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Chapter 3.6.
ECOLOGICAL STUDIES

Andrea VETEŠNÍKOVÁ ŠIMKOVÁ & Jiří JARKOVSKÝ

Introduction

Basic ecological studies in fish parasitology focus on parasite distribution in host populations, the structure of parasite communities and host-parasite interactions. The effects of some abiotic or biotic factors on parasite distribution (usually measured by parasite prevalence, abundance or aggregation) or parasite diversity have been analysed. The most commonly studied abiotic factors are season, time, water temperature, habitat types and environmental pollution. The most commonly studied biotic factors associated with hosts are species, body size, age, sex, food spectrum, stress, reproduction, immunity, or genetic diversity of hosts. The presence and abundance of a given parasite species in the parasite community may also be strongly affected by other parasite species currently occurring (or coexisting) in the parasite community.

General challenges in ecological studies on fish parasites

The protocol of an ecological study basically depends on the hypothesis to be tested, *i.e.*, predictions and objectives should be set prior to any ecological study. As parasite abundance and diversity can be affected by multiple abiotic and biotic factors, the ecological study should be designed to eliminate these effects. Before starting to investigate ecological patterns in fish parasites, the correct identification of host specimens should be confirmed by a specialist. In case of doubt over host identification or if hybridisation between phylogenetically related host species seems to play a role, molecular markers should also be applied to confirm morphology-based identification.

Sample size is important when investigating parasite diversity (for example, when studying the structure of parasite communities or in the case of comparative analyses of determinants of parasite diversity), investigating parasite distribution in host populations or delimiting host specificity of parasites. However, there are mathematical methods that allow correction for unequal sampling (rarefaction method or simulated random sampling of given sample size). Another confounding effect may be the host body size as parasite diversity (and parasite abundance) generally increases with increased host body size due to allometric relationships. Larger hosts represent a larger and more stable habitat for parasite colonisation. Therefore, when comparing the parasite communities of a given host species between different sites, hosts of similar body size should be selected.

For parasites with a complex life cycle, the presence and abundance of intermediate hosts is another biotic factor influencing the composition of parasite communities and should be taken into account even if the study includes sites with equal sample size and fish hosts of similar body size. Furthermore, parasite diversity and parasite abundance may vary in time and space. In addition, the biotic variables linked to hosts also exhibit temporal and spatial variability (*e.g.*, seasonal changes in water temperature induce changes in fish immunity which affect the level of parasite infection). Therefore, when investigating spatial variability in parasite diversity, the ecological study should be performed under similar environmental conditions (*e.g.*, when comparing the parasite diversity of a given host species among different sites, the fish from all sites should be sampled in the same season, with similar water temperature or water flow).

A very important part of ecological studies on parasite diversity is fish storage following sampling and the time between the collection and processing of fish specimens (*i.e.*, fish dissection and parasite collection). Fish should be quickly transported to the laboratory and placed into containers with the original water and aeration. All fish should be dissected and parasites should be collected and fixed within 48 hours after capture. Alternatively, fish may be frozen and dissected later, but in that case most parasites found are useless for a detailed morphological study. In addition, parasites cannot be detected based on their movement. Finally, host phylogenetic relationships should also be considered. Two congeneric hosts may share parasite species due to common ancestry.

Fish in the life cycle of parasites

Parasites exhibit direct or complex life cycles. In the case of a direct life cycle, parasites require only one host species to complete their ontogenetic development. All monogeneans, some nematodes and most arthropods have a direct life cycle. Parasites with a complex (or indirect) life cycle have one or more obligatory intermediate host species in different stages of their life cycle in which the parasites undergo some developmental and morphological changes (*i.e.*, multiplication of infective stages in intermediate hosts) and definitive hosts (parasites reach sexual maturity in definitive hosts). For many endoparasites with a complex life cycle (*e.g.*, trematodes and nematodes maturing in fish-eating birds), fish act as intermediate hosts. Some endoparasites (*e.g.*, heterophyid metacercariae in the brain of fish and plerocercoids of diphyllobothriidean cestodes in the body cavity) are able to manipulate the behaviour of their intermediate host (here, a fish) to successfully reach the definitive host (PITT – Parasite Increased Trophic Transmission).

Population ecology of parasites – basic terminology

> **Population:** a group of individuals belonging to the same species living at a given time and in a given space; each individual host is parasitised by one or more parasite infrapopulations. The following types of parasite populations have been defined (Margolis *et al.* 1982; Bush *et al.* 1997, 2001; Morand & Šimková 2005).

Infrapopulation: the group of all individuals of a given parasite species infecting a single host specimen; each individual host is parasitised by one parasite population of a single parasite species or more parasite infrapopulations of different parasite species; an infrapopulation is short-living, *i.e.*, its maximal life span is equal to (but usually shorter than) the life of the individual host harbouring this infrapopulation. Parasite infrapopulations are subunits of a metapopulation.

Metapopulation (sometimes termed component population): consists of all infrapopulations of a given parasite species in all host individuals of the same host species in an ecosystem.

Suprapopulation: consists of all parasites of a given species including all developmental stages of this parasite in all hosts in a given ecosystem.

Population ecology of host-parasite interactions is analogous to metapopulation theory. The principal idea of metapopulation theory is that the local populations are interconnected, *i.e.*, there is migration of specimens among local populations. Each individual host represents the equivalent of a habitat patch, which usually includes the infrapopulations of more metapopulations of different parasite species infecting a given host population.

To describe the size and distribution of a parasite population in a given host population, Margolis *et al.* (1982) and Bush *et al.* (1997) proposed the **basic epidemiological parameters** describing the level of parasite infection in a host population:

Prevalence: the proportion of hosts infected by a given parasite species (*i.e.*, the proportion of hosts infected in the whole sample of host specimens examined).

Intensity of infection: the number of parasite specimens found in/on a given host specimen infected.

Mean intensity of infection: the mean number of parasites of a given parasite species over all infected hosts in the sample.

Mean parasite abundance: the mean number of parasites per host specimen in a given host population, *i.e.*, the mean number of parasite specimens calculated when considering both infected and uninfected hosts in the sample.

Parasites are typically aggregated within a host population, which means that many hosts are parasitised by one or very few parasites or are uninfected, and a few hosts are infected with many parasite specimens. The simplest way for the description of this parasite distribution is to calculate the variance/mean ratio. A ratio equalling 1 indicates random distribution, a ratio below 1 indicates a uniform distribution and a ratio higher than 1 indicates an aggregated distribution.

Parasite communities – basic terms

Several types of parasite communities have been defined (Bush *et al.* 1997, 2001; Poulin 2007):

Infracommunity: all populations of different species of parasites in the same host individual.

Component community (or metacommunity): all parasite species exploiting a host population.

Compound community: all parasite communities in an ecosystem.

As infracommunities are subsets of the component community, the maximum number of species in an infracommunity is equal to the number of species in the component community (however, this maximum number of parasite species in an infracommunity is typically not reached and usually no single infracommunity contains all species that are locally available). Infracommunities are short-lived, their maximum life span is equal to that of the host. As component communities are subsets of the parasite fauna, the maximum number of parasite species in a component community is equal to the number of species in the parasite fauna (however, this maximum number of parasite species in a component community is typically not reached). Component communities are longer-lived assemblages than infracommunities as the host population persists in time (Poulin 2007). Component communities are often saturated (expressed by a curvilinear function) by parasite species (the saturation by species is below the number of species in the parasite fauna).

Parasite species are not randomly distributed among infracommunities due to species interactions or other structuring forces. Parasite infracommunities may exhibit so-called **nested patterns** of parasite species distribution when a common parasite species (*i.e.,* usually a parasite with high prevalence and abundance) is distributed in all infracommunities, but rare parasite species occur only in species-rich infracommunities (Patterson & Atmar 1986). This nested pattern is usually explained by different colonisation and extinction rates of species.

Parasite interactions: competition versus coexistence in parasite communities

There are two types of parasite communities:

(1) non-interactive (isolationist) communities, in which niche space is not saturated with parasite individuals and thus interspecific interactions do not play a role (parasites may coexist in the communities);

(2) interactive communities, in which niche space is saturated and interspecific competition plays an important role (Rohde 1977, 1991).

The ecological niche of a given parasite species is the multidimensional habitat volume occupied by specimens of this parasite species. It is defined by physical and biotic variables (Hutchinson 1957 and modified for parasites by Poulin 2007). The comparison of basic niche (measured for a single species infection) and real ecological niche (measured for a multispecies infection) under experimental conditions is the basic way to reveal ongoing competition. The ecological niche of a parasite species is determined by host specificity, microhabitat, macrohabitat (*i.e.*, the habitat of the host), geographical distribution, host age, host food and rarely by host sex (Rohde 1979).

Host specificity

The most widely used descriptor of parasites in their communities is the host specificity. According to the most widely accepted definition, host specificity is the extent to which a parasite taxon is restricted in the number of host species used at a given stage in the life cycle (Poulin 2007). Using a basic measure of host specificity (*i.e.*, host specificity measured by the number of host species), a specialist (or strictly host-specific parasite) is restricted to a single host species, while a generalist (*i.e.*, parasite species with low host specificity) is able to infect at least two host species. Host specificity decreases with an increasing number of host species (*i.e.*, with increasing host range).

Special attention should by paid to parasite species with a complex life cycle. A parasite species with a complex life cycle is often restricted to a single intermediate host species (*i.e.*, it is a specialist at the intermediate host level), but is able to infect a wide range of definitive hosts (*i.e.*, it is a generalist at the final host level). Host specificity may also be expressed by including quantitative ecological data (like abundance), phylogenetic relatedness of hosts or the geographical distribution range of parasite species (Poulin *et al.* 2011). When evaluating host specificity, the scale of the study should be taken into account. Some parasites may exhibit strict host specificity at the local level, but are recorded on a wide range of host species at the regional level.

Analyses of parasite communities – biodiversity indices

Diversity of parasite communities is expressed by species richness or by the relative abundance of species. Species richness is a simple count of the number of species in the community. Relative abundance specifies the number of individuals per species. Biodiversity indices are frequently used to express the diversity in parasite communities (see Maguran 2003). The Shannon index and its evenness have been widely applied for parasite component communities. In contrast, the Brillouin index is useful at the level of the infracommunity. Species dominance in parasite communities can be evaluated using the Simpson index or the Berger-Parker index (see Table 3.6.1 for equations).

Table 3.6.1 Overview of biodiversity indices (S – number of species, N – number of individuals, n_i – number of individuals of the i-th species).

Index	Equation
Margalef index	$D_{Mg} = \frac{(S-1)}{\ln N}$
Menhinick index	$D_{Mn} = \frac{S}{\sqrt{N}}$
Shannon index	$H' = -\sum p_i \ln p_i$, where $p_i = \frac{n_i}{N}$
Brillouin index	$HB = \frac{\ln N! - \sum \ln n_i!}{N}$
Simpson index	$D = \sum \left(\frac{n_i(n_i-1)}{N(N-1)} \right)$
Berger-Parker index	$d = \frac{N_{\max}}{N}$ where N_{max} – abundance of the most abundant species

Parasite communities are compared by calculating the similarity between parasite communities (*e.g.*, similarity between two parasite component communities of the same host species collected from two different sites). The coefficient of associations is calculated with or without taking into account the problem of double zero values (asymmetrical and symmetrical coefficient, respectively). Binary or quantitative data are used to evaluate the similarity between parasite communities. The most often applied asymmetrical indices are the Jaccard index of similarity for binary data and the Sørensen index for quantitative data (see Table 3.6.2 for equations).

Table 3.6.2 Basic similarity indices.

Index	Equation
Jaccard similarity coefficient	$S = \frac{a}{a+b+c}$, where *a* is the number of species occurring at both sites and *b*, *c* is the number of species occurring only at one of the sites
Sørensen quantitative coefficient	$C_N = \frac{2jN}{aN+bN}$, where *aN* and *bN* are the abundance of species at sites A and B, and *jN* is the sum of abundances of species occurring at both sites

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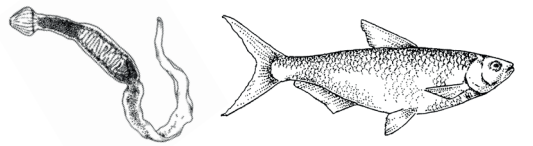
PART 4

A SYSTEMATIC SURVEY OF THE PARASITES OF FRESHWATER FISHES IN AFRICA



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Chapter 4.1.

KEY TO THE PRINCIPAL GROUPS OF THE PARASITES OF FRESHWATER FISHES IN AFRICA*

Roman KUCHTA

1 (2) Microscopic organisms, mostly unicellular, may form cysts containing spores that are not visible to the naked eye, cysts sometimes macroscopic…….**Protista and Myxozoa** (see key in Chapter 3.3.1)

2 (1) Organisms visible to the naked eye (may nonetheless be quite small and larvae may be microscopic), multicellular, may or may not be aggregated into clusters of individuals ..……3

3 (4) Worm-like organism, lacking an articulated exoskeleton with segmented appendages…….....5

4 (3) Organisms with articulated exoskeleton and segmented appendages (appendages may be minute requiring a microscope to be observed)……15

5 (6) Organisms with dorsoventrally flattened body, not round in cross-section……...7

6 (5) Organisms not dorsoventrally flattened, round in cross-section, endoparasitic ……13

7 (8) Organisms with the anterior and posterior attachment organ……..…9

8 (7) Organisms without the posterior attachment organ, usually proglottised [Fig. 4.1F]……**Cestoda** (see Chapter 4.6)

9 (10) Anterior and posterior attachment organs sucker-like, without armatures……...11

10 (9) The posterior attachment organ (haptor) comprising various sclerotised structures (hooks, clamps, squamodiscs) present [Fig. 4.1A, B]……**Monogenea** (see Chapter 4.4)

11 (12) Anterior and posterior attachment organs present with well-defined posterior sucker; intestine not bifurcate; always ectoparasites [Fig. 4.1E] …….**Hirudinea** (see Chapter 4.10)

* The key does not include encysted helminth larvae; these larvae have to be taken out from the cyst before identification or fixation, usually using fine preparation.

12 (11) Posterior attachment organ usually not present, circumoral and ventral suckers present (except for blood-dwelling species and Aspidogastrea); intestine mostly bifurcate; always endoparasitic [Fig. 4.1C, D]……..**Trematoda** (see Chapter 4.5)

13 (14) Anterior end with retractable spined proboscis; intestine absent [Fig. 4.1G] ……...**Acanthocephala** (see Chapter 4.7)

14 (13) Anterior spined retractable proboscis absent; intestine present [Fig. 4.1H] ……..**Nematoda** (see Chapter 4.8)

15 (16) Body not covered by carapace……17

16 (15) Almost whole body covered by carapace; four swimming legs [Fig. 4.1I] ……**Branchiura** (see Chapter 4.9)

17 (18) Organisms with two compound eyes; body dorsoventrally flattened, segmented; more than 4 legs [Fig. 4.1J]……**Isopoda** (see Chapter 4.9)

18 (17) Organisms with one compound eye; body shape variable [Fig. 4.1K] ……..**Copepoda** (see Chapter 4.9)

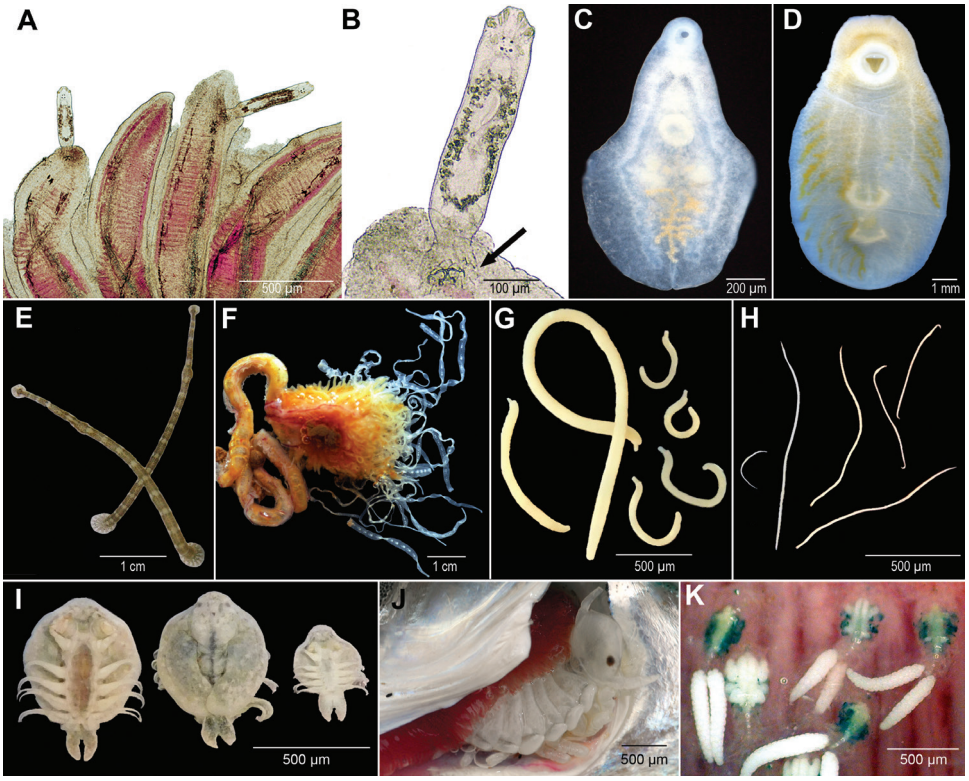

Fig. 4.1. Principal groups of metazoan fish parasites. **A, B.** Monogenea – *Thylacicleidus serendipitus* Wheeler et Klassen, 1988 from *Dichotomyctere nigroviridis*; arrow indicates position of the haptor; **C.** Digenea – *Phyllodistomum* sp.; **D.** Digenea – *Euclinostomum* sp., metacercaria; both from *Clarias gariepinus*; **E.** Hirudinea – *Piscicola geometra* Linnaeus, 1761 from *Cyprinus carpio*; **F.** Cestoda – *Ichthybothrium* sp. in the intestine of *Mesoborus crocodilus*; **G.** Acanthocephala – *Echinorhynchus* cf. *gadi* Zoega in Müller, 1776 from *Microgadus proximus*; **H.** Nematoda – *Procamallanus* sp. from *C. gariepinus*; **I.** Branchiura – *Dolops ranarum* (Stuhlmann, 1892); **J.** Isopoda – *Mothocya renardi* (Bleeker, 1857) from *Strongylura leiura*; **K.** Copepoda – *Ergasilus* sp. on the gills of *C. carpio*. (Photographs by R. Kuchta, O. Kudlai, D. Modrý & E. Řehulková).

Chapter 4.2.

PROTISTA

Linda BASSON & Courtney COOK

Protists parasitising freshwater fishes – basic characteristics, life cycles, classification and principal diagnostic features

Protists do not represent a distinct and monophyletic group of organisms. According to Adl *et al.* (2005) Haeckel's taxon Protista (Haeckel 1866) is no longer formally recognised. However, the popular term "protist" is retained to describe eukaryotes with a unicellular level of organisation (eukaryotic microorganisms or EMs; see Chapter 3.3.1). Therefore, this term will be used throughout this chapter, but with no taxonomic validity. The various groups discussed below belong to supergroups as proposed by Adl *et al.* (2012). The only characteristic these organisms share is the fact that they are all unicellular. Very scant information on protist fish parasites in Africa exists.

Each taxonomic group is discussed separately throughout. Host names are presented according to Froese & Pauly (2017). For the purpose of this chapter, the classification system proposed by Adl *et al.* (2012) has been followed. A brief outline of this system is presented in Table 4.2.1, limited to groups of parasites recorded from African freshwater fishes. A generalised key to major groups is presented in Chapter 3.3.1.

In cases where a representative species for every genus could be obtained from the relevant African literature, these species are presented in diagrammatic drawings. However, in several instances only records of genera are provided, with no species identification and/or micrographs or diagrams. In these cases, a representative species from elsewhere in the world was selected and diagrammatically presented.

Practical key for preliminary determination of fish-infecting EMs in freshly prepared material

1 (2) Protists detectable as macroscopic whitish aggregations, from tiny dots to cyst-like structures of several millimetres in size; on skin, gills, in or on internal organs……3

2 (1) No macroscopic changes visible; protists only detectable by light microscopy……17

3 (4) Microorganisms visible as tiny dots on the body surface and gills, under the microscope dot proves to be one or several large (up to 1 mm) slowly rotating cells, uniformly covered with beating cilia; smaller cells may be

present, next to large ones; cytoplasm full of granules, containing large macronucleus [Fig. 4.2.4E]……***Ichthyophthirius multifiliis***

4 (3) Dot-, nodule-, or cyst-like structures composed of mass of small, uniform, refractile bodies (spores or oocysts)……5

5 (6) Spores very small, typically 3-10 µm in size, usually ovoid and often showing prominent vacuole in posterior part (Microsporidia)……9

6 (5) Spores spherical or ellipsoid-spherical……7

7 (8) Spherical spores with a large central vacuole/light refracting bodies [Fig. 4.2.2B]……***Dermocystidium***

8 (7) Organisms spherical or ellipsoidal bodies of about 10-20 µm in size, each with 4 sharply delimited (coccidian oocysts)…… 15

9 (10) Microsporidian not directly associated with fish, hyperparasite [Fig. 4.2.2F] ……..***Unikaryon***

10 (9) Microsporidians associated directly with fish……11

11 (12) First merogony stages with diplokarya [Fig. 4.2.2D]……***Neonosemoides***

12 (11) No diplokaryon in the developmental series……13

13 (14) Xenoma wall consists of granulo-fibrillar layer, spores throughout xenoma [Fig. 4.2.2C]…… ***Loma***

14 (13) Merogony and sporogony stages with conspicuous envelope [Fig. 4.2.2E] ……***Pleistophora***

15 (16) One pole of sporocyst bearing special structure (Stieda body) [Fig. 4.2.2I] …….. ***Eimeria***

16 (15) Sporocyst without Stieda body [Fig. 4.2.2J]……..***Goussia***

17 (18) Protists infecting surface (skin, fins, nasal pits or gills)…….. 19

18 (17) Protists infecting intestine, other internal organs or blood……55

19 (12) Organisms that move……21

20 (11) Sessile or motionless organisms attached to surface……29

21 (14) Protists with flagella or cilia on the cell surface ……23

22 (13) Cells with amoeboid movement and changes of body shape [Fig. 4.2.2A] ……***Entamoeba***

23 (16) Protists possessing 2 flagella, moving with jerky, creeping motion or swimming spirally forward (flagellates)……..25

24 (15) Protists 20 µm and larger, either covered uniformly with cilia or with several ciliary belts or circular ciliary wreath; they move directly forward, glide over the surface, or roll on the spot (ciliophorans)……..…41

25 (26) No mitochondrion present [Fig. 4.2.5F] ……..***Hexamita***

26 (25) Mitochondrion present …… 27

27 (28) Long tubular mitochondrion contains numerous nucleoids so that there are many small kinetoplasts throughout the body [Fig. 4.2.5G]…… ……. ***Ichthyobodo***

28 (27) Single branched mitochondrial ribbon forms massive, elongate kinetoplast on the ventral surface [Fig. 4.2.5H]…… ***Cryptobia***

29 (30) Refractile granules in cytoplasm……31

30 (29) Goblet-like or cylindrical, each with wide free end and encircled by wreaths of beating cilia; cells may contract a little (sessilines)…… 33

31 (32) Pyriform or sack-like flagellated protist, cytoplasm yellowish or greenish (parasitic dinoflagellates) [Fig. 4.2.2H]……***Piscinoodinium***

32 (31) Cytoplasm dark due to refractile granules, with bundles of tubules ending in knob-like shapes (suctorians) [Fig. 4.2.4D]……..***Capriniana***

33 (34) Sessilines attach directly to substrate via scopula……35

34 (33) Sessilines attach to substrate via a stalk……39

35 (36) Permanent locomotory equatorial fringe present [Fig. 4.2.5D]…… ……***Ambiphrya***

36 (35) Locomotory fringe of cilia only present in free-swimming larval stage …… ……..…….. 37

37 (38) Body elongate, macronucleus compact, conical or ellipsoidal [Fig. 4.2.5B] ……..***Apiosoma***

38 (37) Body cylindrical, macronucleus sausage-shaped [Fig. 4.2.5C]…… ……..***Riboscyphidia***

39 (40) Stalk highly contractile and unbranched [Fig. 4.2.5E]……***Vorticella***

40 (39) Stalk non-contractile, bearing a small colony of several zooids [Fig. 4.2.5A] ……***Epistylis***

41 (42) Cilia in distinct rows……43

42 (41) Cilia limited to aboral wreath (around concave adhesive disc) and an adoral spiral of cilia (feeding organelles at the opposite side of adhesive disc); aboral side with distinct adhesive disc consisting of prominent interlinking

denticles (mobilines)……45

43 (44) Ciliary rows limited to one surface of the organism……53

44 (43) Pyriform ciliophorans with 2-30 meridional kineties [Fig. 4.2.4F]…… ……***Tetrahymena***

45 (46) Adoral spiral makes a full turn or slightly more……47

46 (45) Adoral spiral makes less than one full turn……49

47 (48) Denticles have well-developed rays and blades [Fig. 4.2.6C]…… ……***Trichodina***

48 (47) Denticles have stunted blades [Fig. 4.2.6A]……***Hemitrichodina***

49 (50) Denticles have well-developed rays……51

50 (49) Denticles have rays that merely form small hooks [Fig. 4.2.6D]…… ……***Trichodinella***

51 (52) Denticles interlinked only by central parts [Fig. 4.2.6B]…… ……. ***Paratrichodina***

52 (51) Denticles interlinked by central parts, as well as by a prominent anterior projection of blades, fitting tightly into corresponding notches in blades of preceding denticles [Fig. 4.2.6E]……***Tripartiella***

53 (54) One side bears longitudinal or strongly arched ciliary rows [Fig. 4.2.4B] ……***Amphileptus***

54 (53) Ventral ciliature reduced to two longitudinal belts close to body margins [Fig. 4.2.4C]…….. ***Chilodonella***

55 (56) Protists in internal organs or urinary tract……57

56 (55) Protists in blood……..63

57 (58) Microsporidia (see 5; in any organ), coccidian oocysts (see 8; in intestine), or amoebae (see 22)

58 (57) Protists with surface showing cilia…… 59

59 (60) Cilia uniformly covering body of ciliophoran……..61

60 (59) Cilia limited to aboral wreath as well as an adoral spiral of cilia. The aboral side with distinct adhesive disc consisting of denticles (endoparasitic trichodinids) [Fig. 4.2.6C]…… ***Trichodina***

61 (62) Spindle-shaped cells, with both ends pointed, showing sluggish movement; two to many monomorphic nuclei [Fig. 4.2.2G]……***Protoopalina***

62 (61) Ciliophorans covered uniformly in longitudinal rows of cilia; single elongate macronucleus and single spherical micronucleus [Fig. 4.2.4A]…… …….. ***Balantidium***

63 (64) Motile protists, slender cells, typically 10-15 µm long, moving with a wriggling or undulating motion, with 1 or 2 flagella [Fig. 4.2.3D]…… ……...***Trypanosoma***

64 (63) Non-motile protists only visible in stained blood smears, found within blood cells…… 65

65 (66) Intraerythrocytic meronts (division stage showing more than one nuclei) and gamonts (sexual stage showing a single nucleus)…….. 67

66 (65) Intraerythrocytic gamonts only [Fig. 4.2.3C]…….***Desseria***

67 (68) Intraerythrocytic meronts rounded [Fig. 4.2.3A]……..***Babesiosoma***

68 (67) Intraerythrocytic meronts vermicular (wormlike) [Fig. 4.2.3B]……***Cyrilia***

Fig. 4.2.1. A. Life cycles of the ciliophoran *Ichthyophthirius multifiliis* Fouquet, 1876 (direct life cycle without intermediate hosts); **B.** The blood kinetoplastid *Trypanosoma* sp. (indirect life cycle where leeches serve as intermediate hosts). (Illustration by M. Luo.)

Table 4.2.1. Classification system for the protists according to Adl *et al.* (2012).

Supergroup	First rank	Second rank – examples
AMOEBOZOA	Archamoebae	Entamoebidae (*Entamoeba*)
OPISTHOKONTA	Holozoa	Ichthyosporea (*Dermocystidium*)
	Nucletmycea	Fungi (*Eimeria*, *Glugea*, *Loma*, *Neonosemoides*, *Pleistophora*, *Unikaryon*)
EXCAVATA	Diplomonanida	Hexamitinae (*Hexamita*)
	Euglenozoa	Prokinetoplastina (*Cryptobia*, *Ichthyobodo*, *Trypanosoma*)
SAR	Stramenopiles	Opalinata (*Protoopalina*)
	Alveolata	Dinoflagellata (*Piscinoodinium*)
		Apicomplexa (*Babesiosoma*, *Cyrilia*, *Desseria*, *Eimeria*, *Goussia*, haemogregarines)
SAR	Alveolata	Ciliophora; Trichostomatia* (*Amphiletus*, *Balantidium*) Phyllopharyngea* (*Chilodonella*) Suctoria** (*Capriniana*), Oligohymenophorea*; Hymenostomatia** (*Ichthyophthirius*, *Tetrahymena*) Oligohymenophorea*; Peritrichia** (*Ambiphrya*, *Apiosoma*, *Epistylis*, *Hemitrichodina*, *Paratrichodina*, *Riboscyphydia*, *Trichodina*, *Trichodinella*, *Tripartiella*, *Vorticella*)

* fifth rank; ** sixth rank

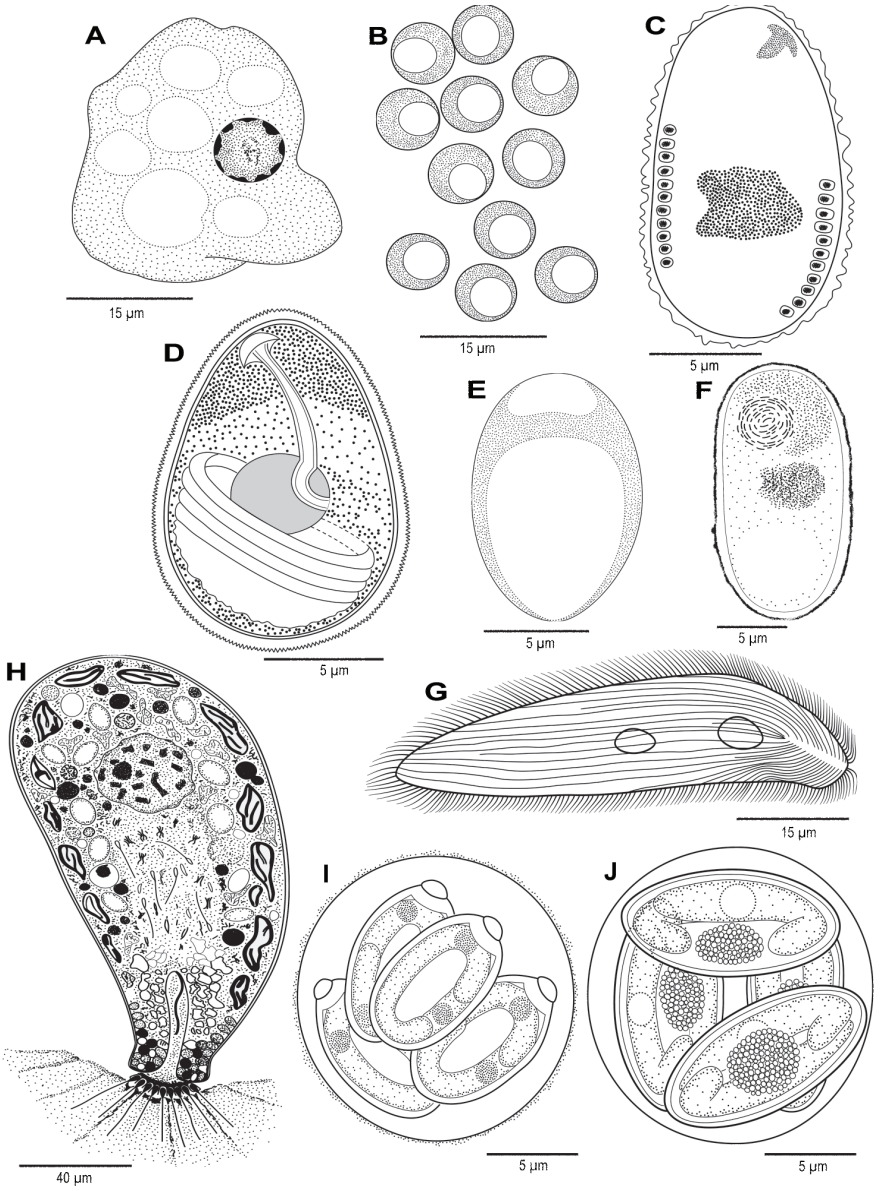

Fig. 4.2.2. Schematic line drawings of fish-infecting eukaryotic microorganisms (EMs). **A.** *Entamoeba salpae* (Alexeieff, 1912) from *Boops salpa*; **B.** *Dermocystidium branchiale* Léger, 1914 from *Salmo trutta*; **C.** *Loma camerounensis* Fomena, Coste et Bouix, 1992 from *Oreochromis niloticus*; **D.** *Neonosemoides* sp. from *Chrysichthys auratus*; **E.** *Pleistophora elegans* Auerbach, 1910 from *Alburnus alburnus*; **F.** *Unikaryon nomimoscolexi* Sene, Ba, Marchand et Toguebaye, 1997 from *Clarotes laticeps*; **G.** *Protoopalina symphysodonis* Foissner, Schubert et Wilbert, 1974 from *Symphysodon aequifasciata*; **H.** *Piscinoodinium pillulare* (Schäperclaus, 1954) from *Poecilia reticulata*; **I.** *Eimeria variabilis* (Thélohan, 1893) from *Cottus bubalis*; **J.** *Goussia anopli* Molnár, Avenant-Oldewage et Székely, 2004 from *Enteromius anoplus*. (Modified from Davies 1978; Fomena *et al.* 1992; Lom & Dyková 1992; Sene *et al.* 1997; Molnár *et al.* 2004; Reda 2010.)

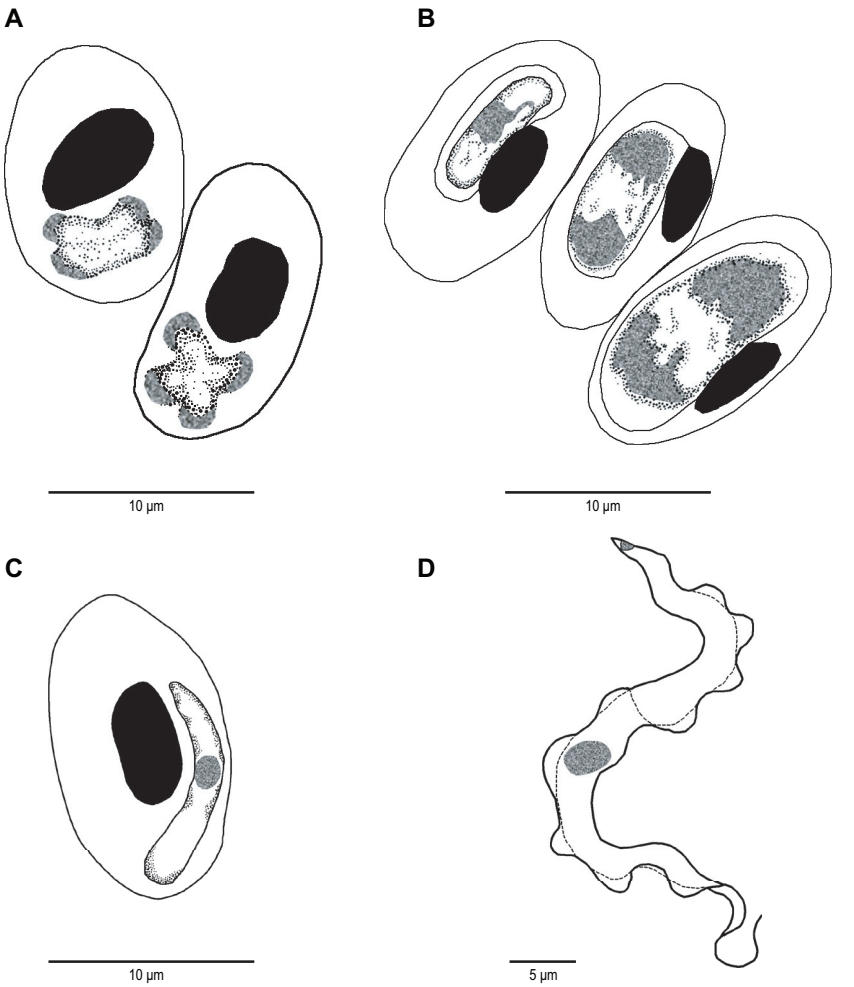

Fig. 4.2.3. Schematic line drawings of blood parasites reported from the peripheral blood of African freshwater fishes; **A.** Left to right: young meront in division and characteristic mature cruciform meront with four merozoites of *Babesiosoma mariae* (Hoare, 1930) from various freshwater fish species; **B.** Left to right: gamont, young meront and mature meront stage of *Cyrilia gomesi* (Neiva et Pinto, 1926) from *Synbranchus marmoratus*; **C.** Gamont stage of *Desseria* sp. from *Mugil cephalus*; **D.** Trypomastigote stage of *Trypanosoma mukasai* Hoare, 1932 from a freshwater fish. (Modified from Hoare 1930, 1932; Lainson 1981; Smit *et al.* 2002.)