

Marine parasitology with special reference to Japanese fisheries and mariculture

K. Ogawa

Department of Aquatic Bioscience, Faculty of Agriculture, The University of Tokyo, Tokyo, Japan

Abstract

Marine parasites with special relation to Japanese fisheries and mariculture include various types of pathogens: those causing mortality, deformity, weight loss, etc.; those giving unesthetic appearances to the hosts; those which are zoonotic. Japanese mariculture typically utilizes net cage culture systems in coastal areas. Parasite invasion in such systems is more difficult to control practically than in freshwater facilities. The limited use of chemicals and drugs for treatment makes the situation even more difficult to handle. About five species of parasites from marine organisms are known to be zoonotic. This is closely associated with the Japanese tradition of eating raw fishes and invertebrates. Infection of maricultured species with zoonotic trematodes, cestodes and nematodes has not been confirmed. On a more positive side, attempts have been made to utilize parasites as biological tags to obtain information on host biology, ecology, etc.

Recent trends in Japanese mariculture include technical improvement in seed production and importation of large quantities of various species of culture seedlings. Drastic increase in the supply of seedlings of selected fish species has resulted in changes in culture methods and created parasite problems on a much larger scale. International trade of live fishes and shellfishes has introduced parasites hitherto unknown to Japan. An efficient quarantine system to prevent and control introduction and spread of marine parasites urgently needs to be established.

Keywords: Marine parasitology; Mariculture; Fisheries; Japan; Zoonosis; Biological tag

1. Introduction

Parasitism is a ubiquitous phenomenon in the marine environment. Ruiz (1991) assumed that probably all marine species are infected with parasites of various kinds. This assumption is also applicable to economically important marine fishes and invertebrates. These parasites provide numerous research opportunities on different aspects such as pathogens, economic impact, zoonoses, biological tags, etc. Parasites of marine

invertebrates are not included in this paper, mainly because only a few parasites of the invertebrates are considered important in Japanese fisheries and aquaculture, and because they have not been intensively studied.

2. Fisheries and aquaculture industry in Japan

As Japan is an island country surrounded by the sea, fishing has always been a basic industry. Annual catch of marine fisheries, including aquaculture, had been consistently over 10 million tonnes (t) for almost 20 years until 1990, and then gradually decreased with decreasing catch in the pelagic waters. According to the latest government statistics, annual catch stood at 8.71 million t with a value of 2.49 trillion yen in 1993. With the decrease of annual catch in both coastal and pelagic waters, aquaculture has gained more economic importance in Japanese fisheries.

Annual production of Japanese mariculture amounted to 1.27 million t in 1993 or 14.6% of total marine fishing, with a value of 613 billion yen. This included not only fish and shrimp culture, but also non-feeding culture of seaweeds, bivalves and ascidians. Annual production of marine fish culture amounted to 259 000 t in 1993, about 20% of total mariculture production, with yellowtail *Seriola quinqueradiata* and amberjack *S. dumerili* being the most important. Production of these species yielded 142 000 t, followed by red sea bream *Pagrus major*, coho salmon *Oncorhynchus kisutch*, Japanese flounder *Paralichthys olivaceus*, tiger puffer *Takifugu rubripes*, etc.

Mariculture in Japan started with the culture of yellowtail in 1930, where fish were reared in tidal enclosures and fed with raw fish. However, since the introduction of a new method of offshore net cage culture in the 1960s, production of yellowtail rapidly increased, mainly because it provided higher productivity and better management. Now more than 20 species of marine fishes are cultured in Japan. Except for Japanese flounder, which is cultured mostly in tanks with running water, most species are cultured similarly in offshore net cages. In the early days, raw fish was used as feed, but with the improvement in facilities such as availability of storage systems provided by fish cooperatives and individual farmers, raw fish was replaced by frozen fish. This system contributed to a stable supply of feed fish. Feeding with dry or moist pellets (a mixture of frozen fish and formula feed) is now widely practiced in Japan. However, future feed may have to be modified owing to the recent sharp decline in the catch of sardine *Sardinops melanostictus*, a major source of feed fish. As to the source of seed for culture, reliance for yellowtail and amberjack was almost entirely on natural populations; fry of these fish are caught along the Japanese coast. This was also the case with the culture of red sea bream and tiger puffer until recently. However, technological innovation such as mass production of seed fish has provided artificially produced fish fry in large quantities. Many species of fish seeds, either for release to the sea or for culture, are produced by national and local governmental organizations and the private sector. Culture of Japanese flounder and carangid *Pseudocaranx dentex*, using mass-produced fry, started in the 1980s. Japanese mariculture has a history of 65 years, during which time culture systems, methods of feeding and seed supply have substantially changed.

3. Parasitic infections of cultured marine fish

Compared with parasite species of various taxa reported from wild marine fish, including protozoans (flagellates, amoebae, coccidians, myxosporeans, microsporeans), cnidarians, platyhelminths (turbellarians, monogeneans, cestodes, trematodes), acanthocephalans, crustaceans and leeches (see Kinne (1984)), those infecting cultured marine fish are limited. However, parasites whose life cycle is completed within the culture environment include pathogenic species and those which give unesthetic appearances to the hosts.

3.1. Parasitic infections associated with host feeding

Traditionally, yellowtail was fed with chopped or minced raw fish, typically anchovy *Engraulis japonica*. Infection of yellowtail with the larval cestode *Callotetrarhynchus nipponica* Nakajima and Egusa, 1973, was a parasite problem associated with feeding of raw fish. The life cycle of the trypanorhynchian cestode involves anchovy as the second intermediate host, yellowtail as the third, and carcharinid sharks as the final hosts, the first intermediate host being unknown (Nakajima and Egusa, 1972). Yellowtail became infected with the cestode through feeding on infected anchovy. With the use of frozen fish as food, the parasite disappeared from the culture sites. Other parasites originating from ingested food, such as some groups of trematodes and cestodes, may very well be excluded from cultured fish by this means.

With the recent drastic decline in catches of sardine, which represented a major source of feed fishes, trials were made to develop a new substitute feed. This includes concentrated soybean protein, instead of fish meal, as the source of protein. Experimental yellowtail fed with the new feed showed green hepatization, caused by occlusion of bile ducts by myxosporean cysts. Control fish fed with fish meal had no such infection (Maita et al., 1994). The parasite was later identified as a new species of the genus *Myxobolus*, *M. spirosulcatus*, by Maeno et al. (1995). Feeding with this specially prepared food without fish meal may have caused a decrease in the host's defense against the myxosporean. At least 10% fish meal in the total diet should have been fed to suppress the outbreak (M. Maita, personal communication, 1995).

3.2. Parasitic infections associated with net cage culture—monogenean infections

At the start of net cage culture of yellowtail, infections with the monogeneans *Benedenia seriola* (Yamaguti, 1934) on the body surface and *Heteraxine heterocerca* (Goto, 1894) on the gills were the most serious diseases. These parasites lay eggs which have a long filament. This filament entangles with the net meshing and thus eggs accumulate within the culture system. Infected fish can be treated with a freshwater bath for *B. seriola* or a bath in NaCl-added seawater for *H. heterocerca*, but eradication is difficult because of tolerance of their eggs to the above treatments. Fish farmers have to make repeated treatments. In the 1970s and 1980s, the application of organic tin coating on the net meshing, to prevent the growth of fouling organisms on the meshing,

suppressed the propagation of these monogeneans. However, the mechanism of suppression is not well understood. The recent ban on the use of the chemical, for fear of accumulation in yellowtail and environmental pollution, has resulted in the recurrence of the problem of monogenean infection. No alternative to the organic tin coating process for suppression of the infection has been developed.

Culture of tiger puffer has rapidly grown since mass production of culture seed was established in the 1980s. From then on, infection with the diclidophorid monogenean, *Heterobothrium okamotoi* Ogawa, 1991, on the gills and branchial cavity wall, became one of the most serious problems in tiger puffer culture. Immature worms are found on the gills, and adults occur half-embedded into the branchial cavity wall. Eggs of this parasite are laid as a long chain, often longer than 2 m (K. Ogawa, unpublished data, 1995) and can very easily entangle with the culture net meshing, resulting in accumulation of the eggs in the culture system. Furthermore, once infected, it becomes very difficult to treat the fish with the methods employed for *B. seriola* or *H. heterocerca* of yellowtail. The parasites feed on host blood and heavily infected fish suffer from anemia. Adult parasites tend to colonize on the branchial cavity wall, where large inflammatory lesions are formed, often leading to necrosis. Heavily infected fish may die owing to anemia and/or lesions formed by adult parasites.

Another problem caused by monogenean infections is related to seed importation. No benedeniine monogenean has been known or described from Japanese flounder and tiger puffer, either from cultured or from wild populations. However, in 1991 a new type of skin monogenean suddenly appeared on these fishes. The parasite was identified as *Neobenedenia girellae* (Hargis, 1955), hitherto unknown among Japanese fishes (Ogawa et al., 1995). A question then arose about the origin of the parasite.

It was revealed that the sudden appearance of the monogenean was closely related to culture seed importation (Ogawa et al., 1995). Fry of many fish species are either caught in the wild or produced artificially in culture, and many more additional seeds for culture are imported, mainly because a large amount of fry are available and because they are relatively cheap. One of the fish species imported is amberjack. Ogawa et al. (1995) demonstrated that the fry were infected with *N. girellae* before shipment to Japan and upon arrival in Japan. Another important point about this problem is that the monogenean showed a very low host specificity (Ogawa et al., 1995), unusual in monogenean infections. This explains why the infection has spread from imported amberjack to other domestic fishes such as Japanese flounder and tiger puffer. The timing of the infection, first confirmed in Japan, coincided well with the rapid increase of amberjack fry importation (Ohno, 1993). It is not certain whether the parasite can finally settle down in Japanese waters because of the possible difficulty in adapting to a new environment, especially to the low temperature of Japanese waters (Bondad-Reantaso et al., 1995). However, the infection has already become a serious problem in subtropical areas such as Okinawa and Ogasawara, where water temperature is higher than 15°C all year round.

3.3. Blood fluke infections

Except for blood flukes, adult trematode infections are generally not very harmful to fish. *Sanguinicola* infections of freshwater fish such as carp *Cyprinus carpio* and

rainbow trout *Oncorhynchus mykiss* are well documented (see Smith (1972)). Until recently, no such serious infections with blood flukes were known among maricultured fish.

Importation of amberjack fry from China and Hong Kong started in the late 1980s (Ohno, 1993), and now culture of amberjack relies heavily upon imported fry. Until then, however, amberjack fry caught in Japanese coastal areas were used for culture seeds, though the catch was small. Mass mortality caused by the sanguinicolid blood fluke *Paradeontacylix* spp. was first confirmed in the winter of 1984 (Ogawa and Egusa, 1986). Flukes were detected mostly in the afferent branchial arteries and heart. Eggs were accumulated in the afferent filament arteries and capillaries of the gills. Thus it was thought that fish mortality was caused by the occlusion of the blood vessels (Ogawa et al., 1989).

The intermediate hosts for freshwater *Sanguicola* are snails, whereas that of *Paradeontacylix* has not been defined. Because the fish became infected after introduction to culture sites (Ogawa et al., 1994), it was suggested that the life cycle is completed within the culture environment. *Aporocotyle simplex* Odhner, 1990, a parasite of pleuronectid flatfishes, such as *Hippoglossoides platessoides*, *Limanda limanda* and *Pleuronectes platessa* in Europe, is the only marine sanguinicolid whose intermediate host is known. Its intermediate host is a tube-dwelling polychaete, *Artacama proboscidea* Malmgren, 1865 (Koie, 1982).

In general, blood flukes of fish are one of the least studied groups of parasites, mainly because of the practical difficulty of detection in the host vascular system. However, recent research has revealed that blood flukes are not such rare parasites as might have been thought. In Japan, several species were found in marine fishes (K. Ogawa, unpublished data, 1995). In South-East Asia, cultured barramundi *Lates calcarifer* harbor hitherto unknown blood flukes (Herbert et al., 1994; Herbert and Shaharom, 1995). Another blood fluke was reported from wild fish populations of groupers of the genera *Plectropomus* and *Epinephelus* in Australia (Overstreet and Koie, 1989). As groupers are intensively cultured not only in Japan, but also in South-East Asian countries, it will not be surprising if the parasite is found from cultured groupers. It seems that blood fluke infections of marine fish are not uncommon and may become more important in marine aquaculture.

3.4. Endemic parasitic infections

Spinal curvature of fish is deformity with many known and unknown causes. Several species of wild fish, such as Japanese bluefish *Scombrops boops*, bluefin searobin *Chelidonichthys spinosus* and scribbled toby *Canthigaster rivulata*, with skeletal abnormalities, were found to harbor many parasite cysts in the brain (Maeno and Sorimachi, 1992a, Maeno and Sorimachi, 1992b). The parasite was identified as *Myxobolus buri* Egusa, 1985. Cultured yellowtail with similar symptoms have been found since the 1970s. The incidence was usually low, but sometimes about 30% of culture stocks showed the deformity. A high correlation exists between the incidence of the deformity and the presence of parasite cysts in the fourth ventricle of the brain (Sakaguchi et al., 1987). The presence of these cysts in this particular region of the brain impairs some

nervous function. However, the exact mechanism of the scoliosis has not yet been described. Once the deformity becomes fixed, infected fish never recover and completely lose their commercial value.

Several *Myxobolus* species infecting freshwater fish have two alternate hosts in their life cycle: fish and oligochaetes (El-Matbouli et al., 1992). The life cycle of *M. buri* has not been elucidated, but it is likely that this marine counterpart has a similar life cycle to that of freshwater *Myxobolus*. It is likely that wild fish are natural hosts for the myxosporean, and yellowtail become infected when they are cultured at sites where the unknown infective stage is present in the water.

Yellowtail and amberjack are cultured in south-western Japan. Trials were made to culture these fishes in Amami and Okinawa, subtropical areas of Japan. These *Seriola* species are not naturally distributed along the coastal districts of Amami and Okinawa, but these areas provided an almost ideal culture environment, where fish grew very fast. Unfortunately, they became heavily infected with the myxosorean parasite *Kudoa amamiensis* in the skeletal musculature (Egusa and Nakajima, 1980). Extensive field surveys revealed that the protozoan infection is endemic among coral fishes of the genera *Abudefduf*, *Chromis* and *Chrysiptera* in the area, and that, under culture conditions, the parasite infects yellowtail (Egusa and Nakajima, 1980) and amberjack (K. Ogawa, unpublished data, 1994). Heavily infected fish entirely lost their commercial value. The life cycle of the parasite has so far not been elucidated, thus treatment has not yet been developed. To date, control measures have not been established. The *Kudoa* infection was a result of fishes being introduced for culture to areas where the myxosporean infection is endemic. Without full knowledge on the parasites' life cycles, fish culture will be difficult in areas where the above myxosporean (*M. buri* and *K. amamiensis*) infections are endemic.

Many pathogens infecting cultured marine fish have apparently been long established at culture sites. All the important parasites discussed above may either have a direct life cycle or a two-host life cycle, where all required hosts are present within the environment. Most fish are cultured for more than a year before market time. This means that seed fish share the culture site with older generations of the same species of fish until the older ones are harvested for market. Assuming that introduced fry are free of parasites, parasites from older generations can easily be transmitted to young fish. Whereas eradication of parasites at all developmental stages can be done in some freshwater culture systems such as isolated tanks and ponds, such treatment is practically impossible in most mariculture systems. Although recent technological innovation has contributed to the increase of new fish species for culture, many of these species, such as tiger puffer and Japanese flounder, encounter parasitic infection problems which have not been experienced before. Another problem is importation of large quantities of various species of culture seedlings. An efficient quarantine system to prevent and control introduction and spread of marine parasites urgently needs to be established.

4. Parasitic infections of wild marine fish

Parasitic infections of wild fish in the marine environment are poorly known compared with those of cultured fish. This is mainly because they are not systematically

studied and because infected fish are more liable to fall as victims to predators in the natural environment. Thus it is very difficult to evaluate effects of parasitic infections among wild fish populations.

Myxosporean genera belonging to *Henneguya*, *Unicapsula*, *Kudoa* and *Hexacapsula* include species which cause the so-called jellied meat or milky condition in the skeletal muscle of marine fish (Konagaya, 1984). No signs of tissue degeneration are shown in the infected muscle fibers while host fish are still alive. In the study of yellowfin tuna *Thunnus albacares*, infected with the myxosporean *Hexacapsula neothunni* Arai et Matsumoto, 1953, Konagaya (1984) demonstrated that proteases contained in the parasite cysts caused jellyfication of the surrounding muscle tissues. The proteases, which hydrolyzed normal yellowfin tuna meat, were characterized and it was concluded that proteases produced by the myxosporean were responsible for jellyfication of host fish. No prophylactic or control measures are available.

5. Zoonotic parasites

Nine species of parasites of marine and brackish origin have been known to be zoonotic, consisting of four larval trematodes from six species of brackish water fishes, one cestode from salmonids infected during migration in the Sea of Okhotsk (Awakura et al., 1985), and four nematodes from marine fishes and squids (Table 1). Another four species (three cestodes and one acanthocephalan) are also zoonotic, probably originating from unspecified marine fishes. Human infections of these parasites are closely associated with the Japanese tradition of eating raw fishes and squids.

So far, the most important zoonotic parasites are *Anisakis simplex* (Rudolphi, 1809) and *Pseudoterranova decipiens* (Krabbe, 1878). A total of 20 582 cases of human anisakidosis were reported up to the end of 1992 (Ishikura et al., 1993). Over 100 species of marine fishes are recorded as hosts for anisakid nematodes, but four species of fishes (chub mackerel *Scomber japonicus*, horse mackerel *Trachurus japonicus*, sardine *Sardinops melanostictus* and walleye pollock *Theragra chalcogramma*) and Japanese flying squid *Todarodes pacificus* are thought to be main sources of human infection (Nagasawa, 1990). With regard to the life cycle of *A. simplex*, striped dolphin *Stenella coeruleoalba* has long been considered as the most suitable final host in Japanese waters (Kagei et al., 1967). However, recent surveys demonstrated that minke whale *Balaenoptera acutorostrata* is a more suitable final host for *A. simplex* than striped dolphin, because the adult nematode size in minke whale is far larger than that in striped dolphin (Kuramochi et al., 1995).

Larva migrans caused by a spiruroid nematode has frequently been reported (Kagei et al., 1992), and it is tentatively designated as Type X larva (Hasegawa, 1978). This larva was found in marine fishes and squids, among which firefly squid *Watasenia scintillans* was thought to be a major source of infection to man (Ando et al., 1992). The final host, possibly marine mammals in the wild, remains to be identified.

Infection of maricultured species with zoonotic trematodes, cestodes and nematodes has not been detected. As for the larval nematodes, *Anisakis* and *Pseudoterranova*,

Table 1

List of zoonotic parasites from marine fishes and squids of Japan

Trematoda	
<i>Heterophyes heterophyes nocens</i> Onji et Nishio, 1915	6 species of brackish water fishes, e.g. <i>Mugil cephalus</i> (Perciformes), <i>Chelon haematocheilus</i> (Perciformes), <i>Acanthogobius flavimanus</i> (Perciformes) <i>Mugil cephalus</i> (Perciformes)
<i>Heterophyes katsuradai</i> Ozaki et Asada, 1925	
<i>Stellantchasmus falcatus</i> Onji et Nishio, 1916	<i>Mugil cephalus</i> (Perciformes), <i>Chelon haematocheilus</i> (Perciformes)
<i>Pygiopsis summa</i> Onji et Nishio, 1916	<i>Mugil cephalus</i> (Perciformes), <i>Chelon haematocheilus</i> (Perciformes)
Cestoda	
<i>Diphyllbothrium nihonkaiense</i> Yamane et al., 1989 syn.: <i>D. latum</i> , partim	<i>Oncorhynchus masou</i> (Salmoniformes), <i>Oncorhynchus gorbusha</i> (Salmoniformes), <i>Oncorhynchus keta</i> (Salmoniformes) ^a
<i>Diphyllbothrium pacificum</i> (Nybelin, 1931)	Marine fish?
<i>Diphyllbothrium yonagoense</i> Yamane et al., 1981	Marine fish?
<i>Diplogonoporus grandis</i> (Blanchard, 1894)	Marine fish?
Nematoda	
<i>Anisakis symplex</i> syn.: <i>Anisakis</i> Type I	164 species of marine fishes, ^b <i>Todarodes pacificus</i> (Cephalopoda)
<i>Anisakis physeteris</i> syn.: <i>Anisakis</i> Type II	26 species of marine fishes, ^b <i>Todarodes pacificus</i> (Cephalopoda), <i>Loligo bleekeri</i> (Cephalopoda)
<i>Pseudoterranova decipiens</i> syn.: <i>Terranova decipiens</i> , <i>Phocanema decipiens</i> , <i>Terranova</i> type A	9 species of marine fishes
<i>Spirurina</i> gen. sp.	<i>Arctoscopus japonicus</i> (Perciformes), <i>Theragra Chalcogramma</i> (Gadiformes), <i>Watasenia scintillans</i> (Cephalopoda), <i>Todarodes pacificus</i> (Cephalopoda)
Acanthocephala	
<i>Bolbosoma</i> sp.	Marine fish?

^a Only one case of infection was reported from *O. keta*. Eguchi (1973) found one individual plerocercoid from 28 specimens of *O. keta*, and Awakura et al. (1985) tried unsuccessfully to find the cestode larva from 109 specimens of *O. keta*.

^b Nagasawa (1990).

however, the possibility of their transmission from crustacean intermediate hosts or fish paratenic hosts to maricultured fish through ingestion of infected hosts, seems likely, as the nematodes have very low host specificity to fishes. So far, there has been no record of *Anisakis* or *Pseudoterranova* infections of cultured fish either in Japan or elsewhere, including maricultured salmonid fishes in the USA (Deardorff and Kent, 1989).

6. Marine parasites as biological indicators of hosts

Parasites can provide information on host biology and such parasites are called biological tags. The efficient use of biological tags for fish studies has, of course, many limitations; MacKenzie (1983) proposed criteria for this purpose. Studies of fish biology using parasites as indicators include stock separation, seasonal migrations, recruitment migrations and adult age-dependent migrations.

Stock identification of Pacific saury *Cololabis saira* in the western North Pacific, using a parasitic copepod *Pennella* sp., was undertaken by Nagasawa et al. (1988). It was thought that Pacific saury, widely distributed in the North Pacific Ocean, consisted of three stocks: western, central and eastern (Odate, 1977). Japan exploits saury in the western and central areas with annual commercial catches exceeding 200 000 t. The parasite was first recorded in the region in 1981, and its population size rapidly increased in the following 2 years. The infected fish were recovered in the western and central North Pacific as well as in the Sea of Okhotsk and the Sea of Japan. However, the parasite population declined dramatically in 1985 with reduced distribution areas, and disappeared in 1986. The dramatic increase and decline of the parasite in the saury population was not very clear. The parasite was thought to be absent in the region before 1981 (Nagasawa et al., 1988). An unidentified species of *Pennella* was reported from Pacific saury in the eastern North Pacific. If the *Pennella* in the eastern stock is conspecific with the one in the central and western stocks, it is possible that the latter parasite was introduced from eastern stock (Nagasawa et al., 1988). The results of the distribution of infected fish suggest that Pacific saury in western and central North Pacific region consist of a single stock (Nagasawa et al., 1985).

7. Conclusion

All the above examples of parasitic infections in the marine environment, even though limited to those of economic importance in Japanese fisheries and aquaculture, clearly show that marine parasitology encompasses a very wide range and scope of studies. At present, we have only fragmented knowledge even about these important parasites. Mariculture systems are generally set in offshore waters, which makes control of parasitic infections much more difficult than in freshwater culture systems. Unique and innovative methods of disease control for mariculture may have to be developed. This is a study field which is open and fertile for veterinary parasitologists.

References

- Ando, K., Sato, Y., Miura, K., Chinzei, Y. and Ogawa, S., 1992. Further observation on the larva of the suborder Spirurina suspected as the causative agent of creeping eruption. *Jpn. J. Parasitol.*, 41: 384–389.
- Awakura, T., Sakaguchi, S. and Hara, T., 1985. Studies on parasites of masu salmon, *Oncorhynchus masou*—VIII. Observations on the seasonal occurrence of *Dipyllobothrium latum* plerocercoid (in Japanese with English abstract). *Sci. Rep. Hokkaido Fish Hatch.*, 40: 57–67.

- Bondad-Reantaso, M.G., Ogawa, K., Fukudome, M. and Wakabayashi, H., 1995. Reproduction and growth of *Neobenedenia girellae* (Monogenea: Capsalidae), a skin parasite of cultured marine fishes of Japan. *Fish Pathol.*, 30: 227–231.
- Deardorff, T.L. and Kent, M.L., 1989. Prevalence of larval *Anisakis simplex* in pen-reared and wild-caught salmon (Salmonidae) from Puget Sound, Washington. *J. Wildl. Dis.*, 25: 416–419.
- Eguchi, S., 1973. *Diphyllbothrium latum* (Linnaeus, 1758). In: K. Morishita, Y. Koyama and H. Matsubayashi (Editors), *Progress of Medical Parasitology in Japan*, Vol. V. Meguro Parasitological Museum, Tokyo, pp. 125–144.
- Egusa, S. and Nakajima, K., 1980. *Kudoa amamiensis* n. sp. (Myxosporea: Multivalvulida) found in cultured yellowtails and wild damselfishes from Amami-Oshima and Okinawa, Japan. *Bull. Jpn. Soc. Sci. Fish.*, 46: 1193–1198.
- El-Matbouli, M., Fischer-Scherl, T. and Hoffmann, R.W., 1992. Present knowledge on the life cycle, taxonomy, pathology, and therapy of some Myxosporea spp. important for freshwater fish. *Annu. Rev. Fish Dis.*, 2: 367–402.
- Hasegawa, H., 1978. Larval nematodes of the superfamily Spiruroidea—a description, identification and examination of their pathogenicity. *Acta Med. Biol. (Niigata)*, 26: 79–116.
- Herbert, B.H. and Shaharom, F.M., 1995. A new blood fluke, *Parasanguinicola vastispina* gen. nov., sp. nov. (Trematoda: Sanguinicolidae), from sea bass *Lates calcarifer* (Centropomidae) cultured in Malaysia. *Parasitol. Res.*, 81: 349–354.
- Herbert, B.H., Shaharom-Harrison, F.M. and Overstreet, R.M., 1994. Description of a new blood-fluke, *Cruoricola lates* n. g., n. sp. (Digenea: Sanguinicolidae), from sea-bass *Lates calcarifer* (Bloch, 1790) (Centropomidae). *Syst. Parasitol.*, 29: 51–60.
- Ishikura, H., Sato, S., Oya, S., Kikuchi, K., Ishikura, H. and Kawai, K., 1993. Human anisakidosis—present status of the incidence in Japan (in Japanese). *Clin. Parasitol.*, 4: 152–155.
- Kagei, N., Oshima, T. and Takemura, A., 1967. Survey of *Anisakis* spp. (Anisakinae, Nematoda) on marine mammals in the coast of Japan (in Japanese with English abstract). *Jpn. J. Parasitol.*, 16: 427–435.
- Kagei, N., Kumazawa, H., Miyoshi, K., Kosugi, I. and Ishii, A., 1992. A case of ileus caused by a spiruroid nematode. *Int. J. Parasitol.*, 22: 839–841.
- Kinne, O. (Editor), 1984. *Diseases of Marine Animals*. Vol. IV, Part 1. Introduction, Pisces. Biol. Anst. Helgoland, Hamburg, 541 pp.
- Koie, M., 1982. The redia, cercaria and early stages of *Aporocotyle simplex* Odhner, 1900 (Sanguinicolidae)—a digenetic trematode which has a polychaete annelid as the only intermediate host. *Ophelia*, 21: 115–145.
- Konagaya, S., 1984. Studies on the jellied meat of fish, with special reference to that of yellowfin tuna (in Japanese with English abstract). *Bull. Tokai Reg. Fish. Res. Lab.*, 114: 1–101.
- Kuramochi, T., Machida, M., Araki, J., Uchida, A., Kushiro, T. and Nagasawa, K., 1995. Minke whales (*Balaenoptera acutorostrata*) are one of the major final hosts of *Anisakis simplex* (Nematoda: Anisakidae) in the northwestern North Pacific Ocean. Oral presentation at the International Whaling Commission, Dublin, Ireland, May 1995.
- MacKenzie, K., 1983. Parasites as biological tags in fish population studies. *Adv. Appl. Biol.*, 7: 251–331.
- Maeno, Y. and Sorimachi, M., 1992a. Skeletal abnormalities of fishes caused by parasitism of Myxosporea. NOAA Tech. Rep. NMFS, 111: 113–118.
- Maeno, Y. and Sorimachi, M., 1992b. Skeletal abnormalities associated with *Myxobolus buri* infection in the brain of some marine teleosts. Oral presentation at International Workshop on Myxosporea, 6–8 October 1992, Ceske Budejovice, Czech Republic.
- Maeno, Y., Sorimachi, M., Ogawa, K. and Kearn, G.C., 1995. *Myxobolus spirosulcatus* n. sp. (Myxosporea, Bivalvulida) infecting the bile duct of the yellowtail *Seriola quinqueradiata* from Japan. *Syst. Parasitol.*, 31: 189–193.
- Maita, M., Aoki, H., Tanaka, S., Shimizu, Y., Yamagata, Y. and Watanabe, T., 1994. On the green hepatization of yellowtail fed with feed without fish meal. Oral presentation at the Spring meeting of the Japanese Society of Fisheries Science, 2 April 1994.
- Nagasawa, K., 1990. *Anisakis* larvae in intermediate and paratenic hosts in Japan. In: H. Ishikura and K. Kikuchi (Editors), *Intestinal Anisakiasis in Japan*. Springer, Tokyo, pp. 23–29.
- Nagasawa, K., Imai, Y. and Ishida, K., 1985. Distribution, abundance, and effects of *Pennella* sp. (Copepoda:

- Pennellidae), parasitic on the saury, *Cololabis saira* (Brevoort), in the western North Pacific Ocean and adjacent seas, 1984. Bull. Biogeogr. Soc. Jpn., 10: 35–42.
- Nagasawa, K., Imai, Y. and Ishida, K., 1988. Long-term changes in the population size and geographical distribution of *Pennella* sp. (Copepoda) on the saury, *Cololabis saira*, in the western North Pacific Ocean and adjacent seas. Hydrobiologia, 167–168: 571–577.
- Nakajima, K. and Egusa, S., 1972. Studies on a new trypanorhynchian larva, *Callotetrarhynchus* sp., parasitic on cultured yellowtail—XV. Life cycle (in Japanese with English abstract). Fish Pathol., 7: 6–14.
- Odate, S., 1977. On the distribution of Pacific saury in the North Pacific Ocean (in Japanese with English abstract). Res. Inst. North Pac. Fish., Fac. Fish., Hokkaido Univ., special volume, 353–381.
- Ogawa, K. and Egusa, S., 1986. Two new species of *Paradeontacylix* McIntosh, 1934 (Trematoda: Sanguinicolidae) from the vascular system of a cultured marine fish *Seriola purpurascens*. Fish Pathol., 21: 15–19.
- Ogawa, K., Hattori, K., Hatai, K. and Kubota, S.S., 1989. Histopathology of cultured marine fish, *Seriola purpurascens* (Carangidae) infected with *Paradeontacylix* spp. (Trematoda: Sanguinicolidae) in its vascular system. Fish Pathol., 24: 75–81.
- Ogawa, K., Andoh, H. and Yamaguchi, M., 1994. Some biological aspects of *Paradeontacylix* (Trematoda: Sanguinicolidae) infection in cultured marine fish *Seriola dumerili*. Fish Pathol., 28: 177–180.
- Ogawa, K., Bondad-Reantaso, M.G., Fukudome, M. and Wakabayashi, H., 1995. *Neobenedenia girellae* (Hargis, 1955) Yamaguti, 1963 (Monogenea: Capsalidae) from cultured marine fishes of Japan. J. Parasitol., 81: 223–227.
- Ohno, J., 1993. Present status and problems in supply and demand of amberjack fingerlings (in Japanese). Youshoku, 35: 57–60.
- Overstreet, R.M. and Koie, M., 1989. *Pearsonellum corventum*, gen. et sp. nov. (Digenea: Sanguinicolidae), in serranid fishes from the Capricornia Section of the Great Barrier Reef. Aust. J. Zool., 37: 71–79.
- Ruiz, G.M., 1991. Consequences of parasitism to marine invertebrates: host evolution? Am. Zool., 31: 831–839.
- Sakaguchi, S., Hara, T., Matsusato, T., Shibahara, T., Yamagata, Y., Kawai, H. and Maeno, Y., 1987. Scoliosis of cultured yellowtail caused by *Myxobolus buri* (in Japanese with English abstract). Bull. Nat. Res. Inst. Aquacult., 12: 79–86.
- Smith, J.W., 1972. The blood flukes (Digenea: Sanguinicolidae and Spirorchidae) of cold-blooded vertebrates and some comparison with the schistosomes. Helminthol. Abstr., Ser. A, 41: 161–204.