in the upper part of the stream (Welch, 1952; Edward and Liss, 1973). Hynes (1970) observed rotifers to be the dominant part of the zooplanktons.

There has been a debate about the regulation of communities by biotic versus abiotic factors (Connell, 1986; Wiens, 1977; Diamond, 1978; Schoener, 1982). Both biotic and abiotic factors influence community structure with their relative importance (Peckarsky, 1983; Power et al., 1988).

**Stream classification**

A plethora of ecological classifications for streams exist (Pielou, 1977) but traditionally the classification for streams/rivers has been fairly qualitative. Davis (1899) was the first who divided streams based on relative...
stage of adjustment – "youthful", "mature" and "old age". Additional river classifications based on qualitative and descriptive delineations were developed by Melton (1936) and Matthes (1956). Illies (1961) famous classification of 'Rhithron' and 'Potamon' zones was based on physical attributes. Leopold and Wolman (1957) presented a quantitative basis for differentiating straight, meandering and braided channel patterns. Lane (1957) developed slope-discharge relationships for braided, intermediate and meandering streams. Culbertson et al. (1967) utilized depositional features, vegetation, braiding patterns, sinuosity, levee formation and floodplain types. Khan (1971) developed a quantitative classification based on sinuosity, slope and channel patterns. Numerous other classifications based on geomorphology/geological settings (Schumm, 1963, 1977), physico-chemical parameters (Pennak, 1971), sedimentological settings (Brussock et al., 1985), stream order/gradient (Savage and Rabe, 1979), stream morphology (Kellerhals et al., 1972, 1978; Galay et al., 1973; Mollard, 1973; Church and Rood, 1983; Montgomery and Buffington, 1993), fish fauna (Hawkes, 1975), macroinvertebrate communities (Wright et al., 1989), substrate type (Meredith et al., 1989), physiography (MacMillan, 1987), hydrological regimes (Hughes and James, 1989; Jones and Peters, 1977; Poff and Ward, 1989) have been proposed.

Rosgen's (1994, 1996) classification is based on channel morphology indices such as gradient, width/depth ratio, substrate type/size and channel confinement in a valley and is followed in the present study.

**Habitat structure**

Habitat has been identified as a major determinant in the distribution and abundance of fishes from earlier times (Shelford, 1911), on which many biological communities are organized (Lohr and Faush, 1997; Schoener, 1974; Rose and Echelle, 1981; Finger, 1982; Schlosser, 1982a, 1987a; Schlosser and Toth, 1984; Angermeier and Karr, 1984; Bain et al., 1988; Angermeier and Schlosser, 1989; Aadland, 1993; Pusey et al., 1993; Matthews et al., 1994; Galactoës et al., 1996). Stream habitat features include channel width and its stability, water depth, stream bed particle size/substrate, current velocity and flow volume (Gorman and Karr, 1978; Rankin, 1995). The influence of these habitat attributes on the structure and function of fish
assemblage has been studied in detail (Evans and Nobel, 1979; Pusey et al., 1993). Fishes have been used widely to determine biodiversity as they are enormously diverse with different species reflecting different environmental conditions (Moyle and Cech, 1988).

Fish diversity has often been positively correlated with habitat complexity (Schlosser, 1982a, 1987a,b). Schlosser (1987a,b) predicted species richness and diversity to increase from shallower habitats to deeper habitats for small warm water streams of mid-western U.S.A. Hocutt and Stauffer (1975) found number of species to be correlated with both width ($r = 0.61$) and depth ($r = 0.60$). Other investigations (Sheldon, 1968; Evans and Noble, 1979; Gorman, 1988a,b; Paller, 1994) have also underlined the importance of depth to the fish species richness.

Substrate complexity has also been observed to affect algal abundance (Gawne and Lake, 1995; Sanson et al., 1995) which in turn may effect the fish community structure. Size related differences in habitat use by stream fishes have only recently been quantified (Moyle and Baltz, 1985; Power, 1984; Baltz and Moyle, 1984). Studies on the role of habitat stability in determining fish community structure have affirmed the significance of both seasonal (Schlosser, 1985) and long-term stream flow variability (Horwitz, 1978). Certain investigators point towards the presence of discrete habitat guilds. In other words, they are habitat specialists (Hynes, 1970; Moyle and Li, 1979; Moyle and Vondraceck, 1985; Leonard and Orth, 1988; Lobb and Orth, 1981; Vadas, 1992; Aadland, 1993; Arunachalam, 2000). Others believe that they are habitat generalists (Horwitz, 1978; Poff and Ward, 1989; Poff and Allan, 1995; Johal et al., 2002). Habitat generalists are associated with larger flow regimes (Harrell, 1978) or other riverine modifications (Goldstein, 1978), however, Braaten and Berry, Jr. (1997) found larger fishes to be evenly distributed in all the habitat types.

Work on the habitat structure and preference of Indian stream fishes are few, though pioneering work was started in late 1980’s on the Western Ghats in south India (Arunachalam et al., 1988; 1997a,b,c). Similar investigations were carried out on Sri Lankan streams (Moyle and Senanayake, 1984; Wickramanayake and Moyle, 1989; Wickramanayake, 1990; Kortmulder et al., 1990).
Studies in Indian waters

India with her unique geological history, highly diverse physiography, monsoon climate with extremes of spatial and temporal variability and high biotic diversity is endowed with equally diverse aquatic habitats (Gopal and Zutshi, 1998). There is a network of 14 major, 44 medium and hundreds of minor river system (Rao, 1975).

Studies on the phytoplankton communities of rivers started with Roy (1949, 1955), Chacko and Ganapati (1949) and Dutta et al. (1954). The rivers Ganga and Yamuna have been investigated regularly for phytoplankton communities (Nautiyal, 1994; Krishnamurthi et al., 1991) besides many other rivers (Prasad and Saxena, 1980; Kar et al., 1987).

Studies on zooplankton communities of rivers are few though numerous investigations were carried out on reservoirs and lakes (Arunachalam et al., 1982; Yousuf, 1989; Subla et al., 1992; Sugunan, 1995). The dominance of zooplankton communities in shallow water bodies by rotifers, copepods and cladocera varies according to the degree of organic pollution (Rao and Durve, 1989; Verma and Munshi, 1987).

Phytobenthic communities of streams and rivers have rarely been investigated (Negi, 1993) though isolated reports on benthos of rivers Ganga are available (Pahwa, 1979; Singh and Srivastava, 1989; Kulshreshtha et al., 1989) and other streams (Gupta and Michael, 1983; Arunachalam et al., 1991). Stream flow, substrate and organic pollution have generally been shown to regulate the species composition and dominance of different taxa in various stretches of rivers (Burton and Sivaramakrishnan, 1993; Sivaramakrishnan et al., 1995).

Fishes are the most extensively investigated and much of the published information has been summarized by Jhingran (1992). Dobriyal and Singh (1988) observed differences in fish fauna of various hillstreams of Garhwal Himalaya to be related to temperature, flow velocity and growth of plankton and benthos. Jhingran and Sehgal (1978) investigated in detail the cold-water fishes of India and their adaptations to low temperature regimes.

The state of Himachal Pradesh and Garhwal region have been subjected to faunal survey in the past by some workers e.g., Bourne (1889),

Though, much of the work reviewed has been done on rivers, streams have largely been ignored. Studies on streams were initiated in South India (Kortmoulder, 1987; Arunachalam et al., 1988, 1997a, b, c), however, a comprehensive study across Western Himalayas lacks.

Western Himalayan hillstreams due to the sensitive mountain geology, ecology and the great command they have by virtue of one of the “hotspot areas” of the diversity prompted us to take such a study. Not many attempts have been made earlier mainly because of the harsh terrain coupled with the lack of commercial fishes in streams. For the rational management of aquatic resources the streams require a better understanding of the condition of fish communities, their habitat requirements and the factors influencing them. Hence, the present studies “Ecology and abundance of fish communities in hillstreams of Western Himalayas and analysis of factors responsible for their distribution” have been undertaken.