Myxosporeans and myxosporidiosis of common carp and gibel carp in China

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I. Initial stage: 1949-1959; description solely based on morphology of myxospores

II. Developmental stage: 1960-1998; traditional taxonomy, epidemiology, histopathology
Hallmark work: Publication of Fauna Sinica, Myxozoa, Myxosporea in 1998

III. Mature stage: 1998-2013; combined morphological and molecular characteristics, host, tissue tropism; molecular epidemiology; life cycle, ecology, host-parasite relationships;

IV. Progressive stage: 2013 afterwards; Genomic era; evolution; phylogenomic analysis; functional genomics
Hallmark work: available of full genome data of Thelohanellus kitauei; ongoing genomic project of Myxobolus honghuensis

Recorded 575 species in 23 genera 1998

Fauna Sinica
Myxozoa, Myxosporea
1998
2.7 million tons/year; third among freshwater cultured fish; About 70 myxosporean species reported.

Most only with simple morphological description.

2.2 million tons/year; Fifth; 100 species.
1. Myxosporean infecting common carp
2. Myxosporean infecting gibel carp
3. Life cycles of fish myxosporean in China since 2009;
Thelohanellus kitauei

Clinical signs,
Giant cystic diseases,
also in Japan, Korea, Israel
The Genome of the Myxosporean *Thelohanellus kitauei* Shows Adaptations to Nutrient Acquisition within Its Fish Host

Yalin Yang\(^1,\dagger\), Jie Xiong\(^2,\dagger\), Zhigang Zhou\(^1,*\), Fengmin Huo\(^1\), Wei Miao\(^2\), Chao Ran\(^1\), Yuchun Liu\(^1\), Jinyong Zhang\(^2\), Jingmei Fan\(^2\), Min Wang\(^3\), Ming Wang\(^4\), Lei Wang\(^4\), and Bin Yao\(^1,*\)

150.7 Mb, 5610 scaffolds
Correction of *M. dispar* as *M. musseliusae* Yakovchuk, 1979  
Infection site: gill filament  
Molecular data: JQ040301
**Myxobolus shangtungensis**

Redescription: *M. shantungensis* Hu, 1965;
Infection site: gill arche;
Molecular data: KJ725079

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**Myxobolus koi**

Redescription: *M. koi* Kudoa, 1919
Infection site: gill lamellae;
Molecular data: KJ725077
Myxobolus cyprinicola

Redescription: *M. cyprinicola* Reuss, 1966
Infection site: intestine wall
Molecular data: KJ725080
**Myxobolus pyramidis**

Redescription *M. pyramidis* Chen, 1958;
Infection site: gill lamellae
Molecular data: HQ613411

Showing plasmodium locating at the tip of gill filaments and spore in frontal and sutural view

Showing the location of plasmodium and no inflammatory responses besides mechanistic extrusion

Cluster in capillary network of gill lamellae-infecting clade
Myxobolus turpisrotundus n.sp.

Correction of *M. rotundus* recorded in China;
Infection site: connective tissue of gill arch, fins, intestine and body surface
Molecular data: EF690299, GU570996

Showing location of plasmodia and no severe host inflammatory response

Plasmodium being going to detach from the dorsal fins
**Henneguya doneci** n. sp.

Redescription *M. doneci* Schulman, 1962; Infection site: gill filaments
Molecular data: EU344898; HM146129; LC011456, JQ690376

Cited from Ye et al. 2012
**Myxobolus ampullicapsulatus** n. sp.

Infection site: gill filaments

Molecular data: DQ339482, KJ725082, KC425225

Showing tiny morphological and molecular difference between *M. ampullicapsulatus* and *M. honghuensis*
**Myxobolus wulii**

Synonyms: *Myxosoma magna* wu & Li, 1986; *Myxobolus quanqiaoensis* Wu & Wang, 1997;
Infection site: hepatopancreas
Molecular data: EF690300

Honeycomb-like hepatocyte completely replaced by mature spores
**Myxobolus honghuensis** n.sp.

Synonyms: *Myxosoma pharynae* Xiu & Lu 2013; *M. ampullicapsulatus* Jsa.a
Infection site: pharynx
Molecular data: KJ725074; JF340216

Tofukasu-like cysts

Many small plasmodia forming a big cyst

Cluster with species with elongate spore
**Myxobolus hearti**

Redescription
Infection site: myocardium
Molecular data: GU574808

![Image of infected tissue with Myxobolus hearti](image-url)

- Normal round plasmodium
- Unnormal plasmodium

Cluster with species with round spore

<table>
<thead>
<tr>
<th>Species</th>
<th>Genebank accession no.</th>
<th>Host species</th>
<th>Infection organ</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. erythrophthalmi</em></td>
<td>EU567311</td>
<td><em>Scardinius erythrophthalmus</em></td>
<td>renal interstitium</td>
<td>Balaton, Hungary</td>
</tr>
<tr>
<td><em>M. alburni</em></td>
<td>EU567131</td>
<td><em>Alburnus alburnus</em></td>
<td>fin</td>
<td>Balaton, Hungary</td>
</tr>
<tr>
<td><em>M. leuciscini</em></td>
<td>DQ439811</td>
<td><em>Leuciscus cephalus</em></td>
<td>heart</td>
<td>Balaton, Hungary</td>
</tr>
<tr>
<td><em>M. dogielii</em></td>
<td>EU003978</td>
<td><em>Abramis brama</em></td>
<td>intestine wall</td>
<td>Danube, Hungary</td>
</tr>
<tr>
<td><em>M. gayerae</em></td>
<td>DQ439809</td>
<td><em>Leuciscus cephalus</em></td>
<td>swimbladder</td>
<td>Danube, Hungary</td>
</tr>
<tr>
<td><em>M. cycloides</em></td>
<td>DQ439810</td>
<td><em>Leuciscus cephalus</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>M. diversiscopularis</em></td>
<td>GU968199</td>
<td><em>Rutilus rutilus</em></td>
<td>gill</td>
<td>Hungary</td>
</tr>
<tr>
<td><em>M. impressus</em></td>
<td>AF507970</td>
<td><em>Abramis brama</em></td>
<td>gill</td>
<td>Balaton, Hungary</td>
</tr>
<tr>
<td><em>M. rotundus</em></td>
<td>EU710583</td>
<td><em>Abramis brama</em></td>
<td>gill</td>
<td>Balaton, Hungary</td>
</tr>
<tr>
<td><em>M. basilamellaris</em></td>
<td>AF507971</td>
<td><em>Cyprinus carpio</em></td>
<td>gill</td>
<td>Japan</td>
</tr>
<tr>
<td><em>M. muskelia</em></td>
<td>FJ10801</td>
<td><em>Cyprinus carpio</em></td>
<td>gill</td>
<td>Hungary</td>
</tr>
<tr>
<td><em>M. pavlovskii</em></td>
<td>AF507973</td>
<td><em>Aristichthys nobilis</em></td>
<td>gill</td>
<td>Hungary</td>
</tr>
<tr>
<td><em>M. pavlovskii</em></td>
<td>HM991164</td>
<td><em>Hypophthalmichthys molitrix</em></td>
<td>gill</td>
<td>Hungary</td>
</tr>
<tr>
<td><em>M. turpinrotundus</em></td>
<td>EF690299</td>
<td><em>Carassius auratus gibello</em></td>
<td>subepidermal tissues</td>
<td>Ezhou, China</td>
</tr>
<tr>
<td><em>M. hearti</em></td>
<td>GU574808</td>
<td><em>Carassius auratus gibello</em></td>
<td>heart</td>
<td>Wuhan, China</td>
</tr>
</tbody>
</table>

Species with round spore:
Thelohanellus wangi n.sp.

Infection site: gill filaments
Molecular data: JX458816

Obvious epithelial hyperphasia at the anterior part of infected gill filaments and a thin connective tissue membrane delimited the plasmodium from cartilage cells of gill filaments.
**Thelohanellus wuhanensis** n. sp.

Infection site: skin  
Molecular data: JQ968687; JQ088179; HQ613410

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Raised plasmodium

Plasmodium

Membranous sheath surrounding spore cited from Liu et al. 2014

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Showing plasmodium developing in the stratum spongiosum of dermis and many melanocytes gathering together around the plasmodia.
*Thelohanellus testudineus* n. sp.

Infection site: skin

Molecular data: KC843624

Showing plasmodium developing in the dermis of the skin and distinct inflammatory infiltration,

Cluster in a *Thelohanellus* clade

Cited from Liu et al. 2013
Myxobolus oralis n. sp.

Infection site: oral cavity
Molecular data: KC315782

Cluster with species with round spore

Cited from Liu et al. 2014
**Henneguya globulata n.sp.**

Infection site: gill filaments

Molecular data: KJ725074; JF340216

**Myxobolus nielii** (Nie et Li, 1973) Landsberg et Lom, 1991

Infection site: gill filaments

Molecular data: KJ725074; JF340216

Phylogenetic relationship consistent with spore morphology (round spore body)
Life cycle study in China

- Firstly reported *Triactinomyxon* type from *Branchiura sowerbyi* (Wang et al. 2000)
  no molecular data

- Secondly *Triactinomyxon* type from *Branchiura sowerbyi* (Zhai et al. 2012)
  molecular data: HM107112
Firstly *Raabeia* type from *Branchiura sowerbyi* (Zhai et al. 2013; Xi et al. 2013) molecular data: AB121146; HQ613409

Firstly *Aurantiactinomyxon* type from *Branchiura sowerbyi* (Xi et al. 2013); molecular HQ613406
● Firstly *Guyenotia* type from *Branchiura sowerbyi* (Xi et al. 2013); molecular data unavailable

● Secondly *Raabeia* type from *Branchiura sowerbyi*
  molecular data: HQ613410
Firstly *Echinactionmyxon* type from *Branchiura sowerbyi*; molecular data: EF690300

Secondly *Echinactionmyxon* type from *Branchiura sowerbyi*; molecular data: unavailable
• Thirdly *Triactinomyxon* from *Branchiura*; molecular data: JX477771

• Firstly *Neoactinomyxum* type from *Branchiura sowerbyi*; molecular data: KP642135, JX458816
Molecular data match

Experimental infection and molecular match

Molecular data match

Molecular data match
Current severe myxosporidiosis of common carp in China

Giant cystic diseases caused by *Thelohanellus kitauei*

Infection prevalence: 70%;
Mortality rate: up to 90%, especially Northern China;
Infection season: from early August to late October, especially Autumn;
Economic losses: 50 million per year;
Control strategy: no practical way
1. Pharynx myxosporidiosis caused by *Myxobolus honghensis*

- Infection prevalence: 70%;
- Mortality rate: up to 100%, especially in Northern Jiangsu Province;
- Infection season: from early May to late October, especially summer;
- Economic losses: 2 billion per year;
- Control strategy: blocking the transmission and inactivating the infective actinospores by Ino-org;
2. Gill myxosporidiosis caused by *Thelohanellus wangi*

- Infection prevalence: 60%
- Mortality rate: up to 100%, especially under anoxia, crowded or other stress
- Infection season: only from early April to late June on fry fish below 7cm in body length
- Economic losses: 10 million per year
- Control strategy: blocking the transmission and inactivating the infective actinospores by Ino-org
Skin myxosporidiosis caused by *Thelohanellus wuhanensis*

- Infection prevalence: 70%
- Mortality rate: no directly lethal, but up to 100% under anoxia, crowded or other stress conditions
- Infection season: only from early April to late June on fry fish below 7cm in body length
- Economic losses: 10 million per year
- Control strategy: blocking the transmission and inactivating the infective actinospores by Ino-org
Acknowledge

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Thank you for your attention