A review on the biology and physiology of loach *Misgurnus anguillicaudatus* in China

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*Misgurnus anguillicaudatus* (Cantor 1842) is the most common loach in the world, habitually, available in Asian regions like China, Korea, India, and Japan. It lives in streams and rice paddy fields, preferably with a soft muddy bottom. The body of a typical loach is elongated with five pairs of barbs surrounding the mouth, and a single short-based dorsal fin. This species is omnivorous and source of diet usually varies from fish and insects, to plant detritus. The fish spawn multiple times per year during a spawning season that lasts from mid-April until mid-October. *M. anguillicaudatus* diploid individuals (2n=50) are common in wild populations. Different polyploidy populations have been reported in various locations in China. It has a delicious taste with high nutritional value, used as a traditional Chinese medicine. The most serious problem in both loach hatcheries and farms is bleeding in head, opercula, and lower jaw, swollen muscles, anus, liver, and spleen, and empty intestines. Characterization and expression profiles of tissue-specific immune genes are highly useful in understanding gene functions, tissue physiology, and transcriptomics of *M. anguillicaudatus*.

**Keywords:** *Misgurnus anguillicaudatus*; Loach; Teleost; Diploid

**Introduction**

China has a long history of reservoir fishery activities. Many reservoirs have been constructed in China since 1950 for various purposes and are also used as important resources for fishery development. The earliest stocking activity of fish seed collected from rivers took place in Dong Qian Hu reservoir, which was impounded some 1000 years ago in the Zhejiang province. At present, reservoir fisheries have become an important component of the fishery industry in China, making a substantial contribution to people’s fish supplies and rural livelihoods. Environmental conservation and wise use of resources are of major concern in developmental activities.

*Misgurnus anguillicaudatus* (*M. anguillicaudatus*) is an autochthonous freshwater fish from eastern Asia. The production of *M. anguillicaudatus* is of great demand, since they are used both for traditional Chinese medicine and food, especially in China, Japan, and Korea. It is commonly called a Pond loach, Oriental weather fish, Oriental weather loach, loach (Chinese Academy Fishery Science 2003) dojo, dojo loach, Japanese Loach. *M. anguillicaudatus* tend to mature very rapidly, possessing an omnivorous digestive system, can live closely packed together, one of the most sought after fish with high market value. So, only a few decades ago, loach fish have been farmed down in Japan. Loach farms have been transformed from earth ditches to concrete ditches, migration is made impossible due to such confinement, and many different chemicals used in the farming process has caused a short life span and reproduction abilities within the fish themselves. Many of the habitats and environments were loach fish thrive have been cultivated into farms for distribution to other countries, such as Korea, and Japan. This species are now one of the most commercially viable options for farmers and fisheries. Circa 1990s, a process and system were implemented in order to allow a full life for loach fish raised in fisheries and as of 2010, more than 204 552 tons were measured and recorded.

**Distribution**

Loach fish (in their native habitats) can be found in a number of locations around the world; but,
predominantly appear in, Korea, China, India, Thailand, Vietnam, Laos, Siberia, Japan, Cambodia, and Taiwan\textsuperscript{10,16,17,18}. Loach fish have been introduced and recorded in countries such as Australia\textsuperscript{19}, Hawaii\textsuperscript{20}, mainland USA\textsuperscript{21}, Mexico and Palau\textsuperscript{22}, the Philippines\textsuperscript{23}, Turkmenistan\textsuperscript{24}, Germany\textsuperscript{25}, Italy\textsuperscript{26} and Spain\textsuperscript{27}, and the Netherlands\textsuperscript{28}. The Loach \textit{M. anguillicaudatus} (Cypriniformes; Cobitidae), is a teleost, found in a number of freshwater areas; but, most predominantly in ditches, rice paddy fields, streams, and places with mud and soft earth\textsuperscript{29,10,11,13}. Due to its highly tolerable environmental nature, fisheries and cultivation of the species has tremendously increased. It can live at temperatures anywhere from 2 to 30 °C and breathes atmospheric oxygen through a gut located in their hind quarter. The loach is able to survive outside water for short time, and during drought situations, it hides into the mud until water availability\textsuperscript{30}

The loach fish is an instantly recognizable creature, due to the 5 barbs found around its mouth, a short, dorsal fin, and a long body (Figure 1). Males who have matured also possess a long, thick pectoral ray\textsuperscript{31}. \textit{M. anguillicaudatus}, though similar in appearance, can be told apart from different forms and species of Misgurnus, due to three distinct characteristics, morphological in nature\textsuperscript{17}.

1. Missing a thin stripe from the pelvis to the abdomen.
2. Odd spots located on the body, dark in color.
3. Large spot, dark in color, located on the caudal base (upper section) and a caudal peduncle featuring some crests (low adipose).

Oriental weather fish are benthic omnivores that generally feed on insect larvae, snails, worms, ostracods, cladocerans, fish eggs, algae and detritus\textsuperscript{4}. Kim \textit{et al.} demonstrated that \textit{M. anguillicaudatus} readily and efficiently consume mosquito larvae and have successfully used them to control mosquito populations in South Korea\textsuperscript{32}. Tabor \textit{et al.} found that in their invaded range in Washington, their diets primarily consisted of crustaceans, such as amphipods and cladocerans, as well as chironomids with minimal detritus and plant matter\textsuperscript{16}. However, in another study, non-native fish in Australia were found with higher levels of algae and detritus in their stomachs\textsuperscript{33}. It was reported that loach can successfully wean to formulated feeds that is feeding larval loach with enriched cladocerans supplemented with formulated feed after 30 days\textsuperscript{34}.

Reproduction

This species is primarily nocturnal, spending most of the day burrowed into mud from where it emerges at night to feed and mate. These fish, like many other cypriniform fish, are generally considered selected organisms in that they mature quickly, reproduce multiple times, and produce a great number of offspring. Members of this species are sexually distinct and reproduce sexually. Males of the species mature rapidly within a year and females mature within one or two years\textsuperscript{35}. In their native range, these fish spawn multiple times per year during a spawning season lasting from mid-April until mid-October. Reproduction occurs at night in which the male locates a female based on scent and wraps his body around the female stimulating her to release a cloud of eggs that he rapidly fertilizes\textsuperscript{36}. The loach usually lives in ditches and streams around paddy fields, immigrating into water-laden paddies in order to lay its eggs in the summer\textsuperscript{10,11,12}. The female produces 1800-15500 eggs per batch with an average survival of 2000 eggs per batch\textsuperscript{31,37}. The eggs are small with a diameter of 800-850mm and are reddish in color with adhesive properties, however they are broadcast into the water column upon conception\textsuperscript{37}. Eggs hatch within 30 hours and larvae remain in water columns for a short period before settling at the bottom\textsuperscript{38}.

Fig. 1 — Lateral view of Misgurnus anguillicaudatus (Cantor, 1842).
Ploidy
As to the loach, diploid individuals (2n=50) are common in wild populations of Japan and a small number of tetraploids (4n=100) have been found among specimens obtained from fish dealers. In China, populations of both diploid (2n=50) and tetraploid (4n=100) loaches have been recorded. Different polyploidy population was reported in various locations in China, diploid population in Sichuan, Guangxi, Heilongjiang, Hebei and Shenglongjia, Zhijiang, Wuhan city, Chibi and Honghu and Chang Jiang River (Hubei province), triploid population in Hohhot, Neimenggu, Tianjin, Hangzhou, Zhejiang, Chibi, Hubei, Honghu, Hubei and Shashi, Hubei, tetraploid population in Wuhan, Shashi, Zhijiang, Wuhan city, Chibi and Honghu and Chang Jiang river (Hubei Province) pentaploidy population in Liangzi Lake area, Yangtze River Basin, hexaploid population in Hubei and also triploid population in Japan. Higher polyploid loaches, such as pentaploids and hexaploids, have been produced by fertilization and manipulation strategies using diploid gametes from the natural tetraploid loach. The previous and present cytogenetic results are summarized in Table 1.

Haematology
In fishery management, a high importance can be placed on cross examining both the status and health of loach fish and some noteworthy conditions have been found in their blood as shown in Table 2. They have been observed to retain high amounts of mature erythrocytes over immature ones. This could also lead to the fact that dissolved oxygen becoming a problem where certain disasters (of an environmental nature) can decrease specific anemic systems. This could be a great indicator to reticulocyte count and its regenerative reaction.

Medicinal Value
Since 1950s, mud loach are consumed as a delicious fish food with high nutritional value and as a traditional Chinese medicine. *M. anguillicaudatus* was widely cultured in the Jiangsu province of China, bringing great profit to their economy in recent years. The loach, for a long time, had been employed as traditional Chinese medicine in folk remedies for treatment of hepatitis, osteomyelitis, carbuncles, inflammations, and cancers, as well as for restoration of health in debilities caused by various pathogens and aging. Some active substances obtained from loach were found to be of high medical value. Studies on the medicinal values of loach showed at various compounds by several authors (Table 3).
Diseases

Bacterial infection is a common and serious economic problem in the cultivation of *M. anguillicaudatus*. Mud loach are susceptible to a wide range of bacterial infections. Mortality has been reported on *M. anguillicaudatus* living in different habitats for many decades. A serious mortality of cultured loach *M. anguillicaudatus* occurred in farms of Donghai County, Jiangsu Province in October 2008 and 2010. Currently, the most serious problem in both loach hatcheries and farms are bleeding in the head, opercula, and ulcer foci. There are reports of hemorrhages at the body surface (including base of fin, head, mouth, and abdomen), ulceration of muscles, and high-level mortalities of loach *M. anguillicaudatus* occurred in farms of Donghai County, Jiangsu Province in October 2008 and 2010. Currently, the most serious problem in both loach hatcheries and farms are bleeding in the head, opercula, and ulcer foci. There are reports of hemorrhages at the body surface (including base of fin, head, mouth, and abdomen), ulceration of muscles, and high-level mortalities of loach *M. anguillicaudatus* cultured in China. Another important bacterial infection is the epizootic ulcerative syndrome. Owing to the intensive culture, bacterial infections often occurred which resulted in serious losses. Recently, it was reported that *Vibrio* sp. infected *M. anguillicaudatus* in some loach farms of China. Table 4 gives a summary of the bacteria affecting freshwater loach.

A pathogenic Asian nematode species of *Camallanus, C. Cotti* Fujita, 1927, were collected from aquarium-kept *M. anguillicaudatus* and deposited by Dr. N. P. Boyce in 1979. *Clinostomum Complanatum* (Rudulphi, 1819) is a digenetic trematode which causes yellow grubs in the muscle of *M. anguillicaudatus* and makes them unsuitable for human consumption. Mass mortalities have been reported in *M. anguillicaudatus* due to infection by *Centrocestus Formosanus*, a trematode parasite. *Lernaea cyprinacea* (anchor worm), an ectoparasitic crustacean, causes infections in skin and the buccal cavity wall of *M. anguillicaudatus*, which makes the fish susceptible to secondary infections of bacteria.

Subclinical covert infectious pancreatic necrosis (IPN), a highly contagious viral disease caused by IPNV and a bi-segmented double-stranded RNA virus belonging to the family Birnaviridae, have been detected in *M. anguillicaudatus*.

Conclusions

*M. anguillicaudatus* is one of the most important aquaculture species in China. The frequent outbreaks of disease have caused decreased production and economic losses. Studies on molecular mechanisms of this fish may be conducive to the development of better aquaculture management strategies in *Misgurnus* farming. However, the gene sequence information of *M. anguillicaudatus* available in the public database is not extensive. DNA library construction and analysis of Expressed Sequence Tags (ESTs) are efficient approaches for collecting genomic information and identifying immune genes. The characterization of all tissue-specific immune genes and their expression profiles are highly useful.
in understanding gene functions, tissue physiology, and transcriptomics of *M. anguillicaudatus*.

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