Review Article

Myxozoan Infestation in Freshwater Fishes in Wetlands and Aquaculture in Punjab (India)

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Abstract | This article reviews the work done on the myxozoan parasites infesting freshwater fishes in 3 wetlands of Punjab i.e. Harike, Kanjali, Ropar wetlands and also aquaculture fishes in Punjab. A recent study conducted by author and co-workers have reported many pathogenic species infesting aquaculture fishes in Punjab. A large number of important commercial fishes in natural and cultured habitat are vulnerable to various infestions, out of which myxozoans are emerging as the major group. Infestion rate has been recorded to be 34.71% in wetlands and 26.28% in aquaculture. Predominate genera are *Myxobolus* Buetschli, 1882 followed by *Thelohanellus* Kudo,1933 infesting gills, operculum, buccal cavity, nasal chamber, eye ball, skin of snout, fins, scale, gall bladder and wall of the alimentary canal. The present document provide the tabulated list of host and myxozoan parasites infesting carp and catfishes in wetlands and cultured ponds of Punjab, India. The most susceptible fish host has been recorded to be *Labeo rohita* infested with as many as 18 species of myxozoans followed by *Cirrhinus mrigala* (14 species), *Catla catla* (12 species), *Labeo calbasu* (11 species) and *Cirrhinus reba* (8 species). Fishes in Kanjali wetland have been found to be more infested (29.6%) in comparison to Harike wetland (24.4%) followed by Ropar wetland (20.4%).

Keywords | Myxozoa, Freshwater fishes, North India, Wetlands Punjab

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INTRODUCTION

In Punjab, three wetlands are in the Ramsar list of international importance viz., Harike wetland (31.17ºN 75.20ºE; primary inflows- Beas and Satluj River; surface ares-4100Ha.), Kanjali wetland (31.42ºN 75.37ºE; primary inflow- Kali Bein rivulet; surface area- 490Ha) and Ropar wetland (31.02ºN 76.50ºE; primary inflow- Satluj River; surface ares-1.365Ha). There are 2 other wetlands of national importance and 5 of state importance (ENVIS Centre, PSCST, Punjab; The Tribune, February 04, 2008). This constitutes an immense fishery resource in the state. Out of total 8285 cultured ponds in Punjab (Fisheries Department Punjab), 6063 are panchayat ponds on government land and 2222 are private ponds. Polyculture species in these ponds consists of Indian major carps: Catla (*Catla catla* Hamilton), rohu (*Labeo rohita* Hamilton) and mrigal (*Cirrhinus mrigala* Hamilton) and exotic carps such as silver carp (*Hypophthalmichthys molitrix* Valenciennes), grass carp (*Ctenopharyngodon idella* Valenciennes), common carp (*Cyprinus carpio* Linnaeus) and bighead carp (*Aristichthys nobilis* Richardson).

Myxozoans are one of the economically important groups of microscopic metazoan parasites as they infest edible fish. New myxosporean pathogens are continually emerging and threatening the development of pisciculture all over the world. They cause production losses and some fish have to be discarded because they are unsightly and not considered to be fit for human consumption. Myxozoans undergo a complex, multicellular development, culminating in the formation of a multicellular spore that is resistant to the external environment.

Although myxozoans are best known for the infestion they cause in teleost (bony fish) but a small number of species have also been found parasitizing bryozoans, platyhelminths, annelids, amphibians, reptiles and birds. So far 19 species have been described from amphibians and reptiles belonging to genera *Myxobolus, Myxidium, Hoferellus, Chloromyxium, Caudomyxum* and *Sphaerospora* (Eiras, 2005). Developmental stages were also found in waterfowl, in nervous system of mammals and were even detected in human faeces (Moncada et al., 2001) but no myxozoan has been known to be hazardous to human health.

Historical Review

There had been lots of twist and turns in the classification of these organisms. Early classifications by Buetschli, 1882 and Dogiel, 1965 placed myxozoans with the Microspora and with parasites now comprising the phylum Apicomplexa (Levine, 1970), together in the class Sporozoa. As the complexities of life cycle were better understood, the class Sporozoa was subsequently referred only to the apicomplexans while the Microspora and Myxozoa remained together in the phylum Cnidospora (Doflein, 1901). More recently, following recognition of profound differences in the ultra-structural composition of these parasites, the Microspora (Sprague, 1977) was raised to the rank of phylum and was found by molecular phylogenetic techniques, to be representative of one of the earliest branching eukaryote lineages (Vossbrinck et al., 1987; Sogin et al., 1989). This had left Myxozoa to stand alone as a phylum without obvious phylogenetic affinities to other protists. Recent developments in myxozoan biology rekindled interest in this group, as it has now been well documented that parasites that were once thought to comprise 2 separate classes, Myxosporea (Butschli, 1881) and Actinosporea Noble in Levine et al. (1980), the latter in fact represented the alternating developmental stage in the life history of a single species. Wolf and Markiw (1984) established that the actinosporean genus "*Triactinomyxon*" is an alternating stage in the life history of species of *Myxobolus*. The repeatability of these findings led to a complete reconsideration of the systematics of the group, heralded by Kent et al. (1994) as the "demise of a Class of Protists," namely the class Actinosporea. Smothers et al. (1994) made phylogenetic analysis of the first myxozoan based on SSU rDNA confirming the marginalized suppositions of earlier authors (Stolc, 1899; Weill, 1938) that myxozoa are multicellular organisms and placed myxozoans within the metazoan. Siddall et al. (1995) remarked that phylogenetic position of the myxozoa within the metazoan was uncertain due to the weakness of SSU rDNA data. There is still debate as to which metazoan group myxozoans are most closely related, whether to radially symmetrical cnidarians such as jellyfish, corals etc. (Smothers et al., 1994; Siddall et al., 1995; Hanelt et al., 1996; Siddall and Whitting, 1999) or to the bilateral animals such as nematodes, flatworms etc. (Okamura et al., 2002; Zrzavy and Hypsa, 2003) as they have characteristics of both of them. Monteiro et al. (2002) discovered that *Buddenbrockia plumatellae,* a worm-like parasite, is a myxozoan and strengthened the case for its bilateral origin, as body plan was superficially similar. However, Siddall et al. (1995) emphasized that functional relationships between polar capsule/filaments and nematocysts argue more for an association with cnidarians. According to National Center for Biotechnology Information, myxosporeans are currently classified as the Myxozoa and are closely related with phylum Cnidaria (Szczepaniak et al., 2010).

Life Cycle

The life cycles of only 25 myxozoan parasites are known (Kent et al., 2001). Wolf and Markiw (1984) discovered myxosporean life cycles alternating between two host species. With few exceptions, the life cycle of myxozoans include two alternating hosts, an aquatic invertebrate (an oligochaete or a polychaete worm or a bryozoan and a vertebrate host, mainly teleost fish. The myxospore is ingested by an annelid/bryozoan, which undergo schizogony and gametogony and develop in to an actinospore, a triradiate stage. The waterborne actinospores are released from oligochaetes and infect fish via gills or skin. Amoeboid sporoplasm containing the infective secondary cells leaves the actinospore valve, construct and actively penetrate the host integument. In the respective tissue, sporoplasm released from the actinospore divide by endogony and undergo presporogonic multiplication.

Spore Morphology

The vegetative structures offer no distinctive morphological features, classification has been based solely on the structure of spores (Lom and Arthur, 1989). Myxozoan spores have proteinaceous shell valves, nematocysts-like polar capsule(s) with coiled extrusible polar filament(s) and an amoeboid infective sproplasm. Spores are uniformly small sized, 10-25µm long but valvular extension(s) attain lengths of 30-60 µm and have 2-3 shell valves. Valves are joined along a thickened suture which is sinuous or straight. The actinospore may have size up to 300µm. The polar filament(s) are for anchoring function.

Classification

More than 2,180 species in 60 genera belonging to the Class Myxosporea of the Phylum Myxozoa has been described (Lom and Dykova, 2006). However, three more genera i.e. *Soricimyxum fegati* from liver of *Sorex araneus* Prunescu et al., 2007, *Gadimyxa atlantica* from urinary system of *Gadus morhua* Koie et al., 2007 and *Thelohanelloid bengalensis* from gall bladder of *Arius sagor* Sarkar, 2009 have been described subsequently. *Myxobolus* is the most common genus reported worldwide which include 744 species (Eiras et al., 2005). The second Class i.e. Malacosporea include only two genera (*Tetracapsuloides* and *Buddenbrockia*) with total four described species (Table 1).

In India, Kalavati and Nandi (2007) reported 104 species of *Myxobolus* from Indian fishes in addition to 175 species belonging to 29 genera in total. Kaur and Singh (2012a) gave synopsis of 131 nominal species of *Myxobolus* reported from India and a revised dichotomous key of 59 genera of the Class Myxospore. Recently Eiras et al. (2014) in a synopsis listed 112 nominal species of *Myxobolus*, out of which 29 species were from India.

The Classification of the Class Myxosporea based on Lom and Dykova (1992) with Class Malacosporea as described by Canning et al. (2000) is given below:

Phylum Myxozoa

1. Class Myxosporea

- **Order Bivalvulida** (marine and freshwater, spore with two valves)

- **Suborder Variisporina** (marine and freshwater, mostly coelozoic) includes *Ceratomyxa, Chloromyxum, Hoferellus, Myxidium, Myxobilatus, Ortholinea, Parvicapsula, Polysporoplasma, Sinuolinea, Sphaerospora* and *Zschokkella.*

- **Suborder Platysporina** (marine and freshwater, mostly histozoic) includes *Myxobolus*, *Henneguya* and *Thelohanellus.*

- **Suborder Sphaeromyxina** (marine with ribbon-like polar filaments in polar capsules at opposing end of spore) includes *Sphaeromyxa.*

- **Order Multivalvulida** (marine with greater than 2 spore valves) includes *Hexacapsula, Kudoa, Trilospora,* and *Unicapsula.*

2. Class Malacosporea (freshwater with soft valves, parasites of bryozoans)

- **Order Malacovalvulida** includes *Tetracapsuloides* and *Buddenbrockia.*

Molecular and Phylogenetic Aspect

Presently, molecular classification has become another approach in taxonomic and phylogenetic studies in myxozoans. The focus of these studies has been on comparative analysis of small subunit (SSU) ribosomal DNA (rDNA) sequence. Smothers et al. (1994) were first to use sequence analysis to study the phylogenetics of the Myxozoa. Since then, these sequences of myxozoans have been employed by several investigators to address systematics and life-cycle questions. An outgrowth of these studies has been the development of sensitive PCR tests based on rDNA sequences, which are routine diagnostic tools in some fish health laboratories (Szekely et al., 2009 a, b; Molnar et al., 2010).

Until recently, only spore morphology served as a means of identification of myxozoan species. Nowadays, molecular methods have become increasingly important in phylogenetic analyses and taxonomic identification of myxosporeans. Holzer et al. (2004) gave the molecular relationships and phylogeny in a community of myxosporeans and actinosporeans based on their 18S rDNA sequences. Fiala and Bartosova (2010) gave the history of myxozoan character evolution on the basis of rDNA and EF-2 data. Eszterbauer (2004), Milanin et al. (2010), Gleeson and Adlard (2012), Hartigan et al. (2012) and Adriano et al. (2012) investigated the phylogenetic relationships of the species within a particular genus. These studies have demonstrated that many factors influence species clustering, such as the phylogenetic proximity of the host, tissue tropism, geographic distribution and morphology characteristics. Carriero et al. (2013) analysed 18SrDNA gene sequences of 12 *Myxobolus*/*Henneguya* and showed strongest evolutionary signal on the basis of phylogenetic affinity of the fish host, clustering according to order and/or family of the host.

In India, Mondal et al. (2014) studied the molecular and morphometric characterization of *Thellohanellus caudatus* Pagarkar and Das, 1993 infecting the caudal fin of *Labeo rohita* (Hamilton).

Pathogenicity

Many myxozoan infections are relatively benign, but some species are pathogenic. Those that cause mortality and other damage have been the focus of most myxozoan research. Myxosporean parasites are among the most important fish pathogens (Schmahl et al., 1989) and more than 2,300 species have been reported to infect fish (marine and freshwater fish) in natural and cultured environment (Adriano et al., 2006, 2009a,b; Feist and Longshaw, 2006; Eiras et al., 2008; Azevedo et al., 2009).

Myxobolus is the genus with the greatest number of species and many of these are reported as pathogenic to fish (Kent et al., 2001; Feist and Longshaw, 2006). Probably the most frequently cited example of myxozoan parasitism is the whirling disease, caused by *M. cerebralis* (Hedrick et al., 1998). In this case, the parasite infects the cartilages of the host's head and spine, causing deformities that result in the characteristic whirling behaviour. Others that are associated with host mortalities are *Tetracapsuloides bryosalmonae,* the cause of proliferative kidney disease in Pacific salmon (Kent et al., 2001), *Enteromyxon leei,* an intestinal parasite of Mediterranean sea bream (Diamant, 1992) and *Henneguya ictaluri* in pond- reared catfish (Pote et al., 2000). Importance of genus *Henneguya* as pathogen of freshwater fish has been described by several authors such as Pinto (1928a,b), Jakowska and Nigrelli (1953), Dykova and Lom (1978), Kalavati and Narasimhamurti (1985), Martins and Souza (1997), Martins et al. (1999), Hallett and Diamant (2001).

Hemananda et al. (2008) reported *Henneguya manipurensis* as the main cause of ulcerative disease syndrome in freshwater fish *Anabas testudineus* of Manipur, (India).

Recently, Kaur et al., (2013 a, b; 2014) reported pathogenic effects of some myxozoan parasites affecting gills of cultured carps. Multilocular gill infections were found which were of two types viz., intralamellar (LV) and intrafilamental vascular type (FV) causing necrosis, hemorrhage, reduction in respiratory surface (about 15-20% of total gill filament). In the case of infection in the scales the plasmodia were embedded within the layers and, in the case of fins and fin rays the plasmodia were located on the surface as well.

Fetherman et al. (2014) introduced resistant varieties of trout by crossing the German rainbow (GR) and Colorado River rainbow (CRR) and demonstrated that these could survive and reproduce in rivers with high prevalence of *M. cerebralis.*

Zoonosis

As regard to the zoonosis of myxozoans they are not considered to be of human health risk, because they do not have been shown to infect human beings. There are reports of occurrence of spores of *Henneguya salmonica* parasitic in salmonid fishes in Canada (McClelland et al., 1997), *Myxobolus plectroplites* parasitic in freshwater fish *Plectroplites ambiguous* in Australia (Boreham et al., 1998) and *Myxobolus* sp. in Colombia (Moncada et al., 2001) in human stool samples of patients with gastrointestinal disturbance, suggesting that this aspect requires serious consideration. Hessen and Zamzame (2004) during a study on intestinal parasitic infections in immune-compromised patients complaining of diarrhea have reported presence of myxospores in stools. Martinez de Velasco et al. (2008) have speculated a potential public health impact of *Kudoa* spp. as a food borne allergen for humans with allergic gastrointestinal symptoms.

MYXOZOAN PARASITES OF INDIAN FISHES

Phylum Myxozoa has been studied by only limited number of workers in Indian subcontinent. Most of the work in India has been done on freshwater and marine fishes mainly in two states, West Bengal and Andhra Pradesh. In West Bengal, Chakravarty (1939, 1943); Chakravarty and Basu (1948); Raychaudhury and Chakravarty (1970); Bajpai and Haldar (1982a,b); Bajpai et al. (1981); Haldar and Mukherjee (1985); Sarkar and Mazumdar (1983a,b); Haldar et al. (1981, 1983, 1996); Pagarkar and Das (1993); Das (1996); Basu and Haldar (1999, 2002a,b, 2003, 2004); Bandyopadhyyay et al. (2006/2007); Hemananda et al. (2006, 2009, 2013); Basu et al. (2006, 2009); Acharya and Dutta (2007); Madhavan et al. (2013) have contributed significant number of species from freshwater and marine fishes belonging to genera *Myxobolus, Thelohanellus, Myxidium* and *Henneguya.* Basu and

Haldar (1999) listed as many as 28 species under the genus *Thelohanellus*. Sarkar (1982a, b, 1984, 1985a,b,c, 1986a,b,c, 1987, 1989, 1993,1994,1995a,b, 1996a,b, 1997, 1999a,b, 2004) contributed a lot and described large number of species belonging to genera *Myxobolus, Thelohanellus, Chloromyxum, Zschokkella, Myxidium, Sphaerospora, Unicapsula, Henneguya, Ceratomyxa, Coccomyxa, Ortholinea, Neoparvicapsula, Myxoproteus* and *Kudoa* from freshwater and marine fishes of West Bengal.

In Andhra Pradesh, researchers such as Southwell and Prashad (1918); Ganpati (1941); Tripathi (1952); Bhatt and Siddiqui (1964); Qadri (1962a,b,c, 1967); Qadri and Lalitha (1965); Lalitha (1969); Narasimhamurti (1970); Mandal and Nair (1975); Seenappa and Manohar (1980a, b, 1981); Kalavati and Narasimhamurti (1981, 1984, 1985); Kundu (1985); Narasimhamurti and Kalavati (1979, 1986) and Padma and Kalavati (1992) recorded and described numerous myxosporean species from marine as well as freshwater fishes.

Kalavati and Nandi (2007) gave significant details in a handbook on myxosporidian parasites of Indian fishes and reported 104 species of *Myxobolus* from Indian fishes in addition to 175 species belonging to 29 genera in total. Earlier also a check list of about 80 species of myxosporidians was given by Kalavati et al. (1981) which was the only compilation after Tripathi (1952). Although reports of myxosporean species from other parts of India are few except some from freshwater fishes of Manipur (Hemananda et al., 2009, 2010) and Kerala (Sheeja and Janardanan, 2006). Hemananda et al. (2006) during an investigation on the incidence of myxozoan parasites in *Cirrhinus mrigala* recorded pathogenicity and mortality due to *Myxobolus haldi* infecting gill filaments. Eiras and D'Souza (2004) reported two species of *Myxobolus* from gills of *Mugil cephalus* collected at Goa. Sarkar (2009) described a new genus *Thelohanelloid bengalensis* from the gall bladder of a marine fish, *Arius sagor*.

MYXOZOAN PARASITES OF FRESHWATER FISHES IN PUNJAB

In North India, Gupta and Khera (1987a, 1988a,b,c,d, 1989a,b, 1990, 1991) recorded 25 species belonging to genera *Henneguya, Myxidium, Thelohanellus* and *Unicauda* infesting freshwater fishes. In addition, they also reported a new genus *Lomosporus indicus* found infecting gills of freshwater fish *Labeo calbasu*, however, Lom and Dykova (1992) later on synonymised it as the genus *Neothelohanellus* Das and Haldar (1986). Gupta and Khera (1987b) reviewed the genus *Henneguya* to remove the existing confusion in the literature giving the basic differences between genus *Henneguya* and *Unicauda.* Some of the species which were misplaced under the genus *Unicauda* were transferred to *Henneguya.* Gupta and Khera (1988c) also transferred all the 18 species belonging to the *Myxosoma* from Indian freshwater fishes to the genus *Myxobolus*.

Kaur and Singh (2008, 2008-2009, 2009a,b, 2010a,b, 2010/2011, 2011 a-g 2012a,b), Singh and Kaur (2012a,b,c, 2014a,b,c) and Singh (2011) recorded 45 species of myxozoans representing 4 genera, namely, *Myxobolus* (26 species), *Thelohanellus* (16 species), *Neothelohanellus* (1 species), *Triangula* (2 species). Recently, 6 species belonging to the genus *Henneguya*, 2 species of *Myxobolus* (Kaur et al. 2013a, b) 2 species of *Thellohanellus* (Kaur et al. 2014a, b) and one species of the genus *Unicauda* (1 species) have been collected from wetlands and cultured carps. Plasmodia were detected in gills, operculum, buccal cavity, nasal chamber, eye ball, skin of snout, fins, scale, gall bladder and wall of the alimentary canal. Infection rate in three wetlands was 55.8%. *T. lamelliformis* Kaur and Singh, (2014b) and *T. rohi* Kaur and Singh, (2014b) have been recently reported infecting primary gill lamellae of *Catla catla* (Hamilton) and caudal fin of *Labeo rohita* (Hamilton) respectively.

In the three wetlands of Punjab viz. Kanjali, Harike and Ropar wetland, 12 species of carps (Table 2), 2 species of catfish (*Wallago attu and Mystus seenghala*), 2 species of murrels (*Ophiocephalus punctatus and O. marulius*) and 1 species each of gourami (*Colisa lalia*), batchwas (*Eutropiichthys murius*) and grey feather back (*Notopterus notopterus*) (Table 1 and 2) were examined. A total of 1,158 carps were examined which comprised *Amblypharyngodon mola* vern. mola carplet, *Carassius carassius* vern.crucian carp, Catla catla vern. thail, *Cirrhinus reba* vern. reba carp, *Cirrhinus mrigala* vern., mrigal, *Ctenopharyngodon idellus* vern. grass carp, *Cyprinus carpio carpio* vern. mirror carp, *Hypothalmichthys molitrix* vern. silver carp, *Labeo bata* vern. bata, *Labeo calbasu* vern. Kalbans, *Labeo dero* vern. gid, *Labeo rohita* vern. rohu and *Puntius filamentosus* vern. blackspot barb. 402 carps (9 species) were infested

Table 1: Myxozoan parasites of carps of Punjab.

S. No.	Host examined	Myxozoan parasites recorded
1	*Amblypharyngodon mola* vern. mola carplet, molelia (Common name: makhani)	*Myxobolus moli* Fomena et al. (1985) (revised diagnosis and new nomenclature *M.* sp. 4 Fomena et al., 1985)
2	*Catla catla* vern. thail (Common name: thail)	*M. mahendrae* Sarkar (1986a); *M. gorhami* Gupta and Khera (1991); *M. catli* Kaur and Singh (2011b); *M. magauddi* (Bajpai et al., 1981) Gupta and Khera, 1988a; *M. parsi* Das (1996); *M. sclerii* Kaur and Singh (2010a); *Thelohanellus boggoti* Qadri (1962b); *T. qadrii* Lalitha Kumari (1969); *T. kanjalensis* Singh and Kaur (2014a); *T. mrigalae* Tripathi (1952); *T. mucousalis* Kaur and Singh (2011b); *T. thaili* Singh and Kaur (2012c), *T. lamelliformis* Singh and Kaur (2014b)
3	*Cirrhinus reba* vern. mori, kursa (Common name: mori, sunni)	*M. kalmani* Kaur and Singh (2011b); *Triangula ludhianae* (Syn. *M. ludhianae* Gupta and Khera, 1991) comb. n.; *M. harikensis* Kaur and Singh (2011b) ; *T. kalavatae* Singh and Kaur (2014a); *T. haldari* Singh and Kaur (2012b); *T. globulosa* Singh and Kaur (2012a); *Triangula cirrhini* Kaur and Singh (2011b)
4	*Cirrhina mrigala* vern. mrigal (Common name: naraini, marakh)	*Myxobolus calbasui* Chakravarty (1939); *M. haldari* Gupta and Khera (1989a); *M. venkateshi* Seenappa and Manohar (1981); *Thelohanellus calbasui* Tripathi (1952); *Myxobolus bhadurius* (Sarkar, 1985b) Gupta and Khera, 1988a; *M. eirasi* Kaur and Singh (2009a); *M. kanjalii* Kaur and Singh (2011b); *M. mehlhorni* Kaur and Singh (2011a); *M. naini* Kaur and Singh (2008); *M. punjabensis* Gupta and Khera (1989b); *M. roparae* Kaur and Singh (2011b); *M. slendrii* Kaur and Singh (2009b); *M. venkateshi* Seenappa and Manohar (1981) *M. basui* Kaur et al. (2013b)
5	*Labeo bata* vern. bata (Common name: bata)	*M. calbasui* Chakravarty (1943); *M. catlae* Chakravarty (1943); *M. haldari* Gupta and Khera (1989a); *M. rohitae* Haldar et al. (1983); *M. venkateshi* Seenappa and Manohar (1981); *Thelohanellus calbasui* Tripathi (1952); *T. avijiti* Basu and Haldar (2003a)
6	*Labeo calbasu* vern. kalbans (Common name: kalbasu)	*M. filamentosus* (Haldar et al., 1981) Gupta and Khera, 1988a; *M. lalithae* Gupta and Khera (1988d); *M. rohitae* Haldar et al. (1983); *M. saranae* Gupta and Khera (1990); *M. venkateshi* Seenappa and Manohar (1981); *T. calbasui* Tripathi (1952); *T. rohitae* (Southwell and Prashad, 1918) Kudo, 1933; *T. caudatus* Pagarkar and Das (1993); *T. gangeticus* Tripathi (1952); *T. kalbensi* Singh and Kaur (2014a); *Neothelohanellus indicus* (Gupta and Khera,1988b) Lom and Dykova, 1992
7	*Labeo dero* vern. gid (Common name: gid)	*Myxidium labeonis* Gupta and Khera (1988c); *Myxobolus calbasui* Chakravarty (1943); *M. catlae* Chakravarty (1939); *M. haldari* Gupta and Khera (1989a); *M. ludhianae* Gupta and Khera (1991); *M. punjabensis* Gupta and Khera (1989b); *M. rohitae* Haldar et al. (1983); *M. venkateshi* Seenappa and Manohar (1981); *T. dyocheilus* Gupta and Khera (1987a); *T. deri* Singh and Kaur (2012b)
8	*Labeo dyocheilus* (Common name: Brahmaputra Labeo)	*Myxidium labeonis* Gupta and Khera (1988c); *Myxobolus calbasui* Chakravarty (1939); *M. catlae* Chakravarty (1943); *M. haldari* Gupta and Khera (1989a); *M. ludhianae* Gupta and Khera (1991); *M. punjabensis* Gupta and Khera (1989b); *M. rohitae* Haldar et al. (1983); *M. venkateshi* Seenappa and Manohar (1981); *Thelohanellus dyocheili* Gupta and Khera (1987a)
9	*Labeo rohita* vern. rohu (Common name: rohu)	*Myxobolus calbasui* Chakravarty (1939); *M. haldari* Gupta and Khera (1989a); *M. rohitae* Haldar et al. (1983); *M. venkateshi* Seenappa and Manohar (1981); *M. patialensis* Kaur and Singh (2010b); *M. punjabii* Kaur and Singh (2010c); *M. saugati* Kaur and Singh (2011b); *M. saranae* Gupta and Khera (1990); *M. stomum* Ali et al. (2003); *M. sushmii* Kaur and Singh (2010c); *T. murtii* Gupta and Khera (1987a); *T. rohi* Singh and Kaur (2014b); *M. nanokiensis* Kaur *et al.* (2013a) *T. filli* Kaur et al. (2014a) *T. dykovi* Kaur *et al.* (2014b); *T. bifurcata* Basu and Haldar (1999); *M. potularis* Madhavan *et al.* (2013); *M. longisporous* Nie and Li (1992)
10	*Puntius sophore* vern. chital, ticker barb (Common name: spot fin swamp barb)	*M. chittalii* Kaur and Singh (2010d)
11	*Puntius sarana* (common name: olive barb)	*Myxobolus bhaduria* (Sarkar, 1985) n. comb.; *M. saranae* Gupta and Khera (1990)
12	*Hypophthalmichthys molitrix* (common name: silver carp)	4 species of *Myxobolus*, 1 species of *Thelohanellus* (unidentified)

Table 2: Myxozoan parasites of some catfishes and other fishes of north India

S. No.	Host examined	Myxozoan parasites recorded
1	*Wallago attu* (Common name: boal, borali, freshwater shark)	*M. duodenalis* Kaur and Singh (2010b).; *M. szekeli* Kaur and Singh (2011b); *T. batae* Lalitha Kumari (1969); *T. wallagoi* Sarkar (1985b), *T. rohi* Singh and Kaur (2014b)
2	*Channa punctatus* (Common name: spotted snake head)	*Myxobolus aligarhensis* Bhatt and Siddiqui (1964)
3	*Mastacembelus armatus* (Common name: spiny eel)	*Myxobolus eeli* Mandal and Nair (1975); *Unicauda armati* Gupta and Khera (1987b)
4	*Nandus nandus* (Common name: mottled nandus)	*Henneguya nandi* Gupta and Khera (1987b)
5	*Tor putitora* (Common name: golden mahaseer)	*Myxobolus gorhami* Gupta and Khera (1991)

(34.71%) with as many as 40 species of myxosporeans belonging to the genera *Myxobolus, Thelohanellus, Neothelohanellus, Henneguya, Unicauda* and *Triangula*- table 1. In addition to this, a total of 245 other fishes and a catfish, *Wallago attu* vern. boal were examined, 30 were found infested (12%) with 10 species of myxozoans belonging to genera *Myxobolus* (5 species), *Thelohanellus* (3 species), *Henneguya* (1 species) *and Unicauda* (1 species)-table 2. No infestion was found in *Channa striatus* vern. murrels, *Trichogaster* sp vern. gourami, *Eutropiichthys vacha* vern.batchwa, *Chitala chitala* vern. grey feather back fish.

Infestion rate was found to be the highest in *Cirrhinus mrigala* (57.1%), followed by *Catla catla* (51.4%) and *Labeo dero* (33.3%) from Ropar wetland. In Kanjali wetland, the infestion rate was also highest in *C. mrigala* (49.6%) followed by *L. calbasu* (41.6%) and *L. rohita* (38.8%). In Harike wetland, the infestion rate was highest in *Puntius sophore* (80%) followed by *C. reba* (70%) and *Amblypharyngodon mola* (33.3%). Fishes of Kanjali wetland were found to be more infested (29.6%) in comparison to Harike wetland (24.4%) followed by Ropar wetland (20.4%). Two species belonging to the genus *Myxobolus* i.e. *M. moli* Fomena et al. (1985) and *M. stomum* Ali et al. (2003) were recorded from gills and scales of *A. mola* and *L. rohita* respectively for the first time in India.

Four major carps examined were *C. mrigala*, *L. rohita*, *Catla catla* and *L. calbasu*. Among these *L. rohita* was the most susceptible to myxozoans (18 species) followed by *C. mrigala* (14 species), *C. catla* (12 species), *L. calbasu* (11 species) and *C. reba* (8 species). Kalavati and Nandi (2007) also discussed that out of three major carps in India, the most susceptible was *L. rohita*, followed by *C. mrigala* and *Catla catla.* Furthermore they reported the parasite virulence was greater in *Catla catla* with mortality up to 80-90%.

The present study indicated that maximum mean intensity of the parasite species was shown by *M. duodenalis* followed by *Triangula cirrhini* and maximum abundance again by *M. duodenalis* followed by *M. szekeli*. The most infested organ was gills (45.6%) followed by caudal fin (29.4%), scales (16.1%) duodenum (5.12%), pectoral fin (1.92%), pelvic fin (1.67%), eyeball (1.4%), skin of snout (0.38%) and stomach (0.12%). However, no infestion was detected in swim bladder, muscles and skin. In the case of light infestion 10-20 small-sized plasmodia, in heavy infestion 50-70 small-sized and 3-4 large-sized plasmodia were detected on the gills. 4-6 plasmodia were found to be present per scale and 5-7 plasmodia were recorded per fin.

In aquaculture, 4 new species were recorded infesting gills of major carps – *M. nanokiensis, M. basui, T. filli, T. dykovi* (Kaur. et al., 2013a, b, 2014a) along with their pathogenic effects. Large-sized plasmodia of *T. bifurcata* Basu and Haldar, 1999 recorded on the gill lamellae of cultured Indian major carp *Labeo rohita* in Punjab was recorded to be the most pathogenic with fish mortality rate of 20-30% (Kaur and Katoch, 2014).

CONCLUSIONS

Existing knowledge on the phylum Myxozoa- an enigmatic group of organisms is fragmentary, inadequate and incomplete in many parts of India especially in the state of Punjab having rich fish biodiversity. There is great need to identify, describe and satisfactorily classify these parasites both morphologically and at the molecular level. It is evident that study on this group is also important in identification of the pathogenic species which can pose serious threat to fisheries in state of Punjab. This knowledge will help in diagnostics, management and treatment of the diseases caused by these parasites in freshwater fishes.

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