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Review articles

Microparasites of worldwide mullets

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ABSTRACT. The present review is focus on parasitic organisms, previously considered as protozoans. Viral, prokaryotic and fungal parasites caused diseases and disorders of worldwide mullets were also observed. Most of the known viruses associated with a high mortality of mullets were detected in *Mugil cephalus*. Prokaryotic microparasites were registered in *M. cephalus*, *Moolgarda cunnesiu*, *Liza ramada* and *Mugil liza*. Fungal pathogens were associated with representatives of the genera *Aphanomyces*, *Achlya*, *Phialemonium*, *Ichthyophonus*. *Ichthyophonus* sp. can be considered as a potential threat for marine fish aquaculture, especially in culture conditions. A new hyperparasitic microsporidium like organism was recorded in myxozoan *Myxobolus parvus* infecting grey mullet *Liza haematocheilus* in the Russian coastal zone of the Sea of Japan. The protozoan representatives of the phyla Dinoflagellata, Euglenozoa, Ciliophora and Apicomplexa were reviewed and analyzed. The review of myxosporean parasites from grey mullets includes 64 species belonging to 13 genera and 9 families infecting 16 fish species

Key words: worldwide mullets, microparasites, diseases and disorders

Introduction

Separation of microparasites from other parasites based mostly on epidemiological grounds [1,2]. Microparasites are characterized by their ability to reproduce directly within individuals of hosts, their small size and a relatively short duration of infection, and the production of an immune response in infected and recovered individuals [3]. They possess a very short generation time in comparison with their hosts. Microparasites can include prokaryotic and eukaryotic microorganisms, such as viruses, parasitic bacteria, fungi, protozoan and some groups of former protozoans (Myxozoa, Microsporidia).

The mullets (Mugiliformes: Mugilidae) have a worldwide distribution and have been used as a significant source of food in different parts of the world. So far, a few revisionary studies of parasites infecting worldwide mullets have been conducted [4–6]. Information about microparasites also can be found in reports dedicated to selected groups of fish parasites [7–12]. The central purpose of the present review is to explore the biodiversity and pathogenic importance of microparasites, infecting mullets based on existing data and original material obtained during parasitological investigations of mullets. The six-kingdom system of life, revised by Cavalier-Smith [13] is used for establishing of taxonomic location of reviewed microparasites.

Short overview of viral and prokaryotic microparasites

Most of the known fish pathogenic viruses occur in marine fish [10]. *Lymphocystis* sp. was firstly detected in *Mugil cephalus* L. by Alexandrawicz [14]. Viral nervous necrosis (VNN) was detected in *Mugil cephalus* by Ucko et al. [15] in Israel mariculture. Viral diseases cause the mortality of golden grey mullets in the Caspian Sea associated with piscine nodavirus infection, which was described by Zorriehzahra et al. [16]. A systemic iridoviral disease associated with a high mortality was initially recognized in kidneys of the cultured mullet, *Mugil cephalus* in Singapore [17].

Prokaryotic microparasites of mullets were occasionally registered infecting mostly maricultured mullets. *Pasteurella*-like bacterium causing mortality of *M. cephalus* was registered in USA [18]. *Streptococcus* sp. was named as pathogen, caused mortality of mullets and other fishes in USA [19]. Other *Streptococcus* sp. has been associated with mortality in mullets *Liza ramada* (Risso) and *Mugil cephalus* [10]. *Streptococcus agalactiae* Lehmann and Neumann was recorded as dangerous pathogen of *Liza klunzingeri* (Day) in Kuwait Bay [20]. Representatives of the genera *Achromobacter*, *Escherichia*, *and Aeromonas* were isolated from *Moolgarda cunnesiu* (Valenciennes) (=*Mugil cunnesius*) by Almeida and collaborators [21]. *Pseudomonas* and *Vibrio* infections were registered in mullets by Lewis (in Paperna and Overstreet 1981) [4]. Bacterial strains belonging to the genera *Micrococcus*, *Pseudomonas*, *Flavobacterium*, *Aeromonas* and *Vibrio* were isolated from the kidney and the liver of *Mugil liza* Valenciennes (=*Mugil platanus*), captured in Sao Paulo State, Brazil [22]. Mullets were also counted as vectors of bacterial diseases in man, caused by *Aeromonas hydrophilia* (Chester), *Mycobacterium marinum* Aronson, *M. fortuitum* Da Costa Cruz, *Vibrio parahaemolyticus* (Fujino), *Erysipelothrix rhusiopathiae* Uhlenbuch et Fromme and *Leptospira icterohaemorhagiae* (Buchanan) [4]. *Streptococcus* sp., *Vibrio* sp., *Lactococcus garvieae* (Collins et al.) and *Aeromonas hydrophila* caused diseases in *M. cephalus* were isolated in Taiwan [23,24]. Various bacteria, including *Aeromonas* spp., *Alcaligenes* spp., *Pseudomonas* spp. and *Vibrio* spp. associated with red spot diseases (RSD) were recovered from lesions of *Mugil cephalus* in north-east New South Wales, Australia [25]. *Mycobacterium* spp. and *Photobacterium damselae* subsp. *piscicida* (Janssen et Surgalla) were recognized as the most frequent causative agent of granulomatous lesions of wild mullet populations from the eastern Ligurian Sea (Italy) [26].

More detailed information about viral and bacterial diseases of fish, including mullets, were gathered in respective reviews of Sindermann [5] and Woo et al. [6].

Fungal pathogens

Fungal pathogen associated with reflex sympathetic dystrophy syndrome (RSD) was firstly recorded in *M. cephalus* from eastern Australia [27]. The role of fungi *Aphanomyces invadans* Willoughby et al., *Achlya bisexualis* Coker and Couch, and *Phialemonium dimorphosporum* Gams and Cooke in the etiology of ulcerative mycosis in *Mugil cephalus* collected from several estuaries and rivers in Florida (USA) was investigated by Sosa et al. [28]. Fungal diseases of mullets caused by *Ichthyophonus* sp. were originated in grey mullet in South Africa [29] and the Mediterranean [30]. The morphology and ultrastructure of this parasite collected from *Liza ramada* (=*Mugil capito*) and *Liza saliens* (Risso) were studied by Franko-Sierra and Alvarez-Pellitero [31]. *Ichthyophonus* sp. can be considered as a potential threat for marine fish aquaculture, especially in culture conditions. This parasite infects hematopoietic organs of fish, namely: kidney, liver, heart, spleen, skin, gills, gall bladder, swim bladder, muscle, pancreas, stomach, and intestine. In case of *Liza ramada* mortalities reached up to 30% of fish infected by *Ichthyophonus* sp. [30].

Phylum Microsporidia Balbiani, 1882 includes highly specialized eukaryotic unicells, living only as obligate intracellular parasites of other eukaryotes [32]. While the view that microsporidia are related to fungi seems to be generally accepted, the recent studies show that microsporidia presents a monophyletic sister group to Fungi [33]. Microsporidia are known as parasites of most of phyla of invertebrates and all classes of vertebrates [8,34]. Microsporidian infections can cause direct loss by high mortality of infected fish and reduction of their marketing value [35].

At least four species of Microsporidia parasitizing mullets were recorded to date.

Due to the degeneration of muscles infected by *Pleistophora destruens* Delphy, lateral curvature (scoliosis) in *Liza aurata* (Risso) were described in 1916 near the Atlantic coast of France [36]. No data excluding short morphological characteristic of the spores were presented by this author.

Microgemma hepaticus Ralphs, Matthews was described in *Chelon labrosus* (Risso) from Cornwall coastal waters, England. The microsporidium infects hepatic cells causing the necrosis and the inflammatory reaction leading to the granuloma formation [37].

Microsporidium (=*Nosema*) *valamugili* Kalavati, Lakshminrayana was described from intestine of *Valamugil* sp. in Andra Pradesh from coastal estuaries, India [38]. No data about pathogenicity were revealed. Taxonomic position of this microsporidium requires clarification [32].

Microsporidium *Loma mugili* Ovcharenko et al.

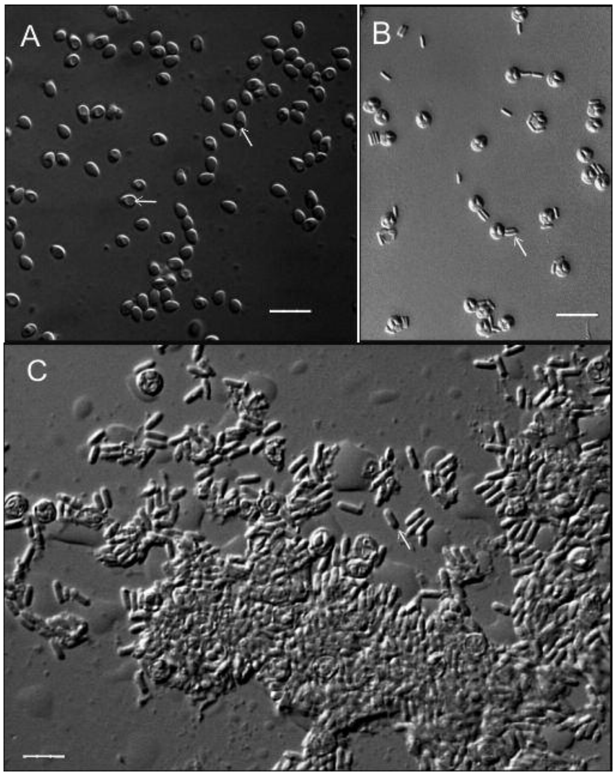

Fig. 1. Undetected new microsporidia from *Liza aurata* (A), and *Myxobolus parvus* (B, C).
A. Live monomorphic spores with big posterior vacuole (arrow). Spores are separated or aggregated into irregular clusters and chains.
B. Hyperparasitic microsporidium from myxozoan *Myxobolus parvus* infecting grey mullet *Liza haematocheilus*. Most of the spores were glued to the spore surface of myxozoans (arrow).
C. Interference contrast micrograph of infected plasmodium of *Myxobolus parvus*. Destructed sporogonic plasmodium is filled by elongate spores of microsporidium.
Bars: 6.5 mμ (A); 20 mμ (B); 12 mμ (C).

was detected causing mortality of juvenile *Liza haematocheilus* (Temminck et Schlegel) (=*Mugil so-iuy*) from Azov Sea, Ukraine. Sporogony of parasites occurs inside of parasitophorous vesicles located in cytoplasm of endothelial cells of gill lamellae [39].

Undetected *Pleistophora* like microsporidium was registered by Paperna and Overstreet in *Crenimugil crenilabis* (Forsskål) from the Red Sea [4]. Spores of microsporidium always occurred in association with the myxozoan *Kudoa* sp. in the intestinal wall of the host.

Another undetected microsporidium we found in our samples of parasites from the Ebro Delta, Spain in May 2004 ex *Liza aurata* (Fig. 1A). Live spores were ovoid with a big posterior vacuole (PV). Giemza stained spores of parasites measured 3.13±0.25 (2.62–3.60) × 2.05±0.17 (1.75–2.47) µm. Monomorphic spores were separated or aggregated into irregular clusters.

A hyperparasitic microsporidium like organism was isolated from myxozoan *Myxobolus parvus* infecting grey mullet *Liza haematocheilus* in the Russian coastal zone of the Sea of Japan, the Razdolnaja River (4°35'N, 32°16E'). Hyperparasite produced elongate spores, measuring 6.4±0.5 (5.1–7.5) × 2.9±0.3 (2.2–3.6) µm. Most of the spores were glued to the spore surface of myxozoans (Fig.1B). Destructed sporogonic plasmodium of *M. parvus* was filled by elongate spores produced by hyperparasite (Fig.1B). Species we found differs from all documented microsporidians infecting Myxozoa (*Nosema ceratomyxae* Diamant and Paperna, *N. notabilis* Kudo, *N. marionis* (Thelohan), and three unnamed Microsporidia) by the shape and spore dimensions and by the host infected.

Protozoan parasites of mullets

Phylum Dinoflagellata Bütschli includes more than 2000 species. About 140 of them are parasites of mostly invertebrate hosts [9]. Three genera (*Amyloodinium*, *Piscinoodinium*, *Ichthyodinium*) are known as economic importance of fish parasites [40]. *Amyloodinium ocellatum* (Brown) and closely related species were reported parasitizing *Mugil cephalus* in Mississippi, Gulf of Mexico, Pacific Ocean [41–43]. The parasite produces a powdery or velvety appearance on gills and skin of infected fish, caused "velvet disease" (amyloodiniosis). It can cause devastating disease and mortality of infected fish [40]. Epizootics have been reported in wild and cultured fish. Water from an outside source may contain dinospores of parasites. The free-swimming dinospores are susceptible to chemotherapy using copper ions, formaline and other agents [42,44]. Treatment with the hydrogen peroxide (75–150 mg/l) eliminated trofonts of *Amyloodinium* without of mortality of infected mullets [45].

Representatives of the genera *Ichthyobodo*, *Cryptobia* and *Trypanosoma* from the phylum Phylum Euglenozoa Cavalier-Smith are known to cause diseases of freshwater and marine fishes [46]. *Cryptobia* sp. was registered infecting the gills of *Moolgarda seheli* (Forsskĺl) (=*Valiamugil seheli*) and *Mugil cephalus* in the Red Sea with low pathological effects [4]. *Hexamita* sp. was also mentioned by Paperna and Overstreet in the intestinal epithelial tissue of juvenile *Liza subviridis* (Valenciennes) (=*Mugil subviridis*) from the Gulf of Eilat, Israel [4]. Pathological aspects of infections have not been studied. *Trypanosoma froesi* Lima was detected from the blood of *Mugil liza* in Brasil [47]. *Trypanosoma mugilicola* Becker and Overstreet is widespread infecting the blood of *Mugil cephalus* in the northern Gulf of Mexico [48], and in lagoons and rivers of southern Africa [49]. Undetected trypanosomes were mentioned by last cited authors in the blood of *Liza richardsonii* (Smith) from the Kowei Lagoon, Southeastern Cape, South Africa.

Phylum Ciliophora Doflein, 1901 contains more than 7000 know species. Few of them are opportunistic parasites. More than 90 species of marine fish including *Chelon labrosus* and *Liza ramada* were registered as the hosts of *Cryptocaryon irritans* Brown [50,51]. The parasite prompts "white spot diseases" by destruction of infected body surface, fins, eyes, and gills. Cryptocaryoniasis appears to be primarily diseases of fishes in tropical environments, and it does not occur in water with temperature below 19° C [52].

Trichodiniidae are widespread ectocommensals of marine and freshwater hosts. A massive number of trichodins can seriously damage the epithelial or epidermal cells. They may even penetrate into the gills and skin [7]. At least eight species were recorded in mugilid hosts. *Trichodinella inversa* (Dogiel) infects *Lisa saliens* in Black Sea [53]. *Trichodina lepsi* Lom was recorded in *Mugil cephalus*, *Liza aurata* and *L. saliens* in the Black, Azov, and Caspian Seas [11]. *Mugil cephalus* and *Liza saliens* was mentioned as hosts of *T. micromaculata* Shtein and *Trichodina partidisci* (Lom) in the Black Sea [54]. *Trichodina liaochoensis* Chen and *Trichodina mankingensis* Chen, Hsieh were described in *Liza haematocheilus* and *Mugil cephalus* from the Liao-Ho River, China [55]. *Trichodina puytoraci* Lom was registered in *Liza saliens* and *Mugil cephalus* in the Black Sea and saline lakes of Romania and Georgia [56]. Three species of trichodins (*Trichodina lepsi*, *T. puytoraci and T. batala* Ali) were registered in Egyptian *M. cephalus* [57]. Ciliophorans *Amphileptus macrostoma* Chen and *Capriniana liaohoensis* Chen was detected in *L. haematocheilus* from the Liao-Ho River, China [55]. *Liza saliens* was mentioned as a host of *Tetrahymena pyriformis* Ehrenberg in the Black Sea. Parasite causes destructions of surface tissues and sometimes inner organs.

Presence of at least six species of ciliophorans (*Tetrahymena pyriformis*, *Ambiphrya ameiuri* Thompson, Kirkegaard and Jahn, *Trichodina ovonucleata* Raabe, *T. pediculus* Ehrenberg, *T. puytoraci*, *T. jadranica* Raabe) was revealed in *L. haematocheilus* after its introduction in the Black-Sea region [58].

Phylum Apicomplexa Levine, 1970 includes a large group of unicellular spore forming parasites of animals. Fish apicomplexans are divided into two major groups located in intestine (Coccidia) and bloodstreams (Adeleidae) of freshwater and marine fish [59–61]. Spore formation of Adeleid parasites take place in invertebrates. The majority of fish coccidians have a relatively low pathogenicity. Lethal infections occur primarily in fish farm ponds, and rarely in natural waters [60,61]. At least three species of haemogregarines were described from blood cells of worldwide mullets. *Haemogregarina mugili* Carini infects *Liza dumerili* (Steindachner) (=*Mugil brasiliensis*) in Brasil [62], *M. cephalus* in Florida [63], *Mugil liza*, and *M. cephalus* in lagoons and estuarine waters, near Săo Paulo, Brazil [64] and *Mugil* sp. in the South Pacific [65]. *Haemogregarina bigemina* Laveran and Mesnil was found by Saunders in *Mugil trichodon* Poey in the Bahamas [66]. Also *H. bigemina* was recorded in more than 90 fish species from 70 genera inhabiting European, North American and South African coasts, the Red Sea and the South Pacific Ocean [11]. Third species *Dactylosoma hannesi* Paperna was found in erythrocytes of grey mullet (*M. cephalus*) from South Africa [67]. Intestinal coccidian parasite *Eimeria* sp. was recorded in grey mullets from the Caspian Sea [59].

Myxozoan parasites

Phylum Myxozoa Grassé includes a diverse group of endoparasites of controversial phylogenetic position. One hypothesis, supported by ribosomal DNA (rDNA) data, place Myxozoa as a sister taxon to Bilateria. The alternative hypothesis, supported by phylogenomic data and morphology, place Myxozoa within Cnidaria [68]. Myxozoa represents one of the economically important and diverse groups of parasites infecting worldwide mullets [11,69]. Parasite life cycles includes vertebrate (commonly fish) and invertebrate hosts (oligochaetes, polychaetes). The recent review of myxosporean parasites from grey mullets reported there 64 species belonging to 13 genera and 9 families infecting 16 fish species from six genera [12].

Twenty species were recorded infecting gills. Four of them were detected exclusively in tissues of gill filaments. Three species: *Myxobolus bizerti* Bahri and Marques, *M. goensis* Eiras and D'Souza, *M. nile* Negm-Eldim, Govedich and Davies, were found in *Mugil cephalus* [70–72]. *Myxobolus parenzani* (Parenzan) was described in *Chelon labrosus* from Mediterranean region [73,74].

Henneguya ouakamensis (Kpatcha et al.) infects heart and gill of *Mugil cephalus* off the Atlantic coast of Senegal [75]. Gill filaments, the kidney and the spleen of *Mugil cephalus* inhabiting the Black Sea and the Caspian Sea were infected by *Myxobolus branchialis* (Markevitsch) [76–78]. Other records demonstrated multiple sites of infection including gills [12]. *Myx. episquamalis* Egusa, Maeno and Sorimachi infects beneath the scales, fins, and gill arches of *Mugil cephalus. Myxobolus achmerovi* Schulman was found in fins, gills, and mesentery of *M. cephalus*, and *L. haematocheila. Myx. adeli* Yurakhno and Ovcharenko was described infecting intestine, swim bladder, pyloric caeca, oesophagus, stomach, and gills of *L. aurata.* Connective tissue of spleen, kidney, gall bladder, swim bladder, intestine, intestinal mesentery, and gills of *Liza* aurata*,* and *L. ramada* was detected as site of *Kudoa trifolia* Holzer et al. *Myxobolus spinacurvarura* Maeno et al. was recorded in intestine, liver, intrahepatic bile ducts and gall bladder, spleen, mesentery, mesenteric vessels, brain, liver, spleen, pancreas, and gill filaments of *M. cephalus.* Digestive organs, excretory system, skin, body cavity, heart and other organs of mullets were mentioned as the site of localization of *Myxobolus bramae* Reus, *Myx. circulus* (Achmerov), *Myx. exiguus* Thélohan, *Myx. parvus,* Schulman, *Myx. rotundus* Nemeczek, *Myx. spinacurvatura*. Gills, muscles, skin, and inner organs including mesentery, intestine, gall and urinary bladders, liver, kidney, gonads, spleen, eyes, fins, heart were recorded as the sites of *Myxobolus muelleri* Bütschli. Pathological changes associated with the myxozoan infection in the gills include fusion of lamellae, inflammation, hyperplasia, pressure atrophy and cellular necrosis [6]. An epizootic among wild populations of mullets has been recorded in the northern Black Sea, due to the myxosporidian *Myxobolus exiguus* [76]. *Myxobolus exiguus* was also recorded in worldwide *Ch. labrosus, L. aurata, L. saliens* and *L. ramada* [12].

Infection of the scales caused by *Myxobolus acutus* (Fujita) was recorded in *Mugil cephalus* and *Liza haematocheilus* in Japan Sea [79,80]. Skin of *Moolgarda seheli* inhabiting the Andaman Sea (Thailand) was also infected by *Myxobolus supamattayai* Kittichon et al. [81]. The multiple infection including skin and scales were registered in *Mugil cephalus* infected by *Myxobolus exiguus*, *M. ichkeulensis* Bahri and Marques, *M. episquamalis* and *M. bramae* from Mediterranean waters [70,82]; and from the Black-Sea region [78,83]. *M. episquamalis* can lead to erosion of the scales and attenuation of the dermis [82]. The myxozoan infection can cause the loss of an aesthetic quality of fish [84].

Pathological changes of the myxozoan infection of muscles range from the minimal host response to the mortality and musculature destructions. Twelve species of Myxozoa from two genera were recorded in musculature and other organs of worldwide mullets. Three of them were detected exclusively in body muscles. *Kudoa bora* (Fujita) was described by Fujita [85] from *M. cephalus* and *Liza carinata* (Valenciennes) of the Pacific coastal waters, in Taiwan. *Mugil cephalus* was recorded as the host of *Kudoa quadratum* (Thélohan) in the Black Sea [78]. Infection of others twelve marine not mugilid hosts of these myxozoan parasites were also recorded in the Eastern North Atlantic Ocean (European coast), Mediterranean, Black (Karadag, Sevastopol) and White Seas, and the Indian Ocean [11,86–88]. Trunk muscles of *M. cephalus*, and *L. haematocheilus* were detected to be infected with *Myxobolus cheni* Schulman in the Liao-Ho River, Chine [76,89]. No data about mortality and musculature destructions of mullets were presented. *Kudoa intestinalis* Maeno, Nagasawa, Sorimachi and *K. valamugili* Kalavati and Anuradha were registered in the intestinal musculature of *M. cephalus* off the Southeastern coast of the Gokasho Bay, Japan, and *Moolgarda cunnesius* (=*Valamugil cunnesius*) in the Visakhaptnam Harbor, Indian Ocean [90,91]. Plasmodia are not detected in trunk muscle, visceral organs, or brains of any fish examined. Seven species of myxozoans were found in various organs including muscles of *M. cephalus. Myx. circulus* infects gills, muscles, kidney, fins, of named host in Black Sea [78,92]. *M. ichkeulensis* was isolated from gills, muscles, skin, and scales of the same host [12,89,93–95]. *Kudoa iwatai* Egusa and Shiomitsu infects muscles, adipose tissue, nerve axons, mesentery, swim bladder, heart, pericardium, kidney, and ovary [96]. *Myx. rohdei* Lom and Dykova was found in kidney, gall bladder, intestine, mesentery, muscles [89]. *Myxobolus bramae* infects all named organs including swim bladder, skin and gills [78,82]. Gills, mesentery, intestine, gall and urinary bladders, liver, kidney, gonads, spleen, eyes, fins, heart, and muscles of *M. cephalus*, *L. aurata*, *L. saliens*, and *L. ramada* were registered to by infected by *Myxobolus muelleri* [89,93,97]. *M. cephalus, Ch. labrosus*, *L aurata*, *L.saliens*, and *L. ramada* were recorded to be infected by *Myx. exiguus* Thélohan [11,12,80,89,98]. Geographical distribution of named species includes the Black Sea region (*Myxobolus bramae*, *M. circulus*, *M. exiguus*, *M. muelleri*), Caspian Sea (*M. exiguus*), Mediterranean (*Myxobolus rohdei* Lom and Dykova, *M. muelleri*, *M. ichkeulensis*, *M. exiguus*), Atlantic ocean (*M. exiguus*, *M. ichkeulensis*, *M. muelleri*), Red Sea (*Kudoa ivatai*), Estuary of the Arrawarra Creek, Australia (*M. rohdei*), Russian coastal zone of the Japan Sea (*Myxobolus exiguus*).

Among the myxozoans, described from mullets, 17 species were found only in the gall bladder. *Sphaeromyxa sabrazesi* Laveran and Mesnil and *Zschokkella admiranda* Yurachno were detected in *Liza aurata* and *Mugil cephalus* in the Black Sea and the Mediterranean [12]. *Zschokkella dogieli* Pogoreltseva, *Zsch. nova* Klŏkačeva and *Pseudalataspora pontica* Kovaljova, Donec and Kolesnikova were registered in *M. cephalus*, *L. aurata*, *L. saliens* in the Black Sea [92,99,100]. *Myxidium incurvatum* Thélohan infects *M. cephalus* in the Pacific Ocean, New Zealand [101]. *Chelon macrolepis* (Smith) (=*Liza macrolepis*), *Mugil cephalus, Rhinomugil corsula* (Hamilton), *Sicamugil cascasia* (Hamilton) and *Chelon parsia* (Hamilton) (=*Liza parsia*) were registered as the hosts of *Zschokella ganapati* Dorothy and Kalavati, *Bipteria indica* Kalavati and Anuradha, *Sphaerospora corsulae* Sarkar and Ghosh, *Myxobolus bankimi* Sarkar and *Kudoa haridasae* Sarkar and Ghosh, respectively, in coastal and estuarine waters of the Indian Ocean [91,102–104]. *Zschokella magna* Chen and Hsieh and *Zsch. mugili* Chen and Hsieh were detected by in *M. cephalus* and *L. haematocheilus* in the Liao-Ho River, China [105]. Mediterranean waters were noticed as localities of myxozoans *Zschokella mugilis* Sitja-Bobadilla and Alvarez-Pellitero, *Zschokella* sp., *Alataspora* sp. infecting the gall bladder of *L. saliens*, *L. ramada*, *M. cephalus*, and *Chelon labrosus* [12,106–109]. *Sphaerospora mugili* Asejeva was registered in *L. haematocheilus* in the Razdolnaja River, the Japan Sea, Russia [80].

Urinary bladder, spleen and liver of mullets were infected with a separate species of Myxozoans. *Ortholinea divergens* (Thélohan), *Myxobolus platanus* Eiras et al., and *M. raibauti* Fall et al., were found in *Liza aurata*, *Mugil liza* and *M. cephalus*, respectively, in Black Sea (Crimea, Ukraine); Lagoa dos Patos (Brasil), and Atlantic Ocean, (Senegal) [98,110, 111]. Undetected *Myxobolus* sp. was also registered in the liver of *Mugil cephalus* in the Mediterranean Ghar El Melh Lagoon (Tunisia) [112].

Twelve species of myxozoans were registered infecting kidney of mullets. Nine of them infect various organs [12]. Three species were found only in kidney. *Polysporoplasma mugilis* Sitja-Bobadilla and Alvarez-Pellitero was registered in *L. aurata*; *L. ramada* and *Ch. labrosus* in the Mediterranean (Ebro Delta, Santa Pola, Spain) and the Black Sea (Crimea, Ukraine) [12,113,114]. *Chloromyxum kotorensis* Lubat et al. and *Sphaerospora rostrata* Thélohan were found in the kidney of *L. aurata* and *Mugil* sp., respectively, off the coastal waters of Montenegro (*C. kotorensis*), Italy and France (*S. rostrata*) [109,115].

Multivalvulid myxosporeans of the genus *Kudoa* have been described in the brain of cultured and wild marine fish off coastal waters of India. *Kudoa tetraspora* Narasimhamurti and Kalavati infects *M cephalus* with minimal pathological changes [116]. *K. iwatai* Egusa and Shiomitsu infects nerve axons and other organs (muscles, adipose tissue, mesentery, swim bladder, heart, pericardium, kidney, and ovary) of farmed *M. cephalus* in the Red Sea [96].

Three undetected species of Myxozoa of two genera were registered exclusively in heart. *Henneguya sp.* and *Myxobolus* sp. were found in *Mugil curema* Valenciennes and *M. cephalus* in Atlantic coast of Senegal [117]. *Myxobolus* sp II. was recorded in *M. cephalus* from the Mediterranean lagoon, Tunisia [112]. *Henneguya ouakamensis* Kpatcha et al., infects heart and gills of *Mugil cephalus* [117]. *Myxobolus bramae*, *M. exiguus*, *M. muelleri*, *M. rotundus* and *Kudoa iwatai* were found in various organs of mullets including heart [12].

Several myxozoans species were found in the mesentery and the intestine of mullets. *Myxidium leei* Diamant et al. was described by Padros et al. from intestine of undetected mullet in marine aquarium in North-East of Spain [118]. *Myxobolus anili* Sarkar was isolated from mesentery associated with duodenum of *Rhinomugil corsula* in the Bay of Bengal, India [119]. *M. mugauratus* (Pogoreltceva) was detected from mesentery of *Liza aurata* in the Black Sea [99]. *Kudoa intestinalis* and *K. valamugili* both infect intestinal musculature of *Mugil cephalus* in coastal waters of the Kii Peninsula (Gokasho Bay, Japan) and *Moolgarda cunnesius* in the Visakhaptnam Harbor, India [90,91]. Intestinal mesentery and pyloric caeca of *Liza ramada* and *L. aurata* caught in the Ebro Delta and the Santa Pola Bay, Spain were infected by *Kudoa unicapsula* Yurakhno et al. [120].

Myxobolus lizae (Narasimhamurti and Kalavati) was described from outer wall of the gut of *Chelon macrolepis* in Indian waters at Andhra Pradesh [89,121].

Myxobolus adeli, *M. bramae*, *M. exiguus*, *M. muelleri*, *M. parvus*, *M. rohdei*, *M. spinacurvatura*, and *Kudoa trifolia* were detectet in various organs of worldwide mullets including intestine [12].

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