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# RECENT ADVANCES IN FISH PHEROMONE RESEARCH WITH EMPHASIS ON THEIR POTENTIAL APPLICATIONS IN AQUACULTURE AND FISHERY MANAGEMENT

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**ABSTRACT – Most of vital activities of fish like alarm communication, sex attraction and synchronization of reproductive processes, individual identification, group cohesion, parent-offspring recognition, territorial markings and migration are shaped by pheromones. The involvement of chemical signals has been assessed mainly by the behavioural responses, chemical nature of these languages are being explored. Various aspects pertaining to fright reaction and alarm substances, sex pheromones and synchronization of reproductive processes, individual recognition and social structure as well as fish migration have been discussed. Problems associated with chemoreception under environmental pollution have been emphasized. Possibilities of utilizing pheromones in advancing maturation and breeding of cultivable species as well as in management of native fish and containment of the invasive/alien species are also highlighted.**

***Key words*** : Alarm pheromones, sex pheromones, individual recognition, migration, aquatic pollution.

## INTRODUCTION

Recent studies have shown the wide distribution of chemical signals among all organisms ranging from protozoans to mammals (Scheuer, 1977; Croll, 1983; Daloze *et al*, 1983; Pandey, 1984, 1987, 2003; Duvall *et al*, 1986; Burke, 1986; Doty and Muller-Schwarze, 1992; Watts *et al*, 1993; Bushmann and Atema, 1996; Lonsdale *et al*, 1998; Schneider and Moore, 2000; Jonston *et al*, 1999; Slattery *et al*, 1999, Johnston, 2003; Wyatt, 2003, 2009) including human beings (Wysocki and Preti, 2004, 2010). There are instances of chemical communication in yeast and aquatic plants especially for the attraction of gametes (Maier and Mueller, 1986; Mueller *et al*, 1990; Kodama *et al*, 1993; Boland, 1995). Pheromones (Greek: pherein- to carry or transfer; hormon- to excite or stimulate) are the substances which are secreted to outside by an individual and received by second individual of the same species, in which they release a specific reaction, for example, a definite behaviour (releaser pheromones) or developmental process (primer pheromones) (Karlson and Luscher, 1959). Unlike hormones, these substances are not secreted into the blood circulation but into the environment and produce effects involving a large degree of genetic programming and influenced little by experience (Pfeiffer, 1982; Sorensen *et al*, 1998; Pandey, 2005). They are low molecular weight (80-300) volatile organic compounds in case of the terrestrial animals (Duvall *et al*, 1986) whereas the semiochemicals of aquatic species appear to be larger in size (high molecular weight) and soluble in water (Liley, 1982; Hara, 1982; Pandey, 1984, 2003; Sorensen, 1992; Lebedeva and Golovkina, 1994). Studies have demonstrated that odours emanating from an individual have encoded messages of its race, sex, age and biological status, however, it is rather difficult to predict which of the many chemicals released by the organism might have pheromonal effect (Sorensen and Stacey, 1999, 2004; Wyatt, 2003, 2009).

Though chemical senses are the most ancient of the sensory systems having evolved about 500 million years ago, studies regarding fish chemoreception have been delayed because they, unlike insects and mammals, live in the aquatic environment and the role of olfaction among this class of vertebrates was poorly understood (Hara, 1975). Teichmann (1962) demonstrated that fishes do have exquisitely sensitive organs of smell like dogs and even 3-4 molecules of the odorants were sufficient to evoke a behavioural response. Sorensen (1996) remarked that living in an aquatic environment, generally devoid of visual cues but rich in dissolved compounds, fish have evolved highly developed chemosensory and pheromonal signaling systems. Studies during the past four decades covering about more than one hundred species have proved that most of the vital activities of fish like alarm communication, sex attraction and synchronization of reproductive processes, individual identification, group cohesion, parent-offspring recognition, territorial markings and even migration are shaped by pheromones but our knowledge in this field is still fragmentary as we know their existence only by behavioral responses, chemical nature of these languages are now being explored

(Parzefall, 1973; Barnett, 1977; Solomon, 1977; Jolly, 1980; Liley, 1982; Colombo *et al*, 1982; Smith, 1982a, 1992; Stacey, 1983, 2003; Stacey and Sorensen, 1991; van Weerd and Richter, 1991; Hara, 1992; Saglio, 1992; Sorensen and Scott, 1994; Sorensen, 1996; Pandey, 1998, 2005, 2009; Sorensen and Stacey, 2004; Hubbard and Scott, 2007; Burnard *et al*, 2008). The mitral cells located in medial tracts of the olfactory pathway convey the pheromonal responses to the brain while the lateral olfactory bundlets are responsible for transducing the feeding stimuli in fishes (Doving and Selset, 1980; Thommessen, 1982, 1983; Sorensen, 1996; Hansen *et al*, 1998; Hamdani and Doving, 2006). An attempt has been made to discuss the recent advances in fish pheromones research and highlight the potential applications of such substances in aquaculture and fishery management.

**Alarm Substances**

Similar to the distress calls of birds and monkeys, alarm pheromones of fish communicate the presence of nearby danger to its conspecifics (Smith, 1986). Phylogenetically, such chemical alarm systems have been identified from the sea anemones to tadpoles of toads (Pfeiffer, 1962, 1963, 1974, 1982; Howe and Seikh, 1975; Smith, 1977, 1992; Chivers and Smith, 1994; Chivers *et al,* 1999; Commons and Mathis, 1999; Brown and Godin, 1997, 1999; Brown and Brennan, 2000). von Frisch (1938) was the first who accidentally discovered fright reactions in the European minnows (*Phoxinus phoxinus*) when he introduced a mechanically injured (physically damaged) fish to the school of minnows, all members became frightened, retreated and took refuge in a hidden place within 30-60 seconds. He showed that the skin contained alarm substance (substance d' alarme, Schreckstoff) which elicited fright reaction (reaction d' effori, Schreckreaktion) among the minnows (von Frisch, 1941). Depending upon the species, alarm behaviour comprises rapid dashing, c-turns, hiding, immobility (freezing), cohesiveness or avoidance of the area (Pfeiffer, 1977, 1982; Malyukina *et al*, 1977; Waldman, 1982; Smith, 1982a, 1992; Mathis *et al*, 1995; Nordell, 1998; Brown *et al,* 2000, 2003; Mirza *et al,* 2001; Haney *et al,* 2001; Wiesenden *et al*., 2004; McCormick and Larson, 2007). *Puntius javanicus* exhibited c-turn behaviour and avoided the area when exposed to conspecific skin extract (Pandey and Chithar, unpublished). The chemically induced alarm reaction can be transmitted visually to other members of the school/ shoal (Pfeiffer, 1977; Smith, 1977, 1982a). There are reports that even the closely-related species also respond to alarm pheromones and experience also plays role in such perception (Smith, 1982b; Brown *et al,* 1995; Chivers *et al*, 1995; Wisenden *et al*, 1995). There are instances that the predator northern pike (*Esox lucius*) consuming the preys (*Pimephales promelas* and *Culaea incostans*) containing the ASCs in skin, releases the alarm pheromone in the faecal matter which are detected by the members of its own or closely-related species.

The distribution of alarm substance and fright reaction among different groups of fishes attracted wide attention (Pfeiffer, 1962, 1963, 1974, 1977, 1982; Gandolfi *et al*,

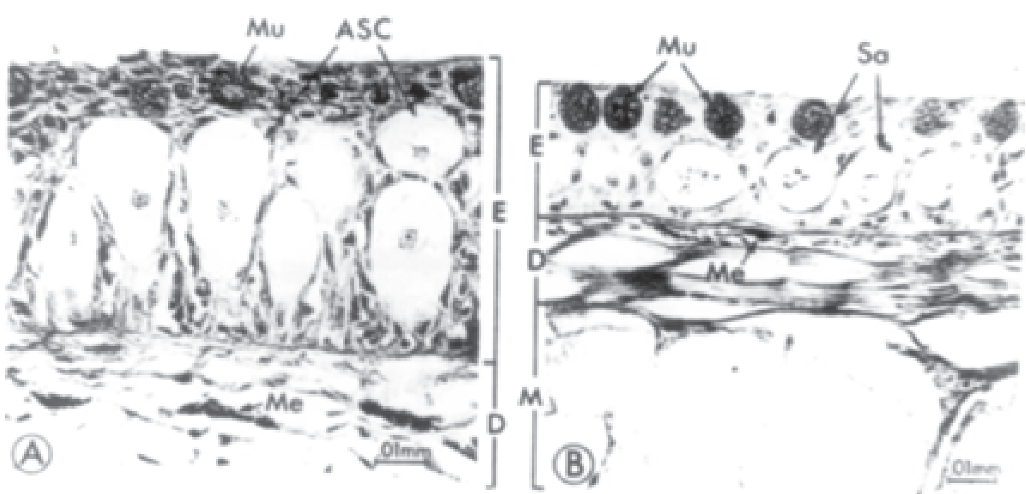


**Fig. 1:** The skin of two groups of fish that exhibit alarm response to skin extract. (a) The skin of an ostariophysan fish, the bluehead chub (*Nocomis leptocephalus*) showing the alarm substance cells (ASC) in the epidermis. (B) The skin of the tesselated darter (*Etheostoma olmstedi*) exhibiting the sacciform cells (Sa) that may contain darter alarm pheromone. (ASC, alarm substance cells; D, dermis; E, epidermis, M, muscle; Me, melanophores; Mc, mucous cells; Sa, sacciform cells) (after Smith, 1986; Courtesy: R. Jan F. Smith and Plenum Press, New York).

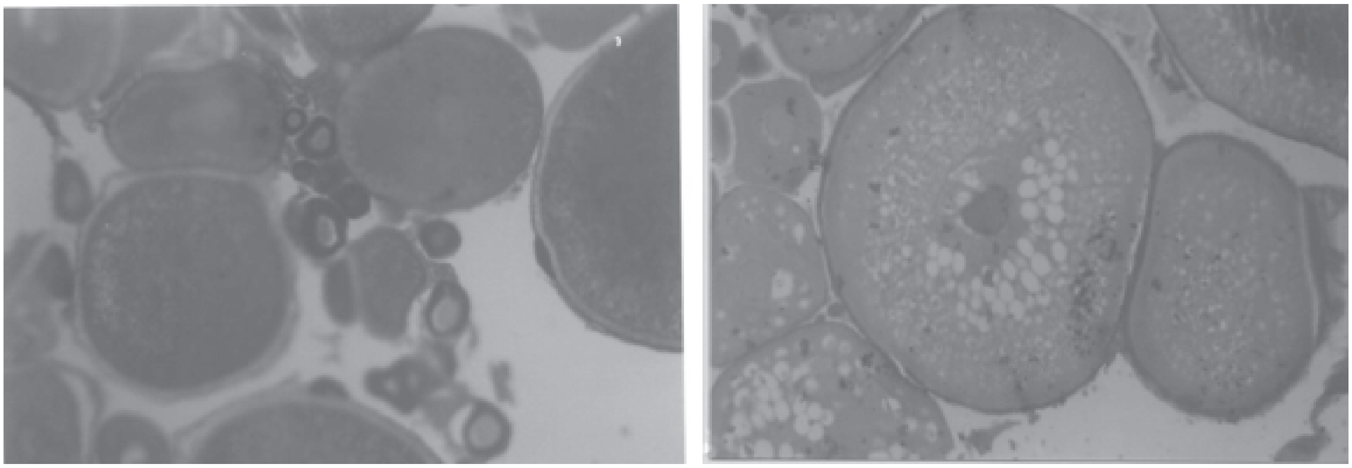

**Fig. 2 :** Ovary of *H. fossilis* - the site of sex signals and index to record the primer effects of male pheromone.

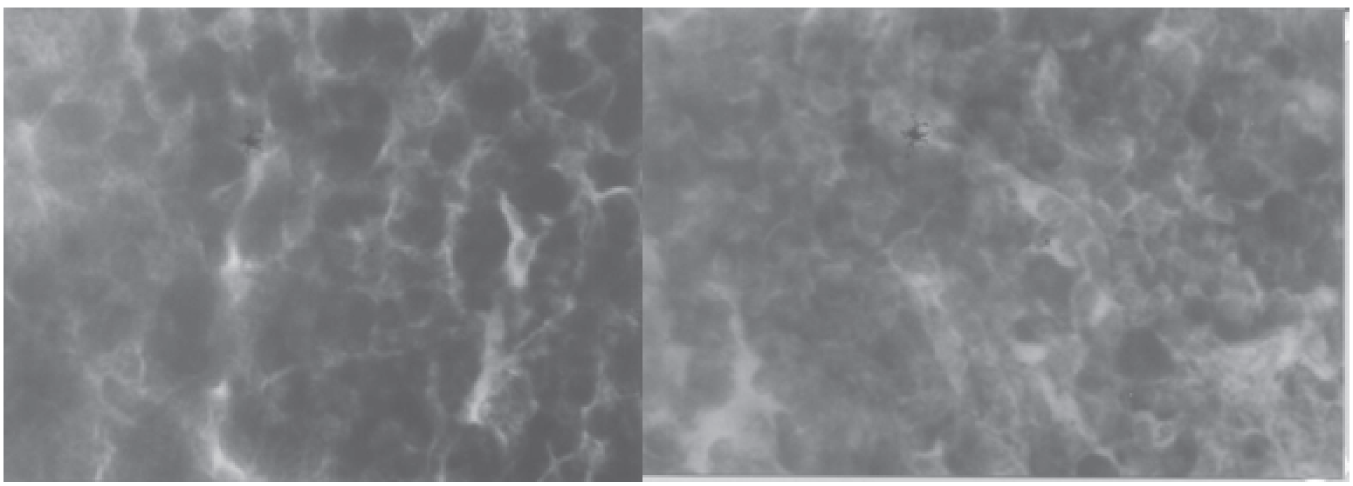

**Fig. 3 :** . Proximal pars distalis of *H. fossilis* showing gonadotrophs- a tool in primer sex pheromone studies.

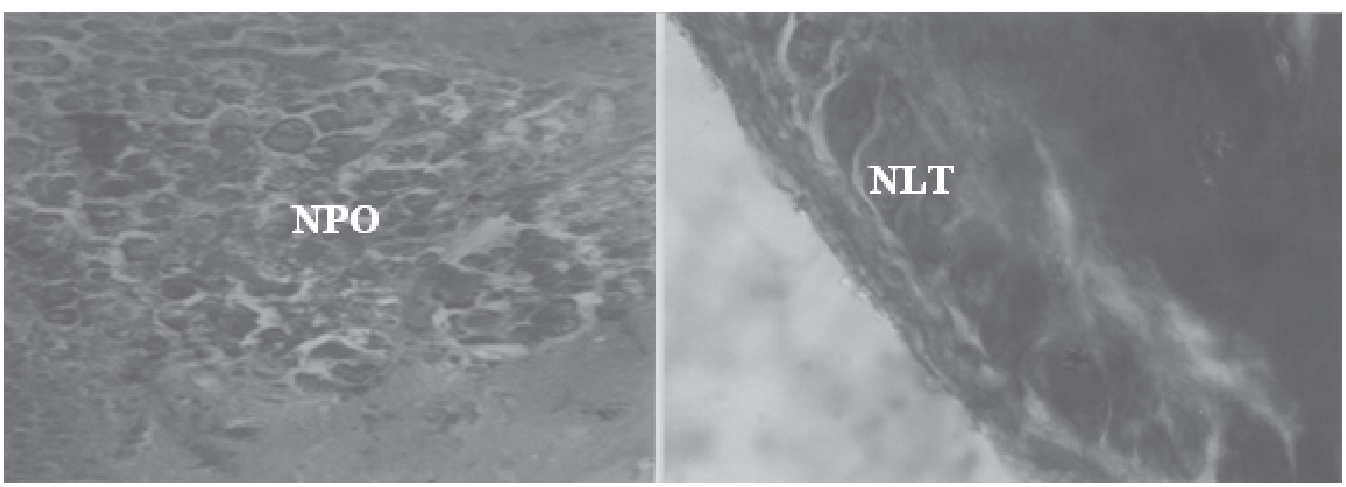


**Fig. 4 :** Hypothalamus of *H. fossilis* showing nucleus preopticus (NPO, left) and nucleus lateralis tuberis (NLT, right) - an importat link for neuroendocrne modulation of primer pheromones.

1969; Gandolfi, 1972; Thines and Legrain, 1973; Aoki and Kuroki, 1975; Carmichael, 1975; Smith, 1977, 1982a; Heczko, 1980; Ahsan and Prasad, 1982; Mathis *et al*, 1995; Nordell, 1997; Berejikian *et al,* 1999; Commens, 2000; Maniak *et al*, 2000; Mirza and Chivers, 2001; McCormick and Larson, 2007). It has been demonstrated that skin of ostariophysan, gonorhynchiform, perciform and other groups of fishes contains alarm pheromone in their large epidermal cells known as club cells (Kolbenzellen), alarm substance cells (ASCs) or sacciform (Sa) cells (Fig. 1). Though the club cells (presumably homologous to ASCs) have been identified in the primitive reedfish, *Erpetoichthys* (*Calamoichthys*) *calabaricus* (Polypteriformes) but the skin extract of this fish does not elicit fright reaction among conspecifics (Hugie and Smith, 1987). Ultrastructurally, alarm substance cells of *Ictalurus punctatus* contained fine homogenously dispersed fibrillar material, cytoplasmic granules concentrated peripherally, tubular type mitochondria with matrix granules (30-50 nm diameter), nucleus irregular with distinct nucleolus, and lysosomes and lipid inclusions in vicinity of the nucleus. Histochemically, proteins were demonstrated in ASCs of channel catfish but carbohydrates were not detected (Yoakim and Grizzle, 1982). These cells do not open directly to the surface of skin but release their contents only after a mechanical injury, presumably by a predator. Interestingly, alarm pheromones are also released into the environment along with the faecal matters of the predatory fishes following consumption of the prey (Brown *et al*, 1995). As per adaptive significance of alarm pheromone is concerned, it is assumed that alarm pheromone diffusing into the surrounding medium alerts and deters conspecifics from the hunting spots thus reducing hunting success of the predators (Smith, 1977; Chivers and Smith, 1998). Alternately, the alarm pheromone diffusing in the medium may function to attract additional predators that interfere with the predation act providing opportunity for the prey to escape (Mathis *et al*, 1995). The response to alarm pheromones appears to be innate and develops in late larval or early juvenile stages (Waldman, 1982). Further, possession of the alarm substance in fishes also reduces cannibalism of young. There exist ample evidences that the fish shows a strong fright reaction after eating its smaller conspecifics (Smith 1977). In a natural stream, the minnow (*Pimephales promelas*) avoided the traps marked with conspecific alarm pheromone (Mathis and Smith, 1992) Interestingly, males of certain ostariophysian fishes with abrasive spawning behaviour loose alarm substance cells during breeding season due to elevated levels of androgen (testosterone) but they still retain the alarm reaction appropriate to their own species (Smith, 1973, 1976 a, b, 1978, 1979, 1982b; Pfeiffer *et al,* 1985a; Smith and Smith, 1986). Starvation/food deprivation appears to affect alarm reaction of *Ethyostoma exile* to skin extract of the conspecifics (Smith, 1981). Wisenden and Smith (1998) observed that presence of unfamiliar shoal-mate enhances the alarm substance cell counts whereas familiarity with the shoal-mate reduces proliferation of these cells among the ostariophysian fishes. Stabell and Lwin (1997) observed phenotypic changes like increase in body depth in crucian carp (*Carassius carassius*) exposed to the odour of northern pike fed on crucian carps. These phenotypic changes appear to be due to primer effect of the alarm pheromone.

Attempts have been made to identify chemical nature of the alarm pheromone of fish. Huttel (1941) suggested the minnow alarm substance to be purine- or pterin-like (double-ringed compounds usually associated with pigments), non-volatile and extremely water soluble. Histamine was also indicated to be alarm substance of certain cyprinids (Reed *et al*, 1972) while Pfeiffer and Lemke (1973) recorded the alarm substance of *Phoxinus phoxinus* to be pterine (isoxanthopterin). Needham (1974) suggested that pterine might be conjugated with a protein carrier to give species-specificity. However, Kasumyan and Lebedeva (1977, 1979) and Lebedeva and Golovkina (1994) showed that the alarm pheromone of the minnow (*Phoxinus phoxinus*) possesses molecular weight approximately 1100, behaves in alkaline medium (pH 8-9) as anion and breaks down when heated. They suggested it to be a carbohydrate compound containing amino groups or a peptide. Hypoxanthine-3-(N)-oxide has been reported to be an active component of the minnow (*Phoxinus phoxinus*) and black tetra (*Gymnocorymbus ternetzi*) alarm signaling system (Pfeiffer, 1978, 1982; Pfeiffer *et al*, 1985b). The central bundles in both tractus olfactorii of the medial olfactory tract of fish conduct the nervous excitation elicited by alarm substance to the higher centres in brain (Pfeiffer *et al*, 1984) resulting in elevation of plasma cortisol, glucose, potassium ($K^+$) and sodium ($Na^+$) levels while plasma calcium ($Ca^{2+}$) depicted an initial increase followed by decline to below normal level suggesting the alarm pheromone to serves as stressor to the recipient fish (Malyukina *et al*, 1982; Lebedeva and Golovkina, 1994, 1999).

### Female Sex Pheromones

There exist reports on congregations of salmonid males around the cages/pens of the mature females during breeding seasons. Fishermen of Mississippi river usually catch large number of male channel catfish, *Ictalurus punctatus,* by placing ripe females in cages of flowing

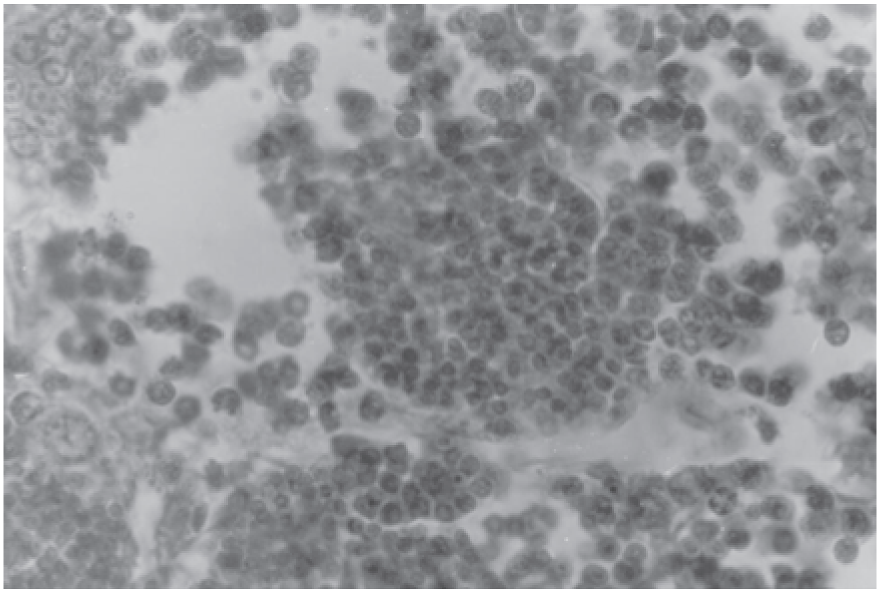

**Fig. 5:** Testis of *Tor putitora* - a source of male pheromones and tool for assessing primer effects of female sex pheromones.

**Fig. 6 :** *Heteropneustes fossilis* forming a tight school even during night.

river (Timms and Kleerekopper, 1972). Tavolga (1956) was the first who systematically studied the sexual behaviour of an estuarine goby, *Bothygobius soporator* and demonstrated that the spermiated (matured) male discriminates between males and females, and also between non-gravid and gravid females on basis of the chemical cues released through their vent. Ovarian fluid was sufficient to evoke courtship behaviour in the males even in absence of females. Gravid female cichlid fish (*Haplochromis burtoni*) becomes attractive to the males during breeding season (Crapon de Caproma, 1974). Water from gravid females seems to increase the nesting and other activities among the males associated with reproduction in anabantids (Rossi, 1969) and cichlids (Crapon de Caprona, 1974). Partridge *et al* (1976) observed that the female goldfish releases a pheromone just after ovulation through vent which induced sexual behaviour among the males. Similar observations were also recorded in *Plecoglossus altivelis* (Honda, 1979), *Oncorhynchus mykiss* (Honda, 1980a), *Misgurnus anguillicaudatus* (Honda 1980b), *Rhodurus ocellatus ocellatus* and *Acheilognathus laneolatus* (Honda, 1982a), *Oncorhynchus masau* and *Oncorhynchus rhodurus* (Honda, 1982b; Kitamura and Ogata, 1989; Yambe *et al*, 1999; Yambe and Yamazaki, 2000, 2001a), *Anguilla rostrata* (Sorensen and Winn, 1984) and *Oncorhynchus mykiss* (Yambe and Yamazaki, 2001b). A female sex pheromone appears to facilitate pair formation and copulation in the marine carcharhinid shark (Johnson, 1978). Also, mature female sea lamprey, *Petromyzon marinus*, releases a pheromone in the ovarian fluid that attracts male

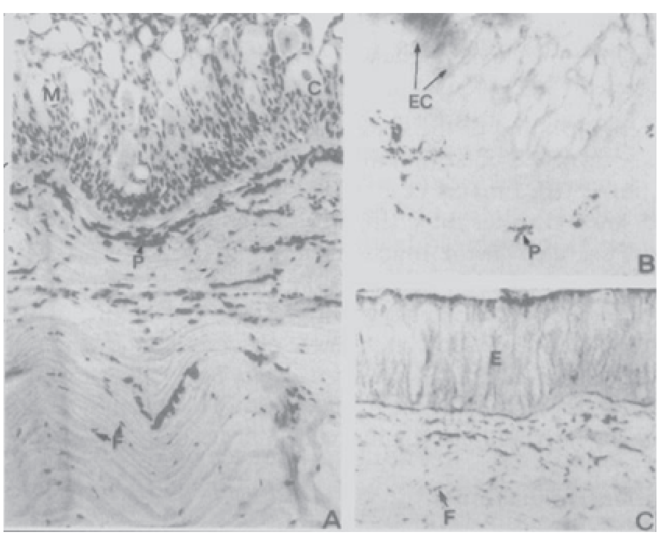


**Fig. 7 :** Histological section of the skin of *Clarias gariepinus*. (A) General structure (Haemealum-eosin x 230).(B) 17α-hydroxysteroid dehydrogenase with weak enzyme activity in the epithelian cells. X145. (C) Uridine-di-phospho-glucose dehydrogenase (UDPGD) enzyme activity is demonstrated in the epidermis and fibroblasts. X 145. (C, club cells; D, dermis; E, epidermis; Ec, epithelial cells; F, fibroblasts; M, mucous gland; P, pigment; SC, stratum compactum; SV, stratum vasculare) (after Ali *et al*, 1987; Courtesy: S.A. Ali and Acememic Press, New York).

conspecifics (Teeter, 1980). A definite threshold of circulating androgen is essential to render the male differentially sensitive to the sex attractant released by gravid females (Yamazaki and Watanabe, 1979; Irvine and Sorensen, 1993; Cardwell *et al,* 1995; Yambe and Yamazaki, 2000, 2001b). Hamdani *et al* (2008) recorded seasonal variations in olfactory sensitivity of the epithelial crypt cells of crucian carp which coincided with the elevated circulating androgen level.

Mature females of goldfish (*Carassius auratus*-Kobayashi *et al*, 1986; Dulka *et al,* 1987; Defraipont and Sorensen, 1993; Stacey *et al*, 1994a; Sorensen *et al,* 1995; Zeng and Stacey, 1997; Zeng *et al,* 1997), yellowfin Baical sculpin (*Cottocomephorus grewingki*-Dmitrieva *et al*, 1988), Atlantic salmon (*Salmo salar*- Moore and Waring, 1996 a; Waring *et al,* 1996), rainbow trout (*Salmo gairdeneri= Oncorhynchus mykiss*-Scott *et al*, 1994; Vermeirssen *et al*, 1997), Baikal cisco (*Coregonus automnalis migratorious*-Ostroumov and Dmitrieva, 1991), common carp (*Cyprinus carpio communi*s-Billard *et al,* 1989; Sorensen *et al*, 1992; Stacey *et al*, 1994b) release primer pheromone in the urine which enhances plasma gonadotropin (GtH) and testosterone (T) levels within 15-30 minutes and milt (sperm and seminal fluid) volume as well as sperm motility among conspecific males after prolonged exposure (6 hours in case of goldfish( Zeng and Stacey, 1996 1997; Ostroumov *et al*, 1996; Stacey, 2003; Sorensen and Stacey, 2004). Males of grey mullet (*Mugil cephalus*) exposed to GnRH+domperidone-treated females registered higher levels of serum 11-ketotestostrone (11-KT) which may probably be due to the release of female sex pheromones (Aizen *et al*, 2005). Dulka *et al* (1992) observed a reduction in pituitary dopamine turnover ensuing enhanced gonadotropin secretion in the males goldfish exposed to the female sex pheromone. Interestingly, mature female *Oreochromis niloticus* becomes attractive to males after 17, 20-dihydroxy-4-pregnen-3-one injection (De Souza *et al*, 1998). Though the exact chemical identity of the primer pheromones is not known but the maturation-inducing hormone, 17,20-dihydrox-4-pregnen-3-one and its sulphate or glucuronide metabolites are the likely candidates because they induce electroolfactogram (EOG) recordings in the olfactory tract even at concentration from$10^{-9}$-$10^{-13}$ mM. The primer pheromone released by the Atlantic salmon (*Salmo salar*) has been suggested to be F-type prostaglandin (Waring and Moore, 1997). Urine of the female evokes maximum response among the conspcific males pointing to the species-specificity of the pheromone (Kitamura and Ogata, 1989; Scott *et al,* 1994; Waring *et al*, 1996; Waring and Moore, 1997).

Mature females release chemical couplin (s) during ovulation which elicits attraction (locomotor behaviour), courtship and spawning in male conspecifics (Gandolfi, 1969; Theissen and Sturdivant 1977; Crow and Liley, 1979; Emanuel and Dodson, 1979; Liley, 1982; Pfeiffer, 1982; Pandey, 1984, 2005, 2009; Johanson, 1985; Yamazaki, 1990; Stacey and Sorensen, 1991; Sorensen, 1996; Sorensen *et al*, 1997; Leberge and Hara, 2003; Burnard *et al*, 2008; Bandypadhyay and Singh, 2009). Theissen and Sturdivant (1977) reported the role of thyroid hormone in releaee of sex attractant in female black molly, *Mollinesnsis latipinna.* Such releaser pheromones induce an immediate response (within 10-30 minutes) without altering the plasma concentration of gonadotrophin (Liley, 1982; Stacey, 1983; Sorensen and Scott, 1994; Yambe *et al*, 1999). Amouriq (1965) was the first to suggest female sex attractant (substance dynamoge'ne) of *Lebestes reticulatus* to be an oestrogen as hexestrol dipropinoate elicited courtship behaviour among males. Okada *et al* (1978) demonstrated that the fraction ($FP_1$) on DEAE cellulose column that evoked male courtship behaviour in pond smelt, *Hypomesus olidus,* declined in activity after heat ($80^0$C; 5 minutes) or trypsin ($30^0$C; 60 minutes) treatments and presumed the substance in genital fluid was either a protein or a substance involving protein in its structure. Kawabata *et al* (1993) reported amino acids as inducer of sexual behaviour in male *Rhodurus occellatus occellatus.* L-Kynurenine (an amino acid) has been reported to serve as sex pheromone of *Oncorhynchus masau* (Yambe *et al*, 2006a) In *Pimephales promelas* (Cole and Smith, 1987), *Carassius auratus* (Sorensen *et al,* 1988), *Salvelinus alpinus* (Sveinsson and Hara, 1995), *Oncorhynchus rhodurus* (Kitamura and Ogata, 1989), *Misgurnus anguillicaudatus* (Kitamura and Ogata, 1990, 1993; Ogata *et al*, 1993, 1994; Kitamura *et al,* 1994) and *Astyanax mexicanus* (Cardwell and Stacey, 1995) the metabolites of prostaglandin $F_2\alpha$ ($PGF_2\alpha$) like 15-keto-, 13,14-dihydro-15-keto-PG $F_2\alpha$ are suggested to function as releaser pheromones. Interestingly, Matsumura (1995) recorded tetrodoxine as sex attractant pheromone to spermiating males in the marine puffer fish (*Fugu niphobles*). Releaser pheromone found in the urine of mature female masu salmon appears to be one or more low molecular weight (less than 10,000) substance soluble in ether under basic condition (Yambe *et al,* 1999).

McKinnon and Liley (1987) and Cardwell *et al* (1992) have suggested the releaser pheromone(s) to function as reproductive isolating mechanism in sympatrically breeding gourami (*Trichogaster trichopterus* and *Trichogaster pectoralis*) and suckers (*Catastomus*

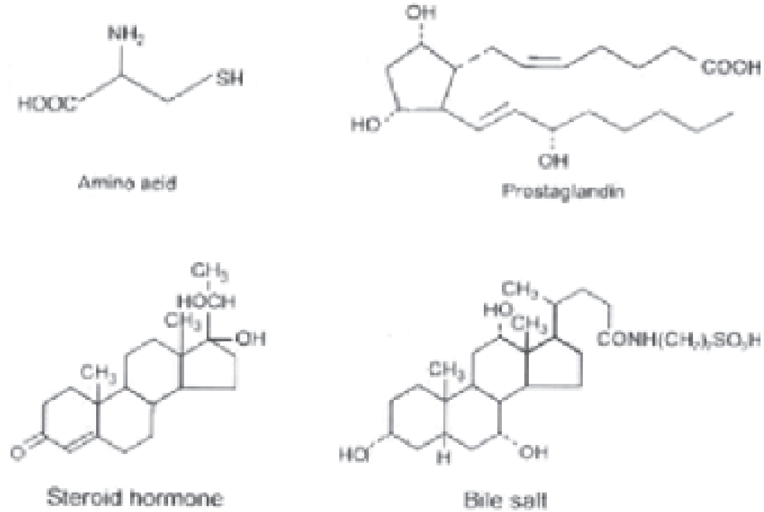


**Fig. 8 :** General chemical structures of four major aquatic odorants for fish (after Hara 1992; Courtesy: T.J. Hara and Chapman & Hall, London).

*catastomus* and *Catastomus commersoni*). As per definition, the pheromones should be species-specific but there are instances of closely-related species sharing to the sex pheromones (Rossi, 1969; Irvine and Sorensen, 1993; Essington and Sorensen, 1996; McLennan and Ryan, 2008) such as goldfish, *Carassius auratus*, crucian carp, *Carassius carassius* (Bjerselius and Olsen, 1993) and goldfish and common carp, *Cyprinus carpio* (Irvine and Sorensen, 1993). Hybridization/interbreeding among closely-related species including brook trout, *Salvelinus fontinalis* and brown trout, *Salmo trutta* is assumed to be due to sharing of the same pheromonal system of prostaglandin F and its derivatives (Essington and Sorensen, 1996). However, other signals like visual, auditory, tactile and electrical are also involved in spawning which may not be overlooked while discussing the process of hybridization/interbreeding in natural environment (Rossi, 1969; Irvine and Sorensen, 1993; Olsen *et al*, 2000; Burnard *et al*, 2008). Pheromone(s) are being implicated in mate choice of *Gasterosteus aculeatus* and *Xiphophorus birchmanni* (Milinski, 2003; Fisher and Rosenthal, 2006).

### Male Sex Pheromones

During breeding season, males become attractive to the female conspecific. Sodefrin, a novel peptide pheromone secreted by the cloacal gland of newt, *Cynops pyrrhogaster* attracts sexually developed females (Kikuyama *et al*, 1998). The male tree frog, *Litoria splendida* releases sex-attracting pheromone, slendiphereine, from paratoid and rostral gland that attracts females (Wabnitz *et al*, 1998). Male fish advertizes its presence to the females by permeating the aquatic environment with male odours (zielinski *et al,* 2003). In some regions of France, male lampreys nearing sexual maturity are placed by the fishermen in the traps to attract females (Fontaine, 1976). The odouriferous secretion of the cutaneous anal gland (rich in mesorchial interstitial cells) of male *Blennius pavo* attracts the females during breeding season (Eggert, 1931). Laumen *et al* (1974) found that appendices of the 1st and 2nd anal fin spines of mature male *Blennius pavo* produce a pheromone which attracts conspecific females. Histological study revealed the presence of numerous invaginations in epidermis of the appendices and secretion of this pheromone is dependent on circulating gonadotropin levels. Burns and Weitzman (1996) suggested the gill gland of male swardtail characin, *Corynopoma riisei* as source of sex attractant pheromone. Sperm-duct gland of freshwater goby, *Padogobius martensi* appears to secrete sex attractant substance (Cinquetti and Rinaldi, 1987; Cinquetti, 1997). Jaski (1939) demonstrated that males of guppy, *Poecillia reticulates* secrete a "chemical couplin" which synchronizes the sexual receptivity among females. Water-borne substance (s) produced by the mature males that attract females to suitable spawning sites have also been described in rainbow trout, *Oncorhynchus mykiss* (Newcombe and Hartman, 1973), black goby, *Gobius jozo* (Colombo *et al*, 1980), fathead minnow, *Pimephales promelas* (Cole and Smith, 1992), Arctic char, *Salvelinus alpinus* (Sveinsson and Hara, 1995) and round goby, *Neogobius melanostomus* (Murphy *et al*, 2001; Zielinski *et al*, 2003; Corkum *et al*, 2006; Marentette and Corkum, 2008). Male *Xiphophorus birchmanni* releases sex attractant pheromone in pulses in urine positioning upstream of females (Rosenthal *et al*, 2010). Colombo *et al* (1980) identified the male sexual pheromone of *Gobius jozo* to be etiocholenolone glucuronide. Male sexual pheromone of the round goby induces gill ventilation in females during breeding season appears to be derivatives of etiocholenolone (Murphy *et al*, 2001). Mature males of Arctic char become more odourous and release metabolites of prostaglandin $F_2\alpha$ to attract mature females and induce spawning behaviour (Sveinsson and Hara, 1995). Interestingly, male masu salmon (*Oncorhynchus masau*) parr avoid the proximity of sexually active males due to a pheromone released in the urine (Yambe *et al*, 2006b).

Teeter (1980) and Adams *et al* (1987) showed the presence of a pheromone in the urinogenital fluid of male sea lamprey, *Petromyzon marinus*, which elicited courtship behaviour in the females. Out of the nine steroid hormones (dehydroepiandrosterone, testosterone, dihydrotestosterone, progesterone, androstenedione, estrone, oestradiol, corticosterone and cortisol) tested, only testosterone evoked a preference response in spawning-run female sea lamprey. Testosterone or a closely related structural derivative was suggested as sex pheromone in the male cyclostome (Adams *et al*, 1987). However, recent studies have shown 7α,12α,24-trihydroxy-5α-cholan-2-one-24-sulphate (3 keto-petromyzonol sulphate, 3 keto-PZS), a bile acid derivative, as sex pheromone of spermiating sea lamprey which induces search and preference behaviour in ovulating females signaling reproductive readiness as well as nest location. Mature ovulating females of *Petromyzon marinus* showed strong tendency to select traps with spermiating males (Johnson *et al.* 2005, 2009; Wagner *et al,* 2006). This pheromone appears to be synthesized in hepatocytes and released in large amount via gill epithelia (Bjerselius *et al*, 1995a; Li and Sorensen, 1997; Li *et al*, 2002, 2003; Yun *et al*, 2002; Siefkes *et al*, 2003).

Seminal vesicles of male African catfish, *Clarias gariepinus*, secrete sex pheromone that attracts females during breeding season. Though 17 free and 8 glucuronide metabolites of sex hormones have been identified in the seminal vesicle fluid (SVF) but 5β-pregnene-3α, 17α-diol-20-one glucuronide and 5β-androstene-3α,17α-diol are more potent olfactory stimulants with threshold value $10^{-9}$mM (Schoonen, 1987; Resink, 1988). Wild breeding male *Clarias gariepinus* recorded 20-folds elevation in level of 5β-pregnene-3α,17 α-diol-20-one glucuronide in the seminal vesicle as compared to those maintained under captivity which may probably be the reason for lack of natural spawning in the catfish kept in ponds (van den Hurk and Resink, 1992).

Mature males of zebrafish, *Brachydanio rerio*, release a pheromone that induced ovulation among females (Chen and Martinich, 1975). Using gas chromatography-mass spectrometry (GC-MS), van den Hurk *et al* (1987) observed the presence of glucuronides of 5α -androstane-3α,17β-diol and cholesterol in male-holding water and suggested that these compounds, probably originating from liver, may be functioning as ovulation-inducing pheromones in this species (van den Hurk and Resink, 1992).

In fishes, males appear to have the most profound effect on the neuroendocrine (hypothalamo-hypophysial-gonad) system the females (Fig. 2-5). Mosher (1954) reported that when a male is introduced into the group of females, it stimulated egg production and its continued presence led to regular oviposition cycles. In the angelfish (*Pterophyllum scalare*), blue gourami (*Trichogaster trichopterus)* and Indian catfish (*Heteropneustes fossilis*), paired females with males possessed ovaries filled with matured ova while ovaries of the grouped females (without males) contain almost no ova but numerous oocytes at various stages of development (Chien, 1973; Pollack *et al*, 1978; Pandey *et al,* 2000). Exposure to other female odours in *Brachydanio rerio* led to severe reproductive suppression because the females exposed to male odours produced 17% more viable eggs than did non-exposed females and 26% more viable eggs than did females exposed to female odour (Gerlach, 2006). There is evidence that the male pheromone(s) of African catfish, *Clarias gariepinus*, accelerates ovarian recrudescence and ovulation among the females probably by enhancing plasma gonadotropin (GtH) level (van Weerd, 1990; van den Hurk and Resink, 1992). Degani and Schreibmam (1993 reported that the aquarium water in which mature male *Trichogaster trichopterus* built nests induced the release of immunoreactive gonadotropin (GtH) from hypophysis (pituitary) resulting in enhanced plasma 17β-estradiol ($E_2$), 17α,20β-dihydroxy-4-pregnen-3-one (17,20-P), 5β-pregnen-3,17α, 20β-triol and 11-ketotestosterone (11-KT) as well as vitellogenic activities suggesting the primer effects of male pheromone on female blue gourami. Since unisexual groupings of the females (without males) disrupts (inhibits) the ovarian development (Pandey *et al*, 2000; Pandey, 2005), it offers opportunity to explore the female-female interacting primer pheromones in fishes.

**Intrasexual Stimulants and School Formation**

Though reports on the odouriferous secretions eliciting male-male and female-female stimulations are rare in vertebrates but the possibilities have been raised from time to time (Crapon de Crapona, 1976; Duvall *et al,* 1986). From the auxillary (underarm) sweat of human (both sexes), androstenol has been identified which arouses both the sexes (Kingsbury and Brooksbank, 1978;

Wysocki and Preti, 2010). Among fishes, male three-spined stickleback, *Gasterosteus aculeatus,* gets stimulated by smelling the odours of its own nest during breeding season. Losey (1969) demonstrated that males of *Hypsoblennius jenkinsi, H. robustus* and *H. genitilis* secrete a chemical during "high courting and mating periods" that releases the sexual appetitive behaviour and sexual receptivity among the males. A pheromone is found in the milt of male herring, *Clupea harengus pallasi* that triggers spawning behaviour (papilla extension) and release of milt in the males (Stacey and Hourston, 1982; Sherwood *et al*, 1991; Carolsfield *et al*, 1997a). This pheromone shows hydrophobic properties similar to those of polar steroids, prostaglandins, or other conjugate forms, and at least one form appears to contain a sulphate or glucuronide group (Sherwood *et al,* 1991). The role of male pheromone has been suggested in synchronization of spawning in the school of herrings. Further, Carolsfield *et al* (1997b) showed that elevated levels of plasma 3$\alpha$, 17$\alpha$–dihydroxy-5$\beta$–pregnen-20-one and 17$\alpha$-hydroxy-progesterone coincided with responsiveness to the spawning pheromone in these fish.

The possibility of involvement of pheromones in school formation and attraction of the mature conspecifics towards the spawning grounds was speculated by McFarland and Moss (1967). Presence of an aggregating pheromone has been implicated in schooling of the Japanese marine catfish, *Plotosus lineatus* (Hayashi *et al*, 1994). Bloom and Perlmutter (1977) have demonstrated the presence of male-male and female-female attractants in the zebrafish, *Brachydanio rerio*. Further, they suggested that the sexual aggregating pheromone system in the zebrafish may serve as reproductive isolating mechanism in the sympatrically breeding *Brachydanio rerio* and *Brachydanio albolineatus* (Bloom and Perlmutter, 1978). Teeter (1980) also hypothesized the involvement of pheromones in aggregating adult lampreys (*Petromyzon marinus*) prior to upstream movement or to keep them together in night during the migration. Algranti (1980) suggested the sexual-aggregating pheromones of zebrafish to be two in number-one attracting male conspecifics and other the females. Interestingly, this attraction was not affected by food or diet of the fish. Algranti and Perlmutter (1981) found that the attractants were contained in the cholesterol-ester fraction (R*f* - 0.94) of the thin-layer chromatogram.

**Individual Recognition**

Some fishes display social organization with well-defined hierarchy. Since individual recognition being the cornerstone of the sociality, its members must be recognized from the individuals of other societies or species (Ward *et al*, 2007). Individual recognition by scent is prominent in mammals (Wyatt, 2003; Thom and Hurst, 2004; Wysocki and Preti, 2010; Archunan, 2010). Todd *et al* (1967) demonstrated that the yellow bullheads (*Ictalurus natalis*), a nocturnal visually-deficient fish, recognizes individuals of its own group by means of pheromones secreted in the skin mucus. Methanol extract of the mucus was also attractive in the top smelt, *Atherinops affinis* (Rosenblatt and Losey, 1967). Individuals of *Salvelinus alpinus* (Hoglund and Astrand, 1973; Hoglund *et al*, 1975; Selset and Doving, 1980; Olsen, 1989, 1990), *Clupea herrangus pallasi* (Dempsey, 1978), *Caecobarbus geertsi* (Berti and Thines, 1980), *Haplochromis burtani* (Crapon de Caprona, 1980), *Astyanix jordani* (Quinn, 1980), *Notropis lutrensis* (Asbury *et al*, 1981), *Oncorhynchus kisutch* (Quinn *et al*, 1983 ; Brannon *et al*, 1984; Quinn and Busack, 1985; Quinn and Tolson, 1986; Quinn and Hara, 1986), *Ictalurus nebulosus* (Carr and Carr, 1985), *Oncorhynchus nerka* (Groot *et al,* 1986), *Astyanax mexicanus* (Defraipont and Thines, 1986), *Phreactichthys andruzzi* (Berti *et al*, 1989; Berti and Zorn, 2001), *Carassius auratus* (Saglio, 1992), *Heteropneustes fossilis* (Pandey *et al*, 2000), *Danio rerio* (Mann *et al*, 2003), *Cyprinus carpio* and *Carassius auratus* (Sisler and Sorensen 2008) are attracted towards waters of the tank previously occupied by their conspcifics. Eels (*Anguilla anguilla*) are usually caught in the traps dripped with conspecific skin extracts (Saglio, 1982). Interestingly, a school of roach, *Ritulus ritulus*, does not disintegrate during night because members of the school maintain contact, presumably through chemical cues (Hemmings, 1966). Individuals of *H. fossilis* congregate and form tight schools during night keeping out the members of *Clarias batrachus* from their school which seems to be mediated by pheromone(s) (Fig. 6). Even broods and young are recognizable to their parents by the odours. McKaye and Barlow (1976) showed that parents of Midas cichlid fish, *Cichlasoma citrinellum,* recognize to their young by means of pheromone. Barnett (1981, 1982) demonstrated that fry of the Midas cichlid fish discriminates even between the mother and father on the basis of urine odour and remarked that the steroid titers in urine could provide information on sex and that of peptide chains in urine could indicate species. Doving *et al* (1980), Frisknes and Doving (1982), Stabell *et al* (1982), Olsen (1987) and Giaquinto and Hara (2008) suggested faecal matter, specifically the metabolites of bile salts, in individual recognition of the Arctic char (*Salvelinus alpines*), Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). Mature lake char (both the sexes) are attracted towards the reefs treated with faeces of the juveniles of the same species. There exist reports that the diet also alters chemistry of the pheromones involved in individual recognition among fishes (Bryant and Atema, 1987). Interestingly, glucurnidation of sex hormones also takes place in the skin of the African catfish, *Clarias gariepinus* which may probably have certain implication in individual/sex recognition (Ali *et al*, 1987) (Fig. 7). Recently, Kime and Ebrahimi (1997) recorded synthesis of 17α,20α-dihyhroxy-4-pregnen-3-one, 17α,20β-dihyhroxy-4-pregnen-3-one, 11-ketotestosterone and other sex hormone conjugates in the gill of goldfish, common carp and trout suggesting gill epithelia to play a role in secretion of pheromones in these species.

During reproductive period, male of some species deposits a layer of mucus on spawning surface which may serves as chemical signals marking the breeding sites and may perhaps communicate status of the occupants (Smith and Murphy, 1974). There exist reports on the substrate marking behaviour in fishes and secretions of mucus, urophysis (caudal neurosecretory system) and urine have been implicated in the production/release of the territorial marking pheromones (Richard, 1974; Milligan, 1978; Atkin and Fink, 1979; Rubec, 1979; Stabell, 1987). Possibly, these marks bear the same biological significance as marking fluid (MF) of the mammals (Brahmachary, 1985; Brahmachary *et al*, 1991; Wyatt, 2009).

Beneficial conditioning of the water by conspecifics and inhibition/retardation of growth under over-crowded condition are assumed to be mediated through pheromones (Yu and Perlmutter, 1970; Francis *et al*, 1974; Solomon, 1977). Todd (1971) remarked that fighting and stress also alter the chemistry of the pheromones of yellow bullhead, *Ictalurus natalis* secreted in the mucus. Dominant male *Oreochromis mossambicus* exhibited increased urination frequency during aggressive behaviour suggesting the presence of a urinary "dominance" pheromone to modulate aggression in rivals (Almedida *et al*, 2005; Barata *et al*, 2007). There exists report that diets also modify the general odour of the catfish (Bryant and Atema, 1987). Chemical modulation of agonistic display has been observed in Siamese fighting fish, *Betta spendens* and the presence of an aggression-suppressing pheromone has been suggested in this species (Colyer and Jenkins 1976; Ingersoll *et al*, 1976). Carr and Carr (1986) observed that the aggression-suppressing pheromone of brown bullhead, *Ictalurus nebulosus* gets inactivated by heat and protease treatments and suggested a protein with molecular weight less than 10,000 as reasonable candidate for the water-borne pheromone.

### Pheromones and Migration

How migratory fish locate their pathways from sea to freshwater and *vice versa* remains a mystery (Harden Jones, 1968; Quinn, 1985, 1990; Black and Dempson, 1986; Brannon and Quinn, 1990). Much work has been done on the homing of salmonids. Claussen Friss (1599-cited by Selset, 1980) remarked that these fishes migrate from the nursery areas to their parental river streams, out to sea and then back to their birth place to spawn (basis of the home-stream theory). Later, Buckland (1880) suggested that each stream has "unique bouquet of odours" and the fish has to "follow its nose" in the detection and discrimination of the natal stream. Though the role of metabolic products of a specific population (pheromones) as homing cues for the salmonids was proposed by Chidester (1924) and White (1934) but this hypothesis was totally eclipsed by the concept of "olfactory imprinting" propounded by Hasler and Wisby (1951) and Hasler *et al* (1978). According to this theory, the young "lock onto" the odours of aquatic vegetations, soil run-off, and other organic chemicals present in the parent stream in their brain and they "retain the olfactory memory" during the interim period of their homeward migration (Hasler and Cooper, 1976; Cooper *et al*, 1976; Hasler, 1983).

Nordeng (1971) realized the pheromone odour tracks to help guide homing of the Arctic char, *Salmo alpinus*. Solomon (1973) demonstrated that the migrating Atlantic salmon, *Salmo salar*, prefers the river in which young of its own populations were living. After exhaustive studies on *Salmo alpinus*, *Salmo trutta* and *Salmo salar,* Nordeng (1977) rejuvenated the pheromone hypothesis. He remarked that the homeward navigation is an inherent response to population-specific pheromone trails released from the descending smolts. The role of pheromones in upstream orientations has been confirmed in rainbow trout, *Oncorhynchus mykiss* and sea lamprey, *Petromyzon marinus*-an anadromous cyclostome (Teeter, 1980; Li and Sorensen, 1997). Miles (1968) demonstrated that elvers of the European eel, *Anguilla rostrata* are attracted towards the water of the streams inhabiting adults of the same species. Sorensen (1984) also corroborated this finding. Stabell (1992) remarked that the specific homing to a native site is under genetic influence and the possible genetic contamination of pheromones due to hatchery escapes or random stocking programmes might seriously interfere with the homing performance and population structure. He emphasized for introduction of the concept of chemical ecology in management practices of commercially important salmonid fisheries.

Our knowledge regarding the chemical nature of these navigational cues is still fragementry. Miles (1968) found the compound(s) involved with attraction of the elvers in *Anguilla rostrata* to be biodegradable, unaffected by autoclaving and non-volatile. Atema *et al* (1973) reported alwife, *Alosa pseudoherengus,* homing pheromones to be heat-stable, non-volatile, polar with molecular weight less than 1,000. Doving *et al* (1980) demonstrated the Arctic char, *Salmo alpines,* migratory cue(s) are present in faecal matter of the smolts, likely to be derivatives of bile salts like taurolithocholate, taurolithocholic sulphate, sulphotaurolithocholate or taurochenodeoxycholate which convey the information to brain through medial portion of the olfactory tract (Thommenssen, 1982, 1983). By employing electrophysiological, biochemical and behavioural approaches, Zhang (1997) also confirmed the chemostimulatory roles of 9 out of 38 authentic bile acids in lake char, *Salvelinus namaychush* and remarked that the olfactory sensitivity and specificity of bile acids were affected by (i) position and orientation of hydroxyls, (ii) hydroxysulphation, (iii) side chain length and (iv) side chain substituents of the molecules. Petromyzonol sulphate (PS), petromyzonamine disulphate (PADS), petromyzosterol disulphate (PSDS) and 3-keto allocholic acid have been identified as migratory pheromone in *Petromyzon marinus* (Li and Sorensen, 1997; Yun *et al*., 2002, 2003; Fine and Sorensern, 2008). The migratory pheromones of sea lamprey are being characterized for application in control and management of the invasive parasite under integrated pest management programme (IPM) (Li *et al*, 2007; Sorensen and Hoye, 2007; Wagner *et al*, 2006, 2009, 2011; Fine and Sorensen, 2008; Vrieze *et al*., 2010, 2011).

**Chemoreception and Water Pollution**

Generally, four groups of chemicals like (i) amino acids, (ii) steroids, (iii) prostaglandins and (iv) bile acids (and their derivatives) (Fig. 8) have been found to be detected by the fish even at minute ($10^{-7}$-$10^{-13}$mM) concentration and each group of chemicals have different receptors at the olfactory system (Hara, 1992). Hara (1982) has given a hypothetical model to show the mode of interaction of amino acids (which serve as feeding stimulants in fish) with olfactory receptor sites.

Bardach *et al* (1968) were the first to study effects of detergents on the chemical senses of the yellow bullhead, *Ictalurus natalis* and found that the concentration of 0.5 ppm (much lower value that inflict lethal damage) impaired the receptor functioning by causing erosion of the chemosensory organ. Bloom *et al* (1978) showed that sublethal (0.5 ppm) exposure to zinc affected the behaviour to the sexual aggregating pheromone (s) in the zebrafish, *Brachydanio rerio*. Linear alkylbenzene sulphate (LAS) significantly depressed chemo-attraction of water conditioned by conspecifics to juvenile Arctic char, *Salvelinus alpines* (Olsen and Hoglund, 1985). Laboratory studies have revealed that the freshwater spawning migration of salmons is being impaired by acidification of rivers (Hara, 1992; Leduc *et al.* 2009). Leduc *et al* (2004, 2008, 2009) found significant reduction in anti-predator response in juveniles of salmonids (*Oncorhynchus mykiss*. *Salvelinus fontinalis* and *Salmo salar*) under weakly acidic condition (pH 6.4) and abolished with further decrease of pH of the water under laboratory as well as field conditions. Electrophysiological recordings of the olfactory epithelium of the adult male *Salmo salar* to testosterone and urine of the ovulated females significantly reduced at pH 5.5-4.5 and abolished at pH 3.5 (Moore, 1994). Exposures of the sublethal concentrations of diazinone and carbofurane significantly reduced the ability of mature male Atlantic salmon parr to respond to priming pheromones of ovulated females (Moore and Waring 1996a; Waring and Moore, 1997).

Fisher *et al* (2006) reported impaired response of the matured female *Xiphophorus birchmanni* to the conspecific male chemical cues due (probably) to humic acid (HA) present ubiquitously in natural environment due to sewage effluent and agricultural runoff. They suggested the possible hybridization of *X. birchmanni* with *X. malinche* owing to the disruption of chemical communication.

Hara *et al* (1983) and Hara (1992) recorded the pernicious effects of an anionic detergent (sodium lauryl sulphate), pH, mercury (Hg), silver (Ag), cadmium (Cd), copper (Cu), nickle (Ni) and zinc (Zn). By calculating $IC_{50}$ value (concentration which inhibits electroolfactographic response by 50 %), they found Ag, Hg, Cu and Cd elicited the most depressive effects on chemoreception in salmonids. They also exposed whitefish, *Coregonus clupeaformis* and rainbow trout, *Oncorhynchus mykiss* to 2.4 mm copper sulphate ($CuSO_4$) solution for two weeks and noted a loss in the phospholipid stainable granules in the receptor neurones of olfactory mucosa, however, recovery in the granules were observed when the fishes were transferred to freshwater for 12 weeks (Hara, 1982). Phospholipids are involved in the electrophysiological (electrolfactogram, EOG) activities of the olfactory epithelium. There are reports that olfactory epithelial cytochrome P-450 and monooxygenase (mixed function oxidase (MFO) are activated by the pollutants (hydrocarbons and heavy metals) (Cangalon, 1983; Tierney *et al*, 2010). Since the present trends of rapid industrialization and increase in population have drastically changed the aquatic environment, it is imperative to include studies pertaining to interactions of various pollutants with the pheromonal communication system in fishes. Barnett (1981) also remarked that the chemically polluted environment can interfere with the success of the parent care.

## Conclusions

Earlier fishes were viewed as "leaky bags" that slowly release various chemicals which served as a "chemical picture" of the animal that others smell and identify as to sex, species, stress level and perhaps size and individuality (Atema, 1980). Urine, ovarian fluid, faeces and mucous are the likely vehicle for the release of pheromones in fishes (Liley, 19982; Colombo *et al,* 1982; Yamazaki, 1990; Pandey, 2005, 2009; Yambe *et al*, 2006a, b; Burnard *et al.*, 2008). From the foregoing discussion, it appears that fishes do employ releaser, primer and imprinter pheromones in their life (Pandey 1984, 2005, 2009; Ostroumov, 1997; Stacey, 2003; Sorensen and Stacey, 2004; Burnard *et al.* 2008). Though the chemical nature of pheromones and sites of their biosynthesis (except alarm substances) are not very clearly defined, there are growing evidences that these chemicals do have communicative roles and shape life among this Class of vertebrates (Stacey, 2003; Pandey, 2005; 2010; Burnard *et al,* 2008)). Interestingly, GnRH has been identified as a potent olfactory stimulant in fish (Anderson and Doving, 1991) but its role in synchronization of the reproductive process in not known. Saralva and Korsching (2007) has identified a novel family of six olfactory receptor (*ora*, olfactory receptors related to class A) genes in teleost fishes (*Danio rerio, Gasterosteus aculeatus, Oryzias latipes, Tetradon nigrovirdis and Takifugu rubripes*). Further studies on their expression in different Class of vertebrates will shed light on the evolution and conservation of these genes through phylogenic evolution. Since these signals are species-specific and operate at molecular levels, they do have potentials for their applications in management and conservation of fisheries. In pisicultural operations, they may be used as selective stimulants to induce spawning at a time and place convenient to fishery managers (Liley, 1980). Since they are externally active, their delivery would eliminate the stress associated with the hormone or drug administration (Stacey *et al*, 1991, 1992, 1994b; Zheng *et al*, 1993, 1997). So far, only a small group of fishes have been studied mostly under controlled laboratory conditions. Such observations on fish pheromones may be extended under simulated natural environments for it better applications (van Weerd and Richter, 1991; Henderso *et al,* 1997; Oslen *et al,* 2006; Burnard *et al*, 2008; Pandey, 2009; Johnson and Li, 2010). There are growing evidence for potential utility of sex pheromones in the management/control of invasive species like sea lamprey, common carp and round goby under integrated pest management (IPM) (Zieliniski *et al*, 2003; Young *et al,* 2003; Sorensen and Stacey, 2004; Corkum, 2004, Wagner *et al*, 2006; Corkum and Belanger, 2007; Wagner *et al*, 2009; Vrieze *et al*, 2010, 2011). These chemical cues may also be employed as artificial baits, selective attractants/repellents, growth stimulators and inhibitors of aggression and cannibalism (Solomon, 1997; Wagner *et al,* 2011). Furthermore, in not too distant future, we would be able to exploit these biogenic trace chemicals for propagating the migratory fishes in new rivers and streams.

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