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Ecology and Zoogeography of Parasites

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1. Introduction

Parasitism is a ubiquitous phenomenon that is probably as old as heterotrophic organisms themselves. It is one of the major types of symbiotic relationship between organisms of different species.

The development of the biological sciences brought about a broader definition of parasitism. By the end of the nineteenth century, it was known that parasites thrive at the expense of their hosts and use the host as their dwellings. The definition of parasitism emphasized the damage parasites inflicted on hosts, the metabolic dependence of parasites on hosts, and ecological interactions between populations of these two species of living organisms. It is also known that parasites can lower the fitness of hosts by exploiting nutritional resources, habitats, and dispersal. Parasites can also modify host behavior and lead to their castration (Levri, 1998).

Parasites can have varied impacts on hosts. The attachment organs of the parasites can cause mechanical damage to host tissues. Acanthocephalan spikes and cestode hooks and suckers can cause intestinal pathology, while monogenean hooks and clamps can damage the structures of fish gill filaments. Large internal parasites or those occurring in great numbers can block digestive tracts. Host tissues can sustain mechanical damage as parasites migrate or pass from one developmental stage to the next. While migrating into the host body cavity, roundworm larvae from the family Anisakidae break through stomach walls or pyloric caecae of the fish, which are the intermediate host. Tapeworm larvae of the genus *Ligula*, which settle in the body cavity, exert pressure on the fish gonads causing castration. They feed either on as yet undigested food or the components of food that has been broken down by enzymes; thus depleting hosts of protein, lipids, carbohydrates, vitamins, and enzymes. The parasites themselves produce enzymes that damage host cells and inhibit physiological processes. Parasitic metabolic products can be toxic to hosts; some parasites produce substances that impede blood clotting (leeches), destroy epithelial cells (cercariae Digenea), which creates the conditions necessary for secondary infection.

In this chapter, parasitism will be examined from the perspective of the close relationship between two organisms: the parasite and the host. The parasite lives at the expense of the host, but it is also dependent on its host in many other aspects. Parasitism is distinguishable from predation by its more extensive reproductive potential, its smaller size and thus limited visibility, and in its representing a lower level of evolutionary advancement.

If the relationship described above is only temporary, then it is referred to it as temporary parasitism. In many cases, this is limited to one-time contact with the host that is

nonetheless indispensable for further parasite development. Temporary parasitism is very similar to predation, especially when a single parasite species interact with numerous host species. In this instance, these parasites can be vectors of the infectious stages of other parasites.

Parasitic relationships that lack metabolic dependence are referred to as nesting or social parasitism, which indicate that organisms using other organisms as nesting sites or for rearing offspring.

2. Ecology of parasitism

Ecology has been defined as the study of interactions between organisms and their environments and among the organisms inhabiting these environments. This is a complex field of study, which is why it should be investigated on various levels. In the ecology of parasites the niche, which is the entirety of the parasite-host relationship and fragmentation, is of fundamental importance (Combes, 1995).

A niche is the entire set of biotic and abiotic factors (variables) that provides a population with living conditions. The number of variables that combine to shape a niche is large, and includes the environmental physicochemical parameters (salinity, temperature, light), host populations (abundance, fluctuations), variability of hosts occurring successively, the occurrence of parasitoids, and the character of the host resources exploited (Rohde, 1994). This last variable occurs repeatedly in the subsequent divisions of the habitat, e.g., on fish gills where parasites that feed on epithelial cells and mucous can occur simultaneously with parasites that draw blood from the blood vessels. Overlapping niches are the main parameter in competition among species.

Despite the large number of potential hosts, the parasite-host system can only exist when conditions are appropriate. The host must inhabit the same ecosystem as the parasite, have contact with the parasite, and offer it appropriate conditions for both life and survival. All of these conditions together are the selection mechanism that operates at the level of the parasite and host genome. Parasites can infect single or numerous hosts during the different developmental stages of their biological cycles; however, each stage has to overcome host metabolic and immunological barriers (Combes, 1995). The parasites that have, through evolution, developed the greatest ability to adapt to environments and to avoid defense mechanisms are the most successful at infecting and exploiting hosts. Success also depends on the creation of survival stages that can endure for certain periods of time in disadvantageous environmental conditions; these include protozoan and myxosporean cysts and helminth eggs. Developmental stages can also be dependent on the host to a certain degree. The parasitic stages of digeneans are sporocysts, rediae, adult stages, free-living miracidium, cercariae, and metacercariae (Buczek, 2003).

The physiological processes of parasites are dependent on the character of the site they inhabit, which is also its source of food. The mutual relationship between parasites and hosts is referred to as specificity, and it can be either narrow (e.g., Monogenea), or wide (e.g., most Nematoda). The older parasites are in phylogenetic development, the more specific they become. The functioning of the parasite-host system is possible when there is convergence between the activities of the particular developmental stages and the availability of food. This is linked also to the secretion by the parasites of digestive enzymes and metabolic regulation depending on their energy demands, which can be markedly

decreased under disadvantageous conditions. An important factor to survival is the possibility of exploiting food reserves accumulated by previous developmental stages.

Both sides participate in the creation of the parasite-host system. Initial contact usually ends in parasite death which results from host defense reactions. Instances of host death are also noted when they are introduced into a new ecosystem. Thus, the younger the parasite-host system is, the more pathogenic are the parasites and the less tolerant of them are the hosts. The aim of the formation and evolution of the parasite-host system is, among others, the reproductive success of both sides (Combes, 1995).

Evolution is a continual process comprising progressive changes in species characters of subsequent generations through the elimination and the selection of individuals in a population. Customarily, this process is viewed on a scale of whole organisms or populations, but all the changes observed in a given organism are molecular. Variability underlies evolution, and it sometimes only manifests as genetic variability. Genetic changes within one species cannot be transferred to another since there is no possibility for lateral gene transfer among most organisms that reproduce sexually. Changes in phenotype are a consequence of gene mutation; the evolution of each partner is conditioned by the pressure of choice from the other partner. One must not forget, however, that choice alone is insufficient as a factor causing co-evolution. Parasite and host selection run in different directions. The best adapted are the parasites, which when they find better hosts and exploit them the best attain great reproductive success. Hosts, in turn, avoid contact with parasites by adopting new behaviors, and if contact is made, they fight it. The costs of these activities are higher for the hosts. Mounting a defense requires energy which is designated for other life processes of the organism. The parasite-host relationship is based on an evolutionary race heading towards "meeting/avoiding" and "survival/killing" (Niewiadomska et al., 2001).

The parasite-host relationship is a dynamic one for both partners. This is linked to morphological, physiological, and structural adaptations that render easier the competition for resources that are more beneficial under given environmental conditions and to biological and ecological factors that ease contact among organisms in the environment. Parasites treating host organisms as environments to inhabit results in disruptions in host physiology, susceptibility to the impacts of toxins, and damage or the stimulation of pathological development of some tissues, and the depletion of nutritional substances. The degree to which these changes occur depends on many factors on the side of both the parasites and the hosts. Where and how parasites infect hosts, parasite sizes, how they feed, and how they migrate are all significant. Hosts defend themselves against parasites with non-specific (phagocytes, inflammation) and specific (cellular or humoral reactions) immune responses (Niewiadomska et al., 2001). One must bear in mind that parasites do not associate with just one host for their lifespans. In most cases the reproductive stage of the developmental cycle requires changes of hosts and environments. In each instance, a parasite-host system is established, although this relationship is not usually as long as that between parasites and definitive hosts. When there is a transition from one generation to the next during developmental cycles, new generations have to establish their own systems with hosts. In consequence, this has led to various types of parasitism that require different adaptation strategies and various paths for that generation to become parasitic.

The concept of fragmentation is defined as how parasites are distributed throughout the biosphere. All parasite species, just as other species do, form different populations. A population is a group of organisms of the same species living simultaneously in the same environment and exerting a mutual influence on each other with equal likelihood of

interbreeding. Such groups, or populations, are isolated geographically so that gene exchange among populations does not occur. In the case of parasites, it is difficult to draw the precise lines that demarcate population distributions, because it does happen that the same parasite species infects different host populations within one geographical region (e.g., in the same water basin) and they do not exchange gene pools. Parasites with a complex developmental cycle can be transported into another region by its intermediary hosts, and only those parasites with simple developmental cycles cannot move farther than their hosts. A set of populations of different species that occupy, at least partially, the same habitat and can impact each other is referred to as a community (Blondel, 1986). In ecological parasitology this term is, in a certain sense, the equivalent of the term "biocenosis".

The proper ecosystem functioning of populations and biocenoses has a defined structure. The structure of a population comprises its abundance, the distribution of organisms in the biotope, and the numerical ratio of juveniles to adults in the biocenoses. The structure of the biocenosis to the abundance, composition, and proportion of species that belong to it, the character of their links to the varied ecological factors, and trophic dependencies combine to create a whole that remains in a state of dynamic equilibrium in the natural environment.

'Infrapopulation' and 'metapopulation' are both terms linked to parasite populations. Infrapopulation refers to all the parasites of one species infecting a given individual host at a given time (Bush et al., 2002). An example of an infrapopulation would be all of the nematode *Hysterothylacium aduncum* (all developmental stages) infecting one cod. A metapopulation (also referred to as a xenopopulation) is the term used to refer to a group of a given parasite species within a host population (Riggs & Esch, 1987; Combes, 1995). These are all infrapopulations that occur within the whole host population. A good example is the nematode *Anisakis simplex* among seals.

The group of all individuals (all developmental stages) living among host populations in an ecosystem form suprapopulations. This concept includes all infrapopulations that occur within an ecosystem (Esch et al., 1975).

The solutions discussed above refer to single-species groups that reflect the concept of population with regard to free-living organisms. Within the category of biocenosis and based on the categories designated for populations, the concept of multi-species groups is proposed. Infracommunity refers to a group of infrapopulations of various parasite species infecting one host species; component community is defined as a group of metapopulations of various parasite species occurring within one host species population. Groups of suprapopulations of various parasite species infecting different host species within a given ecosystem form compound communities (Holmes and Price 1986). In practice, the term infracommunity is often limited to groups of parasites occurring in one organ (Złotorzycka, 1998). The terminology presented here describes groups of parasites at the exclusion of dispersion stages that occur in the external environment. They play an important role in gene flow and the regulation of population numbers since parasites are exposed to high mortality in the external environment. They are food components of free living organisms.

One of the primary elements of population structure and multi-species communities of parasites is their fragmentation. Infrapopulations and infracommunities occur in single hosts, and are often limited to a specific organ.

The locations where parasites live, regardless of whether these are hosts of the external environment, are their habitats. Macrohabitats (biotopes or ecosystems) are the living environments of hosts. Microhabitat is the name used to refer to organs or sections of organs

infected by parasites. The conditions of the various habitats determine whether or not particular parasites can settle there. Every organ is characterized by many morphological and physicochemical parameters, and differences are noted among them even within a single organ. Despite this, the habitats of parasites can nearly always be determined with great precision. The existence of a habitat is the result of the heterogeneity of each living organism. Different genes are expressed in different organs, which is why the environments offered to parasites differ in different parts of hosts (Combes, 1995). Helminths are most frequently particular about the places they choose to settle; these include designated regions of the intestines or the gills. There are, however, many species of parasite that are not 'picky' regarding habitat. These are most frequently cellular parasites. Some habitats are not always immediately available to parasites or their developmental stages, which is why migration is necessary, and makes it imperative to overcome defensive barriers that are also presented by the host organism. The location of parasite habitats impacts the migration process within host organisms, but also on the processes of releasing parasite eggs or larvae into the external environment. If external parasites make direct contact with the external environment, and mesoparasites do so thanks to organs which they inhabit and from which their eggs or larvae are released through natural channels, then internal parasites inside cells, tissues, or organs have no such possibilities. However, this process requires damaging the habitat, and vectors are useful for this, and it is indeed thanks to this process that some leech species transmit flagellates and haemogregarina.

Numerous studies have indicated that parasites do not occur in all the individuals of a species inhabiting a given ecosystem, and that parasites will occur in different numbers among species in which they can develop. The term prevalence is employed to describe this concept; it is the ratio of the number of infected host individuals to the number of individuals examined, and it is expressed in percentages. The mean number of parasites per infected host is the mean intensity of infection, while the number of parasites per individual in a population is the mean parasite density. The distribution of the parasite population among the host population is determined based on these parameters.

Each infracommunity is characterized by a determined parasite species structure that inhabits host organisms. However, studies indicate that some species occur frequently, while others do so less frequently. However, parasite infracommunities are characterized by the occurrence of dominant species that are a constant element of its composition, and they also occur most abundantly. A permanent component are also influents, which do not occur as abundantly as the dominants, and accessory species that appear only sporadically. The range of the frequency of occurrence of parasites is also described by specific terminology that is also used too describe free-living organisms (Bush & Holmes, 1986). Core species are those that occur frequently and abundantly. This term is the equivalent of a dominant species. Intermediate species do not occur as frequently as do core species, while satellite species are those that occur the least frequently and at low abundances.

The qualitative evaluation of the structural quality of communities is based on the terms of richness and diversity. The first of these is expressed in the number and abundance of the species comprising the community, while the second describes the quantitative relationships between the species in a community.

The richness and diversity of parasite communities within a single host or in a host population undergo cyclical fluctuations that are dependent on the structure of the host population. This refers primarily to intermediate and satellite species which can appear only

during determined seasons of the year or host life stages (Niewiadomska et al., 2001). These changes are linked primarily to the host lifestyle and dietary requirements.

The food requirements of the parasites necessitates introducing yet more terminology. Groups of species exploiting sources in similar ways are referred to as guilds. The way in which resources are exploited and their source determine the type of guild (Bush et al., 2002). Groups of parasites of different species that occur in a single host are known as an infraguild. A component guild describes all of the infraguilds of a local host population (Sousa 1990). Such relationships occur when the host intestine is infected by a community of parasites – one feeds on blood, another on products of host digestion, and others that feed on the epithelium.

The range of parasite specificity for hosts is described with the terms 'specialist', 'generalist', and 'intercepted specialists'. The first group includes parasites that are linked to a small number of related host species, and often by just one host species (Price, 1980). Generalists are parasites that are not specialized, and have the ability to colonize many unrelated hosts. The third group comprises parasites that have a narrow specificity, which means they can only overtake and develop in a non-specific host only under specific conditions (Holmes, 1990).

The character of the development cycle is also linked by two different terms. The entire life cycle of autogenic parasites occurs within a single ecosystem. In the aquatic environment, such parasites have simple developmental cycles and the aquatic organism is also the definitive host. The second type of parasite has a complex developmental cycle and both invertebrates and vertebrates serve as intermediate or definitive hosts. Allogenic parasites are those in which only part of the developmental cycle runs its course in the studied ecosystem; the aquatic organism is the intermediate host and the definitive host is a terrestrial vertebrate, which can become infected in one ecosystem and then transfer the parasite to another (Esch et al., 1988).

3. Transmission of marine parasites

Parasites invade hosts in various ways: ectoparasites occur on the exterior of hosts, while endoparasites occur internally. Sometimes it is difficult to assign a parasite to one of these two categories, which is why there is a third category – mesoparasites. Different types of parasitism are presumed to have evolved differently, and were affected by feeding modes, suitable conditions, or pure chance. Studies of parasitism among different taxonomic groups of living organisms indicate there is high diversity in its advance, type, and evolutionary origin. Relationships are also noted among the structures of organisms in a given taxonomic group and the type of parasitism that evolved. All parasitic nematodes and the majority of flatworms are endoparasites, while the majority of arthropods are ectoparasites.

Not all host organisms are colonized by parasites to the same extent. The host species that is predominantly and most abundantly infected within a given biocenosis is referred to as the principal host. Hosts that are infected sporadically, and often without the parasite completing development or suffering mortality, is called an accidental host. Organism in which parasites achieve sexual maturity and often also reproduce is known as a definitive host. Organism in which parasites pass through the earlier stages of development is called an intermediate host (Matthews, 1998). Similarly, parasite life cycles also can be classified as different types. Parasites with direct life cycles have a single host, while those with an indirect life cycle have several hosts.

Any marine organism is a potential host since becoming a host depends on the occurrence of suitable conditions. These include site, season, environmental conditions, the presence of suitable developmental stages, the possibility of contact between the two organisms, and the acceptance of such a relationship (Rohde & Rohde, 2005).

One of the characteristic traits of parasites is often the necessity of changing habitats repeatedly. In the case of most parasites, the same genome must be able to build several generations of differing organisms that are able to find and exploit several different habitats. If the transmission of parasites occurs between different host individuals this is called lateral transmission, while if it is from the parents (mammals) to their immediate offspring, then it is referred to as vertical transmission (Shoop, 1991).

The transmission of parasites from one host to another is known as direct, but it is rarely actual physical contact, but more often the close proximity in the water of two organisms is sufficient. This mode of transmission is used most often by external parasites with direct life cycles. An example are the monogeneans of the species *Isancistrum subulatae* which infects squid by passing from one partner to the other as their tentacles draw closer to copulate (Llewellyn, 1984). A particular type of transmission is vertical, which means that the mother passes parasites to her offspring. The intestinal nematodes *Uncinaria* spp. of the California sea lion, *Zalophus californianus*, and the northern fur seal, *Callorhinus ursinus*, infect young seals as they nurse and take in larval parasites along with milk (Lyons et al., 2000).

The infectious parasite stages are usually juveniles and rarely adults. This mode of transmission is facilitated by the high densities of host populations in aquaculture facilities. Parasites are transmitted through active, free-living stages which have evolved special mechanisms that enable them to find hosts, attach and/or penetrate, and find a suitable habitat. These mechanisms include the following: phototaxis, chemotaxis, adequate hatching time (emergence), or simply being in the right place at the right time. A good example are monogeneans, the pelagic larvae of which attach to the gills or fins of fish, or isopods that penetrate the gill or mouth cavities of the (Ravichandran et al., 2009).

Passive infection occurs when parasites enter the host organism through the body openings, by direct contact, or through trans-uterine or trans-ovarian transmission.

Oral transmission is typical for parasites with complex life cycles, and individual developmental stages are linked through the food chain. The links in this chain are the intermediate hosts that harbor parasite developmental stages, and the definitive host where parasites achieve sexual maturity. Parasites are transmitted when current hosts are consumed by the next host that is suitable the development of more advanced stages.

In the marine environment, the majority of free-living developmental stages are active and alive for a span of 24 - 48 hours. During this period they must find a host and overcome numerous obstacles posed by the external environment. Infectious parasite stages have energy reserves to actively pursue these goals. They are neither morphologically nor physiologically capable of acquiring food, as this would distract them from finding hosts.

The first intermediate host is usually organisms with short life spans, such as copepods, oligochaetes, or molluscs. The likelihood of infecting such host by a minute, delicate juvenile parasite stage is very low, which renders the risk of parasite life cycle disruption immensely high. Longer-lived, predatory decapods, chaetognaths, and small fish are the subsequent links in the food chain. They are intermediate, definitive, or paratenic hosts successively. The paratenic host (otherwise known as the transport host) is not intended to support any further morphological or physiological development of the parasite. It simply serves as a

convenient link between the intermediate and definitive hosts. Parasite numbers gradually increase in the paratenic host so their role is not only to transmit but also to increase the level of infection (through parasite build-up in the body of the paratenic hosts) (Marcogliese, 1995, 2002).

Passive transmission through skin, or mucous membranes, is aided by vectors, which are also known as transmitting organisms. Most frequently, these organisms feed on blood, and parasites undergo a prescribed developmental phase in them. Aquatic organism parasites from the genus *Trypanosoma* with some species of leech playing the role of vector are examples of this life strategy.

As mentioned previously, parasites can successively exploit many different host species throughout development. Component biological cycles use hosts successively; the simplest, holoxenic, has just one type of host, while the most complex, heteroxenic, can include up to four hosts. The number of host species in the developmental history of parasites is usually stable. However, there are exceptions to this rule that do not occur because of evolutionary changes. Shortened cycles can happen for several different reasons. One possibility is that parasites omit one of the intermediate host or definitive host if sexual maturation occurs in the intermediate host; however, the two cycles exist simultaneously with a smaller and constant number of hosts. Other possibilities include achieving sexual maturation earlier (larval stages producing eggs), or when stages that usually occur in different types of host occur successively in one host without themselves undergoing transformation. Shortened cycles are also noted when host and/or developmental stages are eliminated. These processes underscore the plasticity of biological cycles and adaptations that aim to avoid the most sensitive stage which is changing hosts.

Extending cycles is accomplished by including paratenic hosts, in which larval stages occur, but not necessarily to the end of the developmental cycle. Paratenic hosts frequently become reservoirs for invasive parasite stages, which allows parasites to survive when conditions are inappropriate. They also ensure possibilities for infecting hosts through different pathways; younger individuals eat smaller intermediate hosts, while older ones eat larger paratenic hosts. The transmission of some groups of parasites always runs the same course with intermediary and paratenic hosts even if, theoretically, the latter is not necessary.

Many marine species have a wide range of hosts. Low parasite host-specificity allows them to spread faster and more widely in environments. The presence of parasites in environments depends on the presence of hosts. Parasites, therefore, can be regarded as indicators of food chain structure, or as indicators of changes occurring in the quality of aquatic environments.

4. Zoogeography of marine parasites

Biogeography as a scientific discipline began over two centuries ago when Alexander von Humboldt discovered latitudinal gradients in species diversity during an expedition to South America in 1799. He also suggested that temperature might provide an explanation. In the subsequent years, von Humboldt & Bonpland (1805) and his students were the first to name and evaluate the role climate plays in the distribution and structure of vegetation in the world. For many years, zoogeographic study remained a secondary pursuit, until W. L. Sclater (1858) proposed dividing the world into faunal regions based on the distribution of birds. The divisions he proposed are very similar to those that are currently applied.

Zoogeography is, in fact, a branch of biogeography, as it studies the geographic distribution of animals in the past, now, and predicts likely scenarios of this phenomenon for the future. It also includes the study of factors that explain current distributions of animals by drawing on knowledge from other scientific disciplines. These include climatology, ecology, physiography, evolution history, oceanography, limnology, paleontology, systematics, and evolution, and consequently these are able to explain the evolution of relationships between specific species. Zoogeography is based on the following observations:

- every species and higher taxa of animal has a non-random distribution in time and space;
- different geographical regions have sets of typical animals that co-exist, e.g., the fauna of the Baltic Sea is different from that of the Black Sea;
- these differences (and similarities) cannot be explained only by the distances between regions. They are readily observable patterns that refer to species composition and higher animal taxa that developed at the same time and place.

One must remember that the fauna differed distinctly in all geographic regions from that occurs now. Studies have indicated that animals resembling those occurring today or their ancestors could have previously lived in locations that are far removed from their current ranges of occurrence.

Zoogeographic studies of parasites began in 1891 with the work of von Ihering, who noted the significance of the role of parasites in the zoogeography of hosts. Although he was not a parasitologist, von Ihering noted a strict relationship between commensalistic turbellarians and freshwater crustaceans inhabiting both sides of the Andes Mountains and in New Zealand. This provided evidence of the previous biogeographic link between these two lands.

The zoogeography of marine parasites was also studied by Manter (1940, 55, 63). He focused on the relationships and geographic distribution of Digenea along the Atlantic and Pacific coasts of Central America, the biogeographic aspects of marine fish digeneans of America, and the same group of parasites of freshwater fish in South America. Most of these biogeographic arguments lacked foundations stemming from the continental drift theory. Nevertheless, Manter prompted a new approach to studies of marine parasites. In the late 1970s, the earlier term of biogeography was linked with the already accepted continental drift theory and cladistics to create a new research program with repeatable methods that focused on interpreting biogeographic and evolutionary models (Brooks and McLennan, 1993).

Over time, two main trends emerged in zoogeographic models: historical and ecological.

The historical trend recognizes that each geographic region has different species aggregations, and that some systematic groups of organisms exhibit tendencies to aggregate in the same geographic regions where the simultaneous impacts of climate, location, and evolutionary processes are responsible for the general directions of the development of fauna over long periods. Emphasis in this kind of research is placed on the dynamics and statics of the main geographical and geological events affecting vast areas over significant periods spanning as much as millions of years. This approach is based on different groups of animals that evolved simultaneously.

The ecological trend attempts to elucidate the patterns of current distributions primarily through the range of ecological requirements of animals with a particular focus on environmental parameters, physiological tolerance, and the adaptive abilities of the

organisms. Special emphasis is placed on the statistic and dynamics of current events or those which occurred not long ago, but little attention is paid to the time or space of the phenomenon studied.

Initially, zoogeographic studies of marine organism parasites focused mainly on the waters of the northern hemisphere. The first wide-ranging studies of freshwater parasite fauna in the USSR were conducted by Šul'man (1961) and Polyanski (1961). In the 1980s ecological and zoogeographic studies were initiated by Rohde (1981, 1982, 1984), who drew attention to the fact that the parasite distribution in the seas and oceans is uneven. Rohde noted that the Indo-Pacific has more parasite species than does the Atlantic Ocean, and that the species composition in these two areas also differs. He also described the role of latitudinal gradients in parasite species diversity emphasizing that not only is there an increase in the absolute numbers of teleost monogeneans towards the equator, there is likely also a relative increase in the number of parasite species because of the greater number of host species. He also compared the prevalence and intensity of Monogenea infection at various geographic latitudes and concluded that frequencies of occurrence are higher in the tropical zone, while intensity of infection differed significantly and did not exhibit any trends. Rohde explained that in the tropical zone more species can co-exist since their niches are smaller.

Within the context of zoogeography, discussions about temperature center around its significance to the distribution of parasites and to the phenomenon of fluctuations of parasite infection in warm and cold seas, and differences in the species composition between parasite fauna in deep and shallow waters, and the occurrence of relic and endemic species in isolated basins. According to the continental drift theory, it has been confirmed that the Pacific is older than the Atlantic by about 150,000 years, as is probably explained by the occurrence of more species in the Pacific as there has been more time for them to originate and accumulate. The role of zoogeography is crucial in studies of the significance of host migration to parasites, and the possibility of using parasites as biological indicators of host movement and the existence of separate breeding stocks of the same host species. The origin and co-evolution of parasites, their host species, and host specificity are also studied. The zoogeography of parasites is also useful in studies of the origin of host genera (Williams & Jones, 1994).

Different groups of factors and processes can impact the geographic distribution of parasites and their hosts depending on the scale considered. On a global scale, the following can impact distribution:

- the division and movements of land and the appearance of natural geographic barriers that divide and separate biotas (vicariance). For marine organisms, this can be the appearance of new isthmuses or changes in water currents;
- the ability of organisms spread either passively or actively – with parasites, many free-living stages spread actively, while only eggs and internal parasites spread passively;
- the time-frames within which vicariance and spreading occur; in the majority of these types of cases, it was the consequences of both processes.

The success of colonization is determined by many biotic and abiotic factors that influence the reproduction and survival of organisms. For many free-living organisms, competition, predation, and parasitism are important biotic factors impacting their distribution. For parasites this is probably the host biology. On a smaller scale, these factors become more specific. In the marine ecosystem the most important factors are temperature, salinity, depth, and currents. The use of parasites as biological tags in population studies of marine

fish and mammals has proved to be a successful tool for discriminating stocks for all species to which it has been applied. Parasitological data are valuable when conventional tagging are not feasible or it costly and can give misleading results. The distribution patterns of marine parasites are determined mainly by temperature-salinity profiles and by their association with specific masses of water. Analyses of distribution patterns of some parasite species in relation to gradients in environmental (oceanographic) conditions showed that latitudinal gradients in parasite distribution are probably directly related to water temperature. Indeed, temperature, which is a good predictor of latitudinal gradients of richness and diversity of species, shows a latitudinal pattern in south-western Atlantic coasts, decreasing southwards, due to the influence of subtropical and subantarctic marine currents flowing along the edge of the continental slope. This pattern also determines the distribution of zooplankton, with a characteristic specific composition in different water masses. The gradient in the distribution of parasites determines differential compositions of their communities at different latitudes, which makes possible the identification of different stocks of their hosts (Timi, 2007). The eggs and cysts (propagules) of many parasites can be dispersed by the host as it moves and by moving water. Ocean current may be an effective mechanism of dispersion over larger areas and increase the parasites spatial distribution and their chance of coming in contact with an appropriate host (Bush et al., 2002).

5. Host range and distribution

5.1 Protista and Myxozoa

The Protista are characterized by a vast diversity of form and function. To date, about 100,000 species representing 40 families of free-living and parasitizing organisms have been identified, the most important of which are as follows.

The Microsporidia are strictly intracellular eukaryotic parasites (2 - 12 μm size range) characterized by simple ellipsoid unicellular spores containing sporoplasma and single coiled polar tubes, through which, following extrusion, the infectious sporoplasma enters the host cell. Microsporidia infect vertebrates and invertebrates, and the parasite enters the host body through ingestion. Microsporidia can reproduce sexually or asexually, and the life cycles of different species vary.

To date about 100 species belonging to 16 genera parasitizing fish have been identified throughout the world (Lom, 2002). Depending on the location the parasite settles, it causes cell and tissue damage that delays development, growth, or reduces fecundity. It can also cause the mortality of the host.

The majority of Mastigophora are free-living aquatic organisms, but representatives of the families Dinoflagellata and Kinetoplastida are marine organism parasites. They are mostly uninucleated organisms that are equipped at some stage in their life cycles with one or more flagella that permit them to move. Reproduction is either asexual (usually by longitudinal splitting) or sexual.

To date about 4,000 species of Dinoflagellata, including 140 species of external parasites of crustaceans and fish, have been identified. Most of these have chloroplasts, some contain dyes that accumulate in the tissues of fish or filter-feeding shellfish. These dyes are neurotoxins for the mammals that consume the fish or shellfish. The greatest impact of parasitic dinoflagellates is noted in warm-water marine fish, especially in intensive mariculture (Paperna, 1984).

Among the approximately 500 Kinetoplastida species that have been described to date, many parasitize the blood of vertebrates. Their development proceeds with either one or two hosts – fish that are infected by leech vectors. These parasites are distributed widely throughout the world.

Most of the terrestrial and aquatic species of Ciliophora are free-living organisms. Over 150 species, most of which are ectoparasites, occur in fish. Their systematic classification is based mainly on many morphological characters, the course of the developmental cycle, habitats, and life style. These organisms have vegetative macronuclei and reproductive micronuclei, cilia at certain stages of life, and cell membranes. Asexual reproduction occurs through horizontal splitting. Some species also reproduce through conjugation. Marine and brackish-water parasites include sessile ciliates which can live singly or stalked and bearing a colony (Lom & Dykova, 1992). The juvenile stages are free-swimming thanks to cilia that are deployed in a wreath-like structure.

Peritrichous ciliates are often noted on the skin and gills of freshwater and marine fish from the northernmost to the southernmost latitudes of the temperate and tropical zones (Fig. 1.). Their adhesive discs have crowns of hard denticles (Fig. 2.). The shape of these discs as well as the number and structure of the hard denticles are the most useful character for determining species. Transmission is direct among these parasites with low specificity.

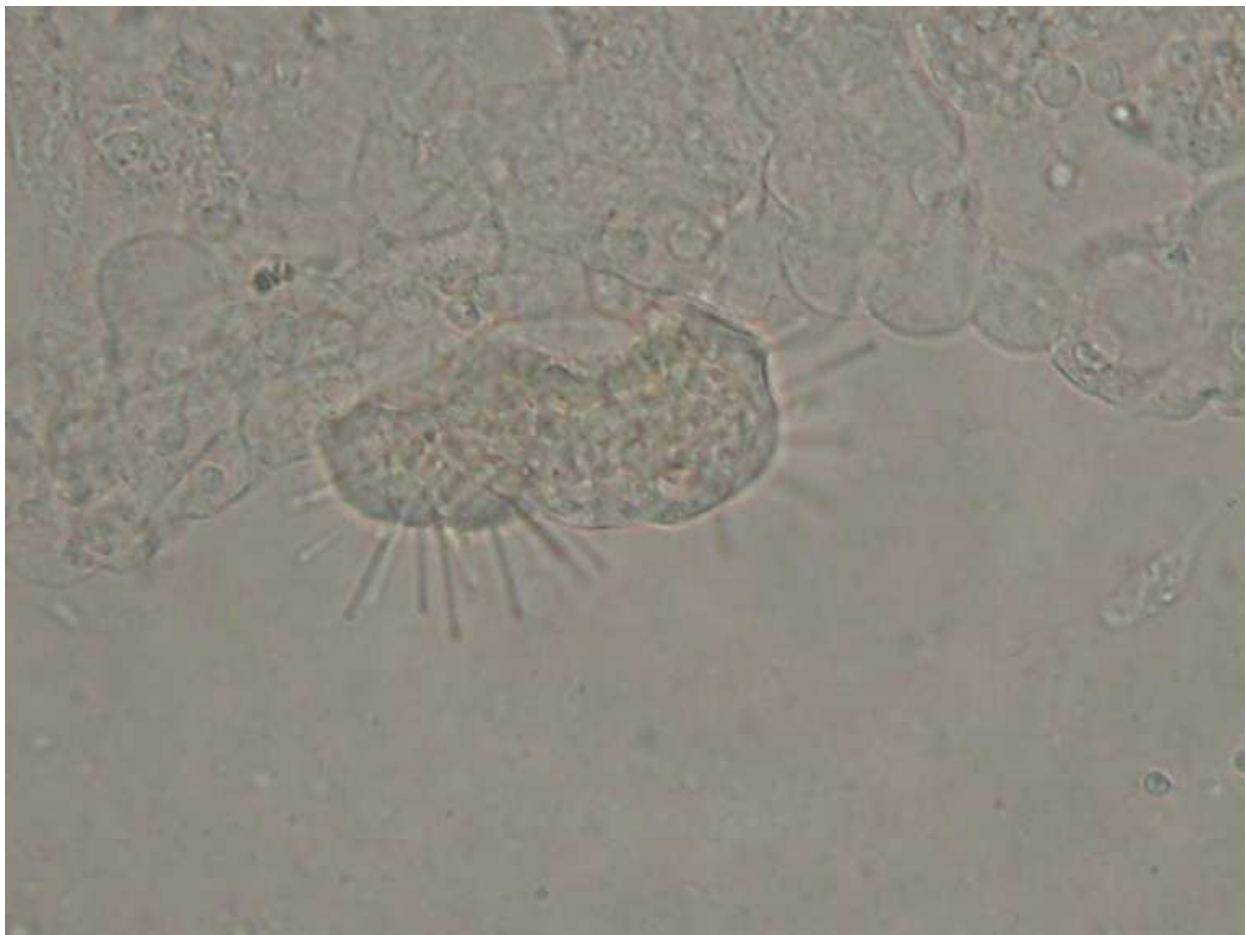


Fig. 1. Peritrichous ciliates on the gills of Chinese mitten crab (microscopic slide, magnification 400x, photograph by E. Sobecka)



Fig. 2. Adhesive disc of *Trichodina* sp. (microscopic slide, magnification 400x, photograph by E. Sobecka)

Ciliates of the orders Prorodontida and Dysteriida are dangerous parasites of fish. The first is a holotrichous ciliate, which occurs in the seas of the tropical, subtropical, and temperate zones. It infects the epithelium of the skin, gills and eyes causing excessive mucus production, epithelial hyperplasia, damage to the continuity of the external covering with the possibility of repeat infection, and impaired gas exchange. Ciliates from the order Dysteriida are cosmopolitan parasites that usually occur in small numbers in the tropical zone; however, when conditions are especially good, it is a cause of high fish mortality (Gallet de Saint Aurin et al., 1990).

Myxozoa are commonly noted fish and invertebrate parasites. To date, about 2,800 species belonging to 61 genera, of which the vast majority are fish parasites, annelid worms, or bryozoans. The first description of a parasite of this group dates to the early nineteenth century (Leydig, 1851). The discovery that *Buddenbrockia* sp., a nematode-like parasite of freshwater bryozoans is a myxozoan, and that the myxozoans originate from bilaterians allowed for a better understanding of the known endoparasites of fish and worms in the class Myxosporea (Okamura et al., 2002). Phylogenetic and genetic studies conducted at this time led researchers to the conclusion that Myxozoa are highly specialized Metazoa that are the cause of several diseases occurring in aquaculture and among wild stocks that are of economic consequence (Feist, 2008). The phylum Myxozoa has two classes – Myxosporea and Malacosporea. The Myxozoa classification depends on spore morphology, but these are increasingly linked with the results of molecular studies (Fiala, 2006; Lom & Dykova, 2006).

Many species have complex life cycles; annelids are definitive hosts whereas vertebrates are intermediate hosts for Myxosporea (Fiala, 2006). They are characterized by multicellular spores with polar capsules that contain extrudible polar filaments that attach to host cells (Fig. 3). These are parasites inhabit tissues or cavities (histozoic), or many organs (coelozoic). Myxozoans occur in fresh, brackish, and marine water throughout the world. They have been noted to infect teleost fish, elasmobranchs, amphibians, reptiles, and, in single cases, octopuses (Arthur & Lom 1985, Heupel and Bennet 1996, Helke & Poynton, 2005; Yokoyama & Masuda 2001). The actinospore stage is noted in polychaetes and sipunculids (Køie et al., 2004). Thanks to their specificity in marine fish and the fact that infections can persist for a lifetime, myxosporeans are used in studies of stock discrimination.

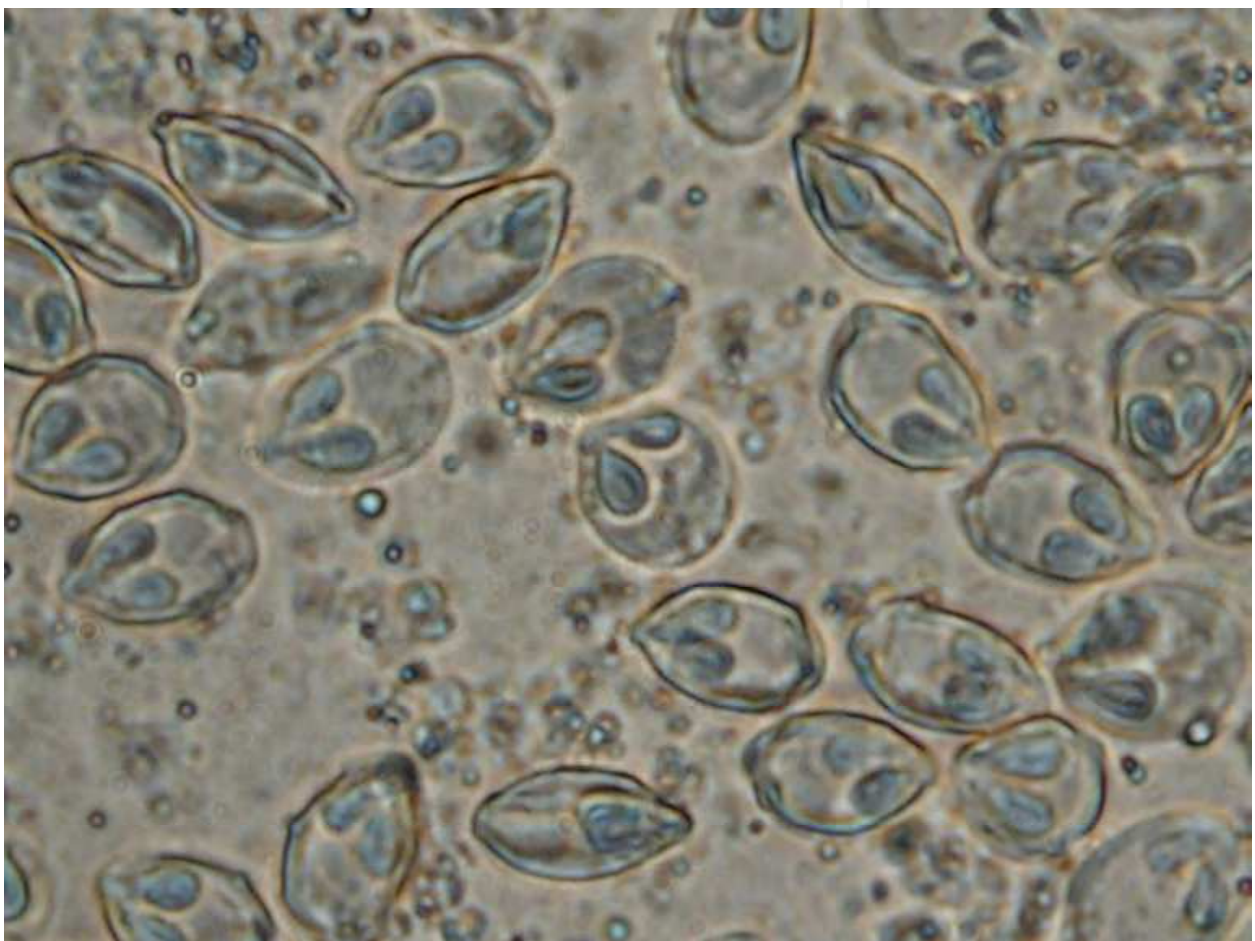


Fig. 3. *Myxobolus* sp. spores on the gills of fish (microscopic slide, magnification 1000x, photograph by E. Sobecka)

5.2 Monogenea

The range of marine animals parasitized by monogeneans includes chimaeras, sharks, rays, Cyclostomata, lungfish, and teleosts, but they infect amphibians and reptiles less frequently (Cone, 1995; Kearn, 1963; Poynton et al., 1997). They settle on the gills, skin, fins, and sometimes in the mouth and nasal cavities and in the urogenital system. Most species occur on one host species, so their range of occurrence coincides perfectly with that of the host species. These are small hermaphroditic organisms (0.1 - 20 mm length range) with a dorsal-

ventral flattening of the body that is usually elongated. It is easy to distinguish them from other flat parasitic worms because of the posterior attachment organ – the opisthaptor, which is its main attachment organ (Fig. 4). The highly varied build and armaments is one of the main taxonomic characters that distinguishes two subclasss – Monopisthocotylea (opisthaptor with hooks) and Polyopisthocotylea (opisthaptor with suckers). The anterior end of monogeneans also have an attachment organ (prohaptor) which can have suckers, warts, pits, growths and attachment glands. The prohaptor is used as the parasite moves. In addition to the differences mentioned earlier in the build of the opisthaptor, the systematic division into two subclasss is based on micro-habitats inhabited, diets, and parasite mobility (Boeger & Kritsky, 2001). Approximately 1,000 species of marine Monopisthocotylea are known. They can inhabit different micro-habitats in fish, feed on mucus and epithelial cells, and very actively move around the body surface of the host (Whittington, 2004).

Polyopisthocotylea, of which to date 1,000 species have been described, usually settle on the gills of fish, feed on blood, and generally spend the majority of their adult lives in one place.



Fig. 4. Posterior attachment organ of monogenean belonging to the subclass Monopisthocotylea (microscopic slide, magnification 400x, photograph by E. Sobecka)

The monogeneans have a single-host reproductive cycle without a intermediate host. This oviparous species releases eggs into the water. When they hatch, the slow-moving, ciliated larvae have to find a host relatively quickly. With viviparous monogeneans, the uterus of the mother releases a fully-formed parasite of the next generation which carries an embryo of the subsequent generation.

Marine monogeneans from both subclasses occur in both brackish and oceanic waters from the littoral zone to the open waters of all the climate zones.

5.3 Digenea

Digeneans, or flukes, are a very abundant group of flatworms (Platyhelminthes) and one of the most abundant groups of parasites. Along with a small group of species from the subclass Aspidogastrea, they comprise the class Trematoda. Approximately 5,000 species from 70 families are fish parasites, the most frequently noted of which are trematodes belonging to Hemiuridae, Fellodistomidae, Bucephalidae, Derogenidae, and Lecithasteridae (Fig. 5.). Sea turtles and iguanas, semi-marine crocodilians, and sea snakes are all infected with trematodes (Yamaguti, 1971; Lafferty, 1993). While heavy parasite infection is not normally noted in sharks, rays, skates, and chimaeras, cetaceans, seals, sirenians, and other marine mammals suffer serious infections from these parasites. It is difficult not to include sea birds in this group of hosts since digeneans from several families mature in them.



Fig. 5. Adult fluke from digestive tract of fish (microscopic slide, magnification 100x, photograph by E. Sobecka)

These are generally parasites of the digestive tract, but in fish they also settle in the bladder, swim bladder, abdominal cavity, gall bladder, ovaries, and blood vessels. These organisms have highly differentiated builds and sizes. They measure from 250 μm to 12 cm in length, and the body is oval like an elongated leaf and usually with dorsal-ventral flattening. Most species have an oral sucker at the anterior end of the body which surrounds the oral opening. The ventral sucker is only for attachment, and its presence and location are both important taxonomic characters. The body surface area can be smooth or it can be covered with scales of different shape of size.

Most Digeneans are hermaphrodites, with only a few families (e.g., Schistosomatidae) that are gonochoristic. They have a complex developmental cycle; after one generation reproduces sexually, the next few generations reproduce asexually (or parthenogenetically, as some researchers prefer). The asexual generations are created with one fertilized egg which develops with ciliated miracidium equipped with eye spots and a group of reproductive cells.

The first intermediate host of the flukes, into which the miracidium must actively penetrate, are snails, mussels, or polychaete annelids. Once there, they transform into mother sporocysts that resemble bags without a hint of either reproductive or digestive systems. One should bear in mind that this is not a larval stage, but is sometimes referred to as the first intramolluscan generation (Rohde & Rohde, 2005). The germinative cells develop into the second asexual intramolluscan generation, known as the daughter sporocyst, or the mother rediae. Rediae settle in the liver-pancreas of the host where they produce a generation of rediae, and then finally cercariae.

The development of sex generations can have two larvae: cercaria and metacercaria. The first is equipped with a tail and swims easily searching for a host (intermediate – invertebrate or vertebrate) into which it usually actively penetrates and settles into the organ that is typical of its species and where it transforms into a metacercaria. This is a small fluke with an immature reproductive system. If the subsequent (definitive) host consumes the infected intermediate host, the metacercaria will develop into a mature digenean in the digestive tract, and less frequently in other organs.

The typical digenean developmental cycle require three hosts, of which molluscs (first intermediate host) are the hosts of the asexual generation, invertebrates or vertebrates (the second intermediate host), in which metacercariae live, and the vertebrates (definitive host), in which hermaphroditic adults mature. The fluke life cycle can be shortened if one of its hosts is unavailable (but not that in which the asexual generation lives). Along with asexual reproduction in the first intermediate host, the reproductive success of digeneans increases, and they are considered to be a perfect evolutionarily-adapted group of parasites.

The different digenean families exhibit different specificity regarding definitive hosts, and rarely are they limited to just one group (e.g., manatee and dugongs). Most of them do not exhibit such tendencies, and the choice of host is usually determined by the composition of its food. The specificity range with regard to the first intermediate host is narrower and does not extend beyond a few species of molluscs. Digeneans occur in the seas of all the climate zones.

5.4 Cestoda

Cestodes, members of the Platyhelminthes, include about 5,000 species from two groups: Cestodaria, which comprises two orders – Gyrocotylidea and Amphylinidea, and

Eucestoda, which comprises 11 orders. This second group will be the focus of this section. Three of these 11 orders are exclusive marine organism parasites. Three others are primarily marine organisms. Eucestoda are parasites with bodies composed of three sections : the attachment organ or scolex, the shape of which and the presence or absence of armaments are characteristic for the representatives of different orders, the short neck where growth occurs, and the ribbon-like body (strobila) and segregated into a linear series of compartments (proglottids) comprising one or more sets of reproductive organs (Caira & Reyda, 2005). In this way, tapeworms meet their reproductive role as there are as many individuals as there are compartments in its strobila. The number and position of the various elements of the reproductive system are subsequent taxonomic characters in the systematics of these parasites. The length of tapeworms ranges from several millimeters to nearly 20 meters. Tapeworms lack a digestive system, and the surface area of the body is capable of absorption. Adult parasites inhabit digestive tracts, and rarely the neighboring organs.

The development of marine eucestodes is not fully understood, and the full developmental cycle has been described only for tapeworms from five orders. The life cycle is complex and begins when an embryonated egg containing a larva (hexacant) is expelled by the definitive host into the water (Chervy, 2002). Here it is swallowed by its first intermediate host, which can include any of the following: Polychaeta; Gastropoda; Euphausiacea; Amphipoda; Copepoda; Cirripedia; Branchiopoda. Some Trypanorhyncha and Pseudophyllidea have free-living larvae (coracidium). The egg or coracidium that is swallowed by the intermediate host develops into the second larva (cercoïd). Further development happens in the subsequent host, which can be any of the following: Cnidaria; Nemertea; Ctenophora; Mollusca; Arthropoda; Echinodermata; Chaetognatha; Agnatha; Chondrichthyes; Osteichthyes; Chelonia; Cetacea; Pinnipedia. This group also includes paratenic hosts, and for some groups of tapeworms, this is also the definitive host, in which the parasite develops into adult form. For others is it simple another intermediate host, in which the third larva develops (metacercoïd, Fig. 6.). These hosts include Chondrichthyes (Chimaeriformes, Batoidea, Galea), Aves, Mustelidae, Pinnipedia, and Cetacea (Caira & Reyda, 2005). Thus, the only developmental form that inhabits the external environment is the hexacant, while the others inhabit subsequent hosts and shape at each stage of development parasite-host relationships.

5.5 Nematoda

Nematodes (roundworms) are one of the numerous types in the animal kingdom with 256 families and in excess of 40,000 species (Anderson, 2000). Many species are free-living, but there are also plant and animal parasites. Nematodes have adapted to every possible inhabitable environment from the tropics to the polar regions. They are even noted in desert sand and natural hot springs. The phylum Nematoda comprises the classes Adenophorea and Secernentea (Anderson, 2000), and parasitic nematodes belong to both. Marine nematodes are grouped into seven orders. Parasite nematodes are generally larger, deposit more eggs, and live longer than do free-living nematodes. They are characterized by the constant number of cells that comprise the adult organism. They measure from 1 mm to 1 m. The nematode body is cylindrical and elongated, but it can be filiform and symmetrical bilaterally. The digestive tract has three sections, and its

structure as well as that of the mouth opening are important taxonomic features. Nematodes (roundworms) are mostly dioecious, and females and males are distinctly different from each other. Eggs are deposited at various stages of development (Fig. 7.). Post-embryonic development include four larval stages, and the juvenile nematode will then undergo four molts before it becomes an adult. During each of these, the larvae shed their old covering in favor of a newly made one. Each moult is preceded by a change in structure regarding the development of digestive and reproductive tracts. Among parasitic nematodes, there are species that require just one host for their developmental cycles (monoxenic life cycle). The hosts for monoxenic marine nematodes include annelids, molluscs, echinoderms, and crustaceans. The development with a heteroxenic life cycle is possible with the participation of intermediate hosts and paratenesis (the use of paratenic or transport hosts). These are crustaceans, jawless fish, Chondrichthyes, and other fish. Birds and marine mammals are definitive hosts for this group of nematodes. Larval nematodes tend to be more widely distributed than are adults, probably because they are less specific in their choice of host.

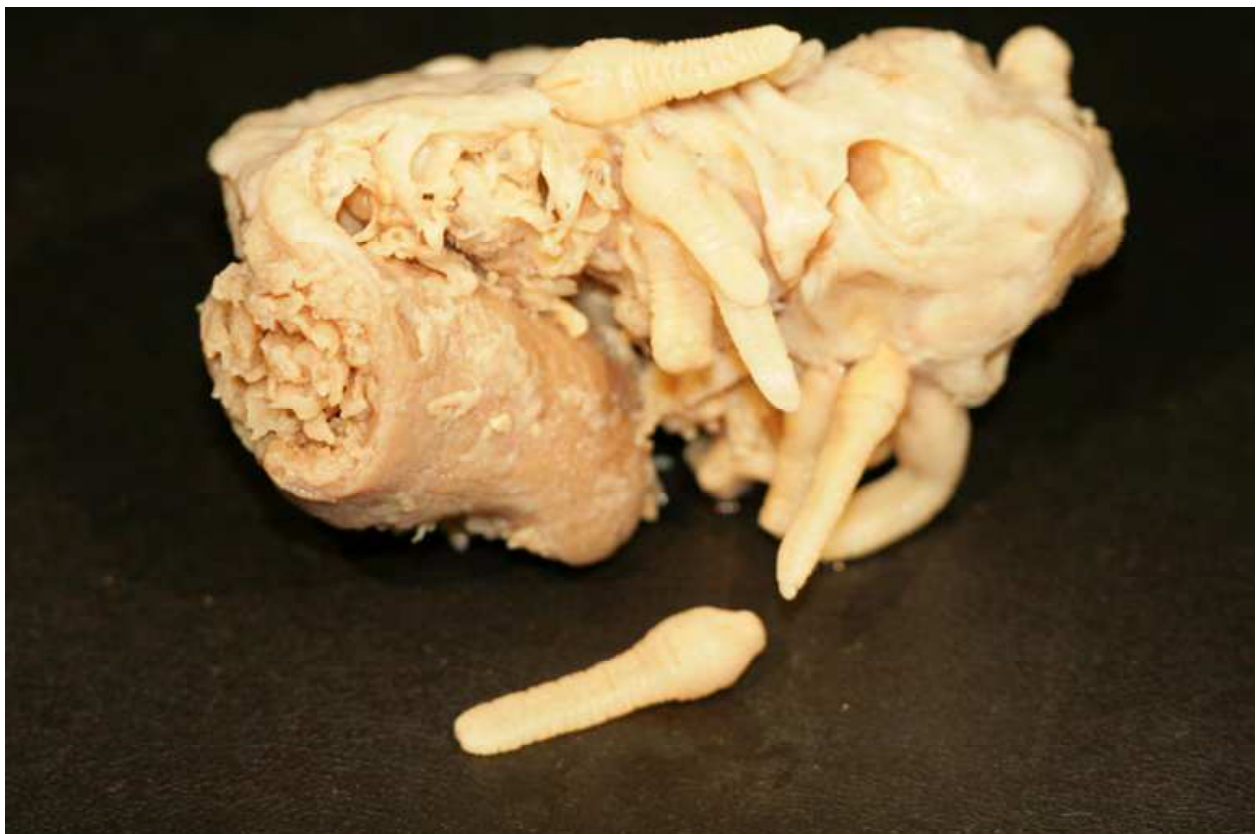


Fig. 6. Trypanorhynch *Hepatoxylon trichiuri* larvae from the liver of snoek, *Thyrsites atun* (photograph by S. Keszka; specimens from the collection of the Division of Fish Diseases, West Pomeranian University of Technology in Szczecin, Poland)



Fig. 7. Eggs of nematodes (microscopic slide, magnification 200x, photograph by E. Łuczak)

5.6 Acanthocephala

Acanthocephalans, also known as thorny or spiny-headed worms, are exclusively parasitic organisms. Over 1,000 species have been noted, and of these nearly half are parasites of the digestive tracts of fish (Taraschewski, 2005). The remaining are noted in amphibians, reptiles, birds, and mammal. The body of the acanthocephalans is cylindrical, slightly flattened, and divided into three parts: the front (praesoma) with its proboscis: a protrusible, armed attachment organ, the neck and the longest posterior section (metasoma) where the internal organs are. The proboscis is spindle shaped, cylindrical, or spherical and has rows of hooks, the number, shape, and arrangement of which are very important taxonomic features. Some systematists insist that because of the likeness of the attachment organs, the lack of a digestive system, and similar excretion systems and developmental cycles mean that all acanthocephalans and tapeworms can be combined. However, body shapes, a similar muscular build, and a pseudocel similarity to the nematodes. Phylogenetic studies have shown that, along with Rotatoria, they do form one taxon (Herlyn et al. 2003). Acanthocephalans from the order Archiacanthocephala are parasites of terrestrial animals while representatives of Eoacanthocephala and Palaeacanthocephala inhabit aquatic vertebrates.

Mature parasites measure from several mm to about 60 cm. These organisms are dioecious, and females are larger than males. The developmental cycle is complex; its eggs contain

fully-formed larvae (acanthors), which, one in the aquatic environment, are swallowed by crustaceans, the intermediate hosts. In the body cavity of the crustacean, the acanthor transforms into the second larval stage (acanthella), which, in turn, makes a cyst and transforms itself into a cystacanth, the larval third stage that invades the definitive host (Fig. 8.). The larvae that are swallowed along with the intermediate host attaches itself to the mucus membranes of the intestines and it matures. The paratenic host actually plays a role in the development of some marine species of acanthocephalans. If the definitive host is a bird or a marine mammal, the amphipod serves as an intermediate host and fish as the paratenic host. The wide specificity with regard to both intermediate host as well as to the definitive host makes acanthocephalans cosmopolitan parasites.

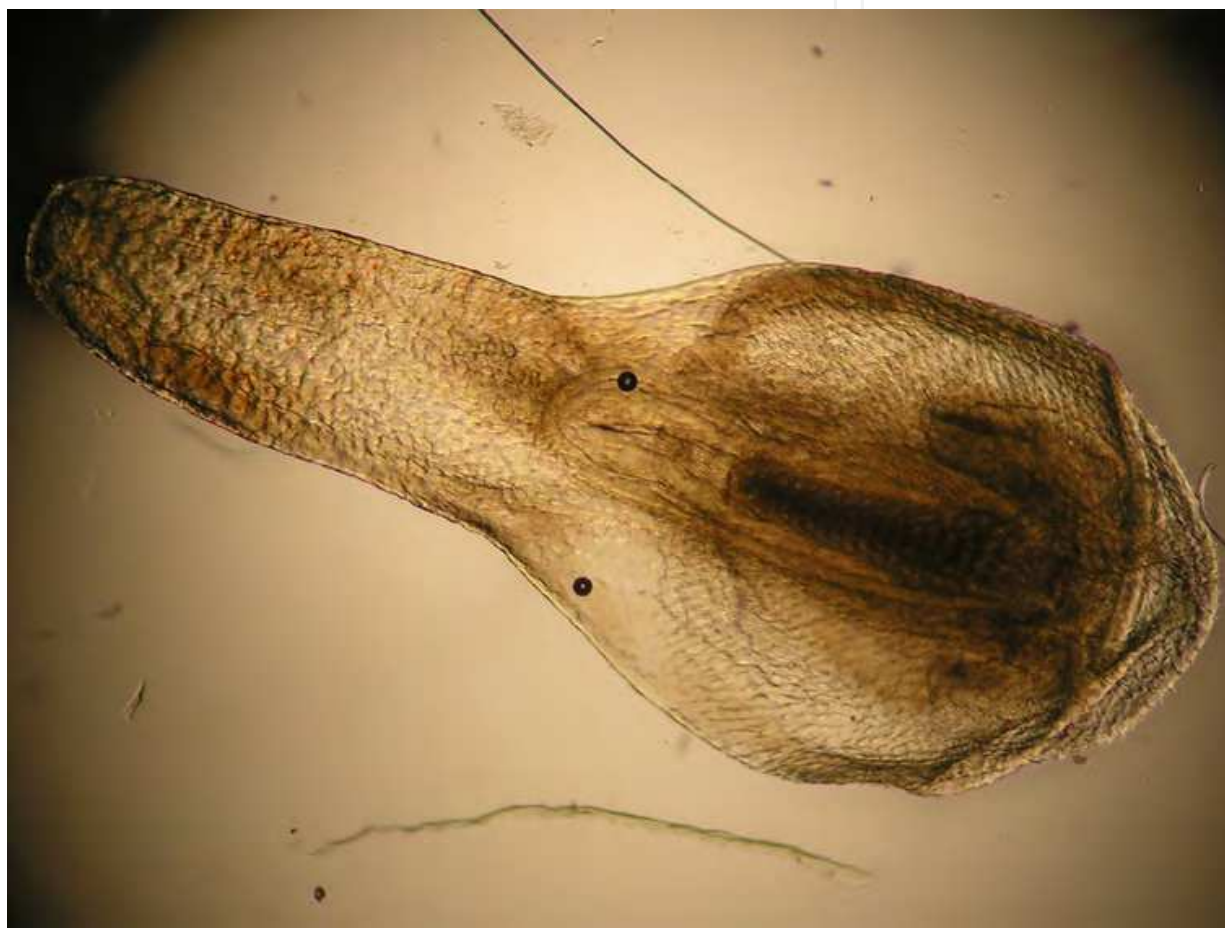


Fig. 8. Cystacanth, the larval third stage of *Corynosoma* sp. from the body cavity of fish (photograph by E. Łuczak)

5.7 Crustacea

Crustacea comprises a group of animals that is omnipresent and the most morphologically differentiated. Most of the species are marine. Among the approximately 50,000 species identified to date, many are parasitic and infect a wide spectrum of host from cnidarians to vertebrates (Bush et al., 2002). The classification of parasitic crustaceans based on Martin and Davis (2001) includes four subclasses, of which the most numerous is Copepoda (11,500 species, 29 orders). These are mostly endo- or ectoparasites of fish and invertebrates, and, to a lesser extent, of marine mammals.

The complexity of adaptations of copepods to the parasitic way of life is positively correlated with the length of time of their evolutionary association with the host. Those copepods that, in size and shape, are similar to free-living 'relatives', have slightly altered builds, retained the ability to swim, and their association with the host is only constant at the adult stage. Well-adapted species modified their build, biology and developmental cycle to such a degree that they almost entirely eliminated free-living developmental stages and increased the numbers of eggs released (Piasecki & Avenant-Oldewage, 2008). Parasite membership in the subclass Copepoda can sometimes only be confirmed thanks to the presence of two egg sacs in the female and nauplii. The males are usually smaller and less altered, with adult stages located near or attached to the females. Among the parasitizing copepods, some species are very small (about 1 mm) and very large (up to 60 cm in length). The developmental cycle of free-living copepods comprises two phases – naupliar (6 stages) and copepodit (5 stages). These same phases also occur during the development of parasitic copepods; the only difference is that most species reduced the number of naupliar stages. The parasites of marine fish are copepods from about 30 families. Most of them have a very narrow host specificity that is limited to even a single species.

The Isopoda parasite group is less abundant than the copepods with just about 450 species, the majority of which are marine ectoparasites inhabiting tropical and subtropical waters (Möller & Anders 1986) (Fig. 9). Juvenile and adult isopod stages from the families Cymothoidae and Aegidae parasitize fish, and also elasmobranchs and crustaceans in small numbers. Gnathiidae males and females are free living as adults. Cymothoidae are forms of protandrous hermaphrodites, which indicates that the specimens develop and function first as males and can then become females. The presence of mature females hampers the further development of males (Grabda, 1991). They measure from 1 to 6 cm in length. Gravid females release eggs into a brood pouch or 'marsupium' formed from their ventral oostegites, where all of larval development occurs.

Gnathiidae is a small group of parasitic isopods that includes about 50 species. They only parasitize during the larval stage. Freshly hatched larvae settle on fish, moult three times before maturing into adults, and then leave the fish host to settle in pairs in the muddy sediments of an aquatic basin where they stop eating, reproduce, and then finally die.

Branchiura, commonly known as fish lice, is a small group of crustaceans that includes about 175 species of parasite from one the family (Boxshal, 2005). They inhabit the surface of the fish body, and less frequently in the gill or mouth cavities. Very few species inhabit marine coastal waters or estuaries, and it is not observed in the open waters of the oceans. The dorsal-ventral flattening of their bodies is pronounced, which allows them to better cling to the host. They are nearly transparent or milky white. The head of the parasite is fused to the first trunk segment, and the large, deep-set movable eyes are visible. On each free trunk segment there are a pair of legs, thanks to which the parasite can switch hosts. The females deposit their eggs in a mucus cocoon that they attach to rocks or vegetation. Swimming larvae hatch from these eggs, find a host, and begin to feed on the host's blood.

The discussion of parasitic crustaceans should include Ascothoracida, Tantulocarida, and Cirripedia. The first of these, Ascothoracida, are ecto-, endo-, mezoparasite echinoderms and cnidarians. Tantulocarida is a group of small (up to 2 mm in length) marine crustaceans that are parasites of many other crustacean species. Rhizocephalan Cirripedia are also crustacean parasites. They are considered to be the most modified of all crustaceans, and are an example of excellent adaptation to the parasitic life strategy (Bush et al., 2002).



Fig. 9. Adult isopod belonging to the family Cymothoidae from the gill chamber of fish (photograph by E. Łuczak)

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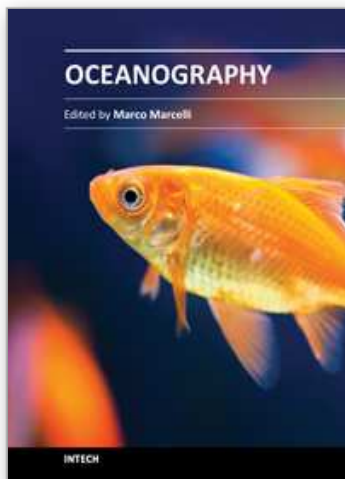
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How inappropriate to call this planet Earth when it is quite clearly Ocean (Arthur C. Clarke). Life has been originated in the oceans, human health and activities depend from the oceans and the world life is modulated by marine and oceanic processes. From the micro-scale, like coastal processes, to macro-scale, the oceans, the seas and the marine life, play the main role to maintain the earth equilibrium, both from a physical and a chemical point of view. Since ancient times, the world's oceans discovery has brought to humanity development and wealth of knowledge, the metaphors of Ulysses and Jason, represent the cultural growth gained through the explorations and discoveries. The modern oceanographic research represents one of the last frontier of the knowledge of our planet, it depends on the oceans exploration and so it is strictly connected to the development of new technologies. Furthermore, other scientific and social disciplines can provide many fundamental inputs to complete the description of the entire ocean ecosystem. Such multidisciplinary approach will lead us to understand the better way to preserve our "Blue Planet": the Earth.

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