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Synopsis of tailed Myxobolidae (Cnidaria, Myxozoa, Myxosporea) infecting Indian fishes

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Abstract: A synopsis of 43 nominal species from five genera of tailed Myxobolidae infecting Indian freshwater and marine fishes is presented. The main characteristic of this group is the presence of at least one tail-like caudal process. For each species, relevant morphological and morphometric data are provided, such as the host(s), site(s) of infection within the host and sampling state. A key for the identification of 13 genera of tailed Myxobolidae is also included.

Keywords: Fish parasites, species diversity, taxonomy, identification key

Species of the family Myxobolidae Thélohan, 1892 of the phylum Cnidaria, subphylum Myxozoa, are characterised by spores usually flattened parallel to the straight sutural plane, bilaterally symmetrical body with two or sometimes one polar capsule. This synopsis accounts the genera of tailed Myxobolidae from fishes of the Indian subcontinent that have at least one caudal process or caudal appendages, which look like 'tails' (Thélohan 1892).

Till now nine genera, i.e., *Henneguya* Thélohan, 1892, *Hennegoides* Lom, Tonguthai et Dyková, 1991, *Neohenneguya* Tripathi, 1953, *Unicauda* Davis, 1944, *Dicauda* Hoffman et Walker, 1978, *Laterocaudata* Chen et Hsieh, 1984, *Phlogospora* Qadri, 1962, *Tetrauronema* Wu, Wang et Jiang, 1988, and *Trigonosporus* Hoshina, 1952, have been reported as tailed Myxobolidae all over the world.

In India, species of only five genera, namely *Henneguya*, *Neohenneguya*, *Hennegoides, Unicauda* and *Phlogospora*, have been reported. In this paper, we provide for the first time an updated synopsis of tailed Myxobolidae in Indian fishes. Most of the research on this group has been carried out mainly in four states (West Bengal, Andhra Pradesh, Punjab and Orissa) on both freshwater and marine fishes.

A number of authors (Chakravarty 1939, Ganapati 1941, Tripathi 1952, Qadri 1962, 1965, Bhatt and Siddiqui 1964, Lalitha Kumari 1965, 1969, Chaudhuri and Chakravarty 1970, Narasimhamurti and Kalavati 1975, Kalavati and Narasimhamurti 1981, 1984, Seenappa et al. 1981, Bajpai and Haldar 1982a,b, Haldar et al. 1983, 1997, Haldar and Mukherjee 1985, Sarkar 1985, Sarkar et al. 1985, Menon 1986, Gupta and Khera 1987, Wu et al. 1988, Kalavati et al. 1992, Susha and Janardhan 1995, Acharya et al. 2004, Gupta and Kaur 2018, Nissa and Kaur 2021) described numerous new species of tailed Myxobolidae from freshwater and marine fishes of West Bengal, Andhra Pradesh, Orissa, Kerala and Uttar Pradesh.

Hemanand et al. (2008), and Kaur and Attri (2015) recently described one species from the freshwater fish of Manipur and Punjab, respectively. Kalavati and Nandi (2007) listed 34 species of tailed Myxobolidae.

The present synopsis updates the number of species infecting Indian fishes in a tabulated arrangement, giving details of morphology and dimensions of cyst, spore body and polar capsules. Site(s) of infection within the host, type host and sampling state are also given.

MATERIALS AND METHODS

The collection of data about myxobolid parasites in Indian fished was based on a detailed internet search to detect references to fish infection by tailed Myxobolidae. A careful check of the references of each paper was done to maximise the probability of getting all the data available. Fish names in Table 1 follow Froese and Pauly (2022).

Key to tailed genera of Myxobolidae

1a. Spores ovoid or pyriform, with two polar capsules and a single tail-like caudal process 2

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Table 1. Synopsis of *Henneguya*, *Hennegoides*, *Neohenneguya*, *Phlogospora* and *Unicauda* spp. infecting Indian fishes. *Abbreviations*: C – cyst; SB – spore shape; D – diameter; SBL – spore body length; STL – total length of spore; WS – width of spore; TS – spore thickness; CA – caudal appendage length; PC – polar capsule; LPC – length of large polar capsule; SPC – length of small polar capsule; NC – number of coils of polar filament inside polar capsule. AP – Andhra Pradesh; K – Kerala; KR – Karnataka; M – Manipur; O – Orissa; P – Punjab; TN – Tamilnadu; WB – West Bengal; UP – Uttar Pradesh. All the measurements are in μm; dimensions of polar capsules are given as length × width.

Species	Infected organ	Spores	Type-host	State
Henneguya basari Gupta et Khera, 1987	Pharyngeal cavity	C oval, white, 500–1000 × 300; SB oval, STL 25.6–39.2 (34.3); WS 3.2–4.4 (3.7); CA 10.0–20.3 (15.3); PC equal and pyriform, 5.0–7.4 (6.3) × 1.4–2.0 (1.7).	*Channa punctata* Bloch	UP
H. bengalensis Gupta et Khera,1987	Buccal cavity	C oval, white, 1000–1250; SB elongate, STL 26.4–29.5 (28.4); WS 2.8–3.9 (3.3); CA 11.6–13.8 (12.61); PC equal and pyriform, 3.3–3.6 (3.5) × 1.1–1.4 (1.2).	*Channa punctata* Bloch	WB
H. bicaudi Kaur et Attri, 2015	Gill filament	C round, 500–700 (D); SB oblongate, SBL 20–22 (21); WS 5.9–6.5 (6.2), CA 8.7–9.0 (8.9); PC equal and pyriform, 3.1 × 2.0; NC 7–8.	*Cirrhinus mrigala* Hamilton	P
H. bicornuata Gupta et Khera, 1987	Branchial epithelium	C oval, milky white, 1200–1500; SB oblongate, STL 26.4–29.2; WS 2.8–3.9; CA 11.6–13.8; PC equal and pyriform, 3.3–3.6 × 1.1–1.4.	*Channa punctata* Bloch	WB
H. bleekeri Haldar et Mukherjee, 1985	Kidney	C round, 1500 × 1000; SB oblongate, STL 20–25.5 (21.9); WS 3.3–5.0 (4.3); CA 10.1–15.5 (13.0); PC equal and pyriform, 3.3–4.4 (3.6) × 1.1–2.2 (1.7); NC 6–8.	*Mystus bleekeri* Day	WB
H. chaudhuryi Gupta et Khera,1987	Gill filaments	SB oblongate, STL 26.3–33.2 (30.0); WS 3.3–4.1 (3.7); CA 14.5–20.0 (17.7); PC equal and pyriform, 5.0–7.5 (6.0) × 1.6.	*Channa punctata* Bloch	WB
H. ganapatiae Qadri, 1970	Gills	SB oval, SBL 9.3–10.0 (9.7); WS 4.0–4.8 (3.7); CA 22–25 (22.3); PC equal and elongate, 3.2–2.6 (3.32) × 1.4 –1.8 (1.6)	*Notopterus notopterus* Pallas	AP
H. latesi Tripathi, 1952	Gills	C small; SB pyriform, SBL 9.0–10.8; WS 4.0–4.8 (4.5); CA 17.2–25.0; PC equal and pyriform, slightly convergent, 3.6 × 2.0.	*Lates calcarifer* Bloch	WB
H. latiusi Gupta et Kaur, 2018	Gills	C spherical, 200–900 (D); S oblongate, 12×4.3; CA 12–14 long; PC equal and pyriform, 4.0 × 2.5.	*Crossocheilus latius* Hamilton	P
H. manipurensis Hemanand, Meiti, Bandypadhyay et Mitra, 2008	Body tissue	SB elongated; STL 23.8–28.0 (25); SBL 12.6–15.4 (14.0); WS 5.6–7.0 (6.3); CA 11.2–12.6 (11.7); PC equal and pyriform, 5.6–6.3 (5.8) × 2.1–2.8 (2.3).	*Anabas testudineus* Bloch	M
H. megalopsi Kalavati, Venkataeswara Rao et Vaidehi, 1992	Gall bladder	SB oval; STL 36.8–40.0 (37.6); SBL 11.2–12.8 (12.4); WS 3.2–3.6 (3.24); TS 2.5–3.0; CA 25.6–37.2 (34.2); PC equal and pyriform, 4.4 x 0.8	*Megalops cyprinoides* Broussonet	O
H. mystasi Haldar, Samal et Mukhopadhyay, 1997	Gills	SB pyriform; STL 35.8–53.8 (46.3); SBL 13.0–18.7 (16.14); WS 1.6–4.0 (2.92); CA 19.5–37.4 (29.85); PC equal and pyriform, 4.0–4.9 (4.36) × 1.6–3.2 (1.92).	*Mystus gulio* Hamilton	O
H. mystusia Sarkar, 1985	Gill filament	C small, creamy white, 200 × 100; SB fusiform; STL 27.0–40.0 (32.33); SBL 12.0–15.0 (13); WS 3.0–4.0 (3.8); TS 2.5–3.0 (2.9); CA 17.0–25.0 (19.3); PC equal and tubular, 5.0–6.0 (5.04) × 1.0–1.3 (1.2).	*Mystus* sp.	WB
H. namae Haldar, Das et Sharma, 1983	Gills and heart	C oval, creamy white, 180–220 × 150–190; SB oblongate, SBL 17.6–19.3 (18.5); WS 5.5–6.6 (6.4); CA 17.6–18.7 (18.5); PC unequal and pyriform, LPC 5.5–6.0 (5.8) × 1.1; SPC 4.4–5.0 (4.9) × 1.1; NC 9–10.	*Chanda nama* Hamilton	WB
H. nandi Gupta et Khera,1987	Gills and heart	C round 399–450 × 342–402; SB oblongate; STL 18–25 (20.2); SBL 9.0–11.0 (9.9); WS 3.0–5.0 (3.9); CA 9.0–15.0 (10.3); PC equal and pyriform, 3.2–4.0 (3.6) × 1.4–2.0 (1.6).	*Nandus nandus* Hamilton	P
H. notopteriae Qadri, 1965	Gills	SB ellipsoidal or lanceolate; SBL 11.5–13.0; WS 4.5–5.0 (4.8); CA 40.5–42.0; PC unequal, LPC golf stick like, 5.0–5.5 × 1.0–1.5; SPC pyriform, 3.5–4.5 × 1.0–1.3.	*Notopterus notopterus* Pallas	AP
H. ophiocephali Chakravarty, 1939	Gills and muscles	C spherical, 2000 (D); SB oval; STL 41.5–52.5 (37.6); WS 6.2–7.2 (3.2); CA 26.0–32.0; PC unequal and pyriform, LPC 6.2–9.3 × 2.1–3.0; SPC 5.2–8.2 × 2.1–3.0.	*Channa gachua* Hamilton	WB
H. otolithi Ganapati, 1941	Bulbus arteriosus	SB oval; SBL 10.0–12.0 (16.1); WS 6.0–8.5; CA 35.0–40.0; PC equal and pyriform, 3.0–4.0 × 2.0–2.5, NC 5–6.	*Otolithes ruber* Bloch et Schneider	TN
H. qadrii Lalitha Kumari, 1965	Intestine	SB oval; SBL 9.2–12.3 (11.0); WS 4.6–5.4; CA 6.2–14.3 (9.8); PC unequal & pyriform, LPC 4.6–6.2 (5.3) × 1.2–1.8 (1.5); SPC 3.9–4.6 (4.5) × 1.2–1.9 (1.5).	*Channa gachua* Hamilton	AP
H. renalis Sarkar, Mazumder et Pramanik, 1985	Kidney	SB broadly oval, SBL 14.4–19.2 (16.8); WS 8.0–11.2 (9.8); CA 4.8–12.8 (7.9); PC equal and pyriform, 4.6–7.6 (5.74) × 2.5–5.1 (4.26).	*Channa marulius* Hamilton	WB
H. ritae Gupta et Khera, 1987	Branchial filament	SB oblongate, STL 39.9–44.8 (42.4); WS 5.0–5.8 (5.2); CA 27.2–31.5 (29.4); PC equal and pyriform, 5.0–5.8 (5.3) × 1.7–2.5 (1.9); NC 6–7.	*Rita rita* Hamilton	WB
H. rubicundi Haldar et Mukherjee, 1985		C cremy yellowish, 2000–1500 (D); SB elongate oval, STL 24.4–36.7 (31.2); WS 3.3–8.1 (5.5), CA 13.3–24.5 (19.7); PC equal and pyriform, 3.3–5.1 (3.7) × 2.2–3.0 (2.3); NC 6–8.	*Odontambliopus rubicundus* Hamilton	WB
H. singhi Lalitha Kumari, 1969	Gill filaments	SB elongate; SBL 11.1–13 (12.3); WS 3.9–5.7 (4.4); CA 30–48 (39); PC unequal and pyriform, LPC 4.8–6.4 (5.7) × 0.8–1.4 (1.1); SPC 3.5–5.5 (4.1) × 1.4–2.0 (1.6); NC 4–5.	*Notopterus notopterus* Pallas	AP
H. tachysuri Menon,1986	Branchial epithelium	C round or oval, white, 1000–3000 (D); SB ovoid, STL 47–60; SBL 12.0–15.0; WS 7.0–8.0; TS 5.0–6.0; CA 35.0–44.0; PC equal and pyriform, 6.0–7.0 × 2.0–3.0; NC 3–5.	*Channa punctata* Bloch	WB

H. thermalis Seenappa, Manohar et Prabhu, 1981	Brain tissue	SB pyriform; STL 47.0–60.0; SBL 12.0–13.2; WS 6.0–8.0; TS 5.0; CA 11.0–13.0; PC unequal; LPC pyriform, 4.0–5.0 × 2.0–3.0; SPC ovoid, 3.0–4.0 × 2.0.	*Lepidocephalichthys thermalis* Valenciennes	K
H. waltairensis Narasimhamurti et Kalavati, 1975	Gill filaments	SB oval; STL 55.0; SBL 14.6–15.5; WS 3.2–4.0; CA 40.0–50.0; PC equal and pyriform, 10.0–12.0 × 1.6–2.5, NC 6–7.	*Channa punctata* Bloch	AP, K
H. zahoori Bhatt et Siddiqui, 1964	Gill filaments	C spherical, whitish, 500 (D); SB biconvex; STL 20.0–30.6 (23.6); SBL 8.0–12.0 (9.6); WS 2.1–3.0 (2.6); CA 12.0–18.6 (13.9); PC equal and pyriform, 4.9–6.7 (5.8) × 0.7–1.1 (0.9).	*Channa punctata* Bloch	WB
Hennegoides senghalae Nissa et Kaur, 2021	Gills	C pale, thread like, 3000–5000; SB inverted pyriform; STL 7.5; WS 3.0–4.5 (3.8); CA (27.0–47.3); PC equal, 1.5 × 0.75, NC 3–4.	*Sperata seenghala* Sykes	P
Neohenneguya tetraradiata Tripathi, 1952	Gills	C irregular, 500; SB spindle-shaped 16.2–21.6 × 5.4; CA two long, equal at both ends 63.0–72.0; PC spherical, 2.0–2.7.	*Odontamblyopus rubicundus* Hamilton	WB
Phlogospora gulio Acharya, 2004	Gill lamellae	S pyriform; STL 40.2–56.5 (53.5); SBL 16.2–20.5 (19.8); WS 4.1–6.2 (5.9); CA 24.0–36.0; PC 9.1–12.3 (11.8) × 3.04.0 (3.5); NC 10–14.	*Mystus gulio* Hamilto	WB
P. mysti Qadri,1962	Gills	S Bunsen flame like; STL 35.0–42.0; SBL 14.0–18.0;	*Mystus bleekeri* Day	AP
P. oculatus Susha et Janardanan, 1995	Gills	S pear-shaped; STL 45.0–90.75 (65.7); SBL 13.5–24.0 (18.5); WS 2.7–3.5 (3.1); CA 30.8–68.3; PC single, ovoid, 7.5–13.2 (9.6) × 1.5–3.1 (2.4); NC 10–13.	*Mystus oculatus* Valencienne	K
Unicauda andharae Kalavati et Narasimhamurti,1981	Gills	SB oval, STL 38.4–47.3 (42.5); WS 4.0–5.4 (4.9); CA 20.8–24.5 (22.8); PC equal and pyriform, 5.0–6.4 (5.9) × 1.0–1.6 (1.2); NC 4–5.	*Channa gachua* Hamilton	AP
U. aplocheili Kalavati, Venkataeswara, Rao et Vaidehi, 1992	Scales	SB pyriform, STL 16.8–18.2 (16.9); SBL 9.8–11.2 (10.3); WS 5.6–7.0 (5.7); CA 5.6–8.4 (7.5); PC equal and elongated, 5.0–6.4 (5.9) × 1.2–1.6 (1.4); NC 4–5.	*Aplocheilus panchax* Hamilton	O
U. armati Gupta et Khera,1987	Gills	C yellow, round, 510 × 391; SB oval, SBL 7.5–9.0 (8.4); WS 5.6–7.0 (5.7); CA 8.0–15.0 (11.5); PC equal and pyriform, 2.0–3.0 (2.7) × 1.5–2.0 (1.6).	*Mastacembalus armatus* Lacépède	P
U. basiri Bhatt et Siddiqui, 1964		SB ovoid, STL 25.6–39.2 (34.3); WS 3.2–4.4 (3.7) CA 10.0–20.3 (15.3); PC equal, 5.0–7.4 (6.3) × 1.4–2.0 (1.7).	*Channa punctata* Bloch	WB
U. bengalensis Chaudhuri et Chakravarty, 1970	Upper buccal cavity	SB oblongate, STL 35.7–45.7 (39.4); WS 2.9–4.3 (4.0) CA 14.3–27.2 (21.5); PC equal, 6.0–7.2 (6.5) × 1.4–1.8 (1.5).	*Channa punctata* Bloch	WB
U. bicornuata Chaudhuri et Chakravarty, 1970	Branchial epithelium, Gills	SB oblongate, STL 26.4–29.2 (28.4); WS 2.8–3.9 (3.3); CA 11.5–13.8 (12.6); PC equal and pyriform, 3.3–3.6 (3.5) × 1.1–1.4 (1.2).	*Channa punctata* Bloch	AP
U. chaudhuryi Bajpai et Haldar, 1982	Gill filament	SB oblongate, STL 26.6–33.2 (30.0); WS 3.3–4.1 (3.7); CA 14.5–20.0 (17.7); PC equal and pyriform, 5.0–7.5 (6.0) × 1.6.	*Channa punctata* Bloch	WB
U. irregularis Haldar, Samal et Mukhopadhyay, 1997	Body muscles	SB pyriform, STL 24.0–39.1 (28.0); SBL 9.7–19.5 (13.3), WS 4.9–6.5 (5.1); CA 9.8–22.8 (14.8); PC equal and pyriform, 4.0–6.5 (5.0) × 1.6–4.0 (2.3).	*Mystus vittatus* Bloch	O
U. minuta Haldar, Samal et Mukhopadhyay, 1997	Gills	SB broadly elongated, STL 16.3–26.0 (20.9); SBL 8.1– 13.0 (9.4); WS 3.2–5.7 (4.1); CA 6.5–16.3 (11.4); PC equal and elongated, 1.6–4.9 (3.9) × 1.6–3.5 (2.2).	*Etroplus suratensis* Bloch	O
U. ritae Bajpai et Haldar, 1982	Gill filaments	SB oblongate, STL 39.9–44.8 (42.4); WS 5.0–5.8 (5.2); CA 27.2–31.5 (29.4); PC equal and pyriform, 5.0–5.8 (5.3) × 1.7–2.5(1.9).	*Rita rita* Hamilton	WB
U. theraponi Haldar, Samal et Mukhopadhyay, 1997	Gills	SB pyriform, STL 27.7–39.1 (33.3); SBL 14.6–22.8 (19.8) WS 4.0–8.1 (5.5); CA 8.1–19.5 (12.9); PC equal and pyriform, 4.9–8.1 (6.2) × 1.6–3.2 (2.5).	*Therapon jarbua* Forsskål	O

1b. Spores with two or more tail-like caudal processes or bifurcated tail; composed of same materials as shell valve 3
2a. Single tail-like caudal process; caudal process symmetrically located at the posterior end .... *Unicauda* Davis, 1944
2b. Single tail-like caudal process, which may be forked at the very end, originating posterolaterally and asymmetrically ..... *Laterocaudata* Chen et Hsieh, 1984
3a. Spores tear-shaped shaped, with a single polar capsule, caudal process bifurcated ..... *Phlogospora* Qadri, 1962
3b. Spores with two polar capsules and 2 caudal processes ... 4
3c. Spores with two polar capsules and 4 caudal processes ... 5
4a. Spores with two caudal processes .... *Henneguya* Thélohan, 1892
4b. Spores with two caudal processes, asymmetric .... *Hennegoides* Lom, Tonguthai et Dyková, 1991
4c. Spores with two caudal processes, extending in opposite directions ..... *Dicauda* Hoffman et Walker, 1978
5a. Spores ellipsoidal with two caudal processes at each end of the spore; polar capsules situated asymmetrically ....*Neohenneguya* Tripathi, 1953
5b. Spores with four posterolateral caudal processes, two from each shell valve .... *Tetrauronema* Wu, Wang et Jiang, 1988
5c. Spores rhomboidal with four caudal processes pointing in the opposite direction, connected by transverse filaments ..... *Trigonosporus* Hoshina, 1952

DISCUSSION

This study provides a synopsis on tailed Myxobolidae infecting freshwater and marine fishes of the Indian subcontinent based on available data along with their host, state records and brief spore description. In total 43 species in five genera are reported. It is noteworthy than more than half of the species (27) belongs to the genus *Henneguya*. This is not surprising because this genus is the second most-species rich of myxozoans and its species infect fish worldwide (Eiras 2002, Eiras and Adriano 2012). The present checklist may help in future studies for taxonomic identification and comparison with their related species of tailed Myxobolidae.

Concerning the pathogenicity, three species of *Henneguya*, *H. mystusia* Sarkar, 1985, *H. otolithi* Ganapati, 1941 and *H. waltairensis* Narasimhamurti et Kalavati, 1945, and one species of *Unicauda*, *U. aplocheili* Kalavati, Venkataeswara Rao et Vaidehi, 1992, were found to be highly pathogenic. Ulcerative body tissue in *Anabas testudineus* Bloch affected by *H. manipurensis* Hemanand, Meiti et Bandypadhyay, 2008 was also observed. In *Mystus* sp. functional disruption of gill lamellae was found, including dilatation of capillaries of primary gill lamellae, and atrophy of secondary gill lamellae caused by *H. mystusia* Sarkar, 1985. *Henneguya otolithi* Ganapati, 1941 infecting the heart of *Otolithus ruber* (Bloch et Schneider) causes damage in the heart, destruction of muscle fibres and is associated with fibroblast infiltration. *Henneguya waltairensis* induces hypertrophy of the gill epithelium and vacuolisation of the cell cytoplasm in *Channa punctata* (Bloch). The symptom of ulcerative skin is caused by *Unicauda aplocheili* Kalavati, Venkataeswara, Rao et Vaidehi, 1992 in *Aplocheilus panchax* Hamilton. In other species infections are not so detrimental or even are inapparent.

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Author contributions statement. All authors participated in the study design and collection of data. GDB and SC modified the key and were involved in bibliographic search from different sources, i.e. internet search and central library access. AKP and JCE planned and edited the manuscript. All authors had critically read and approved the final manuscript.

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