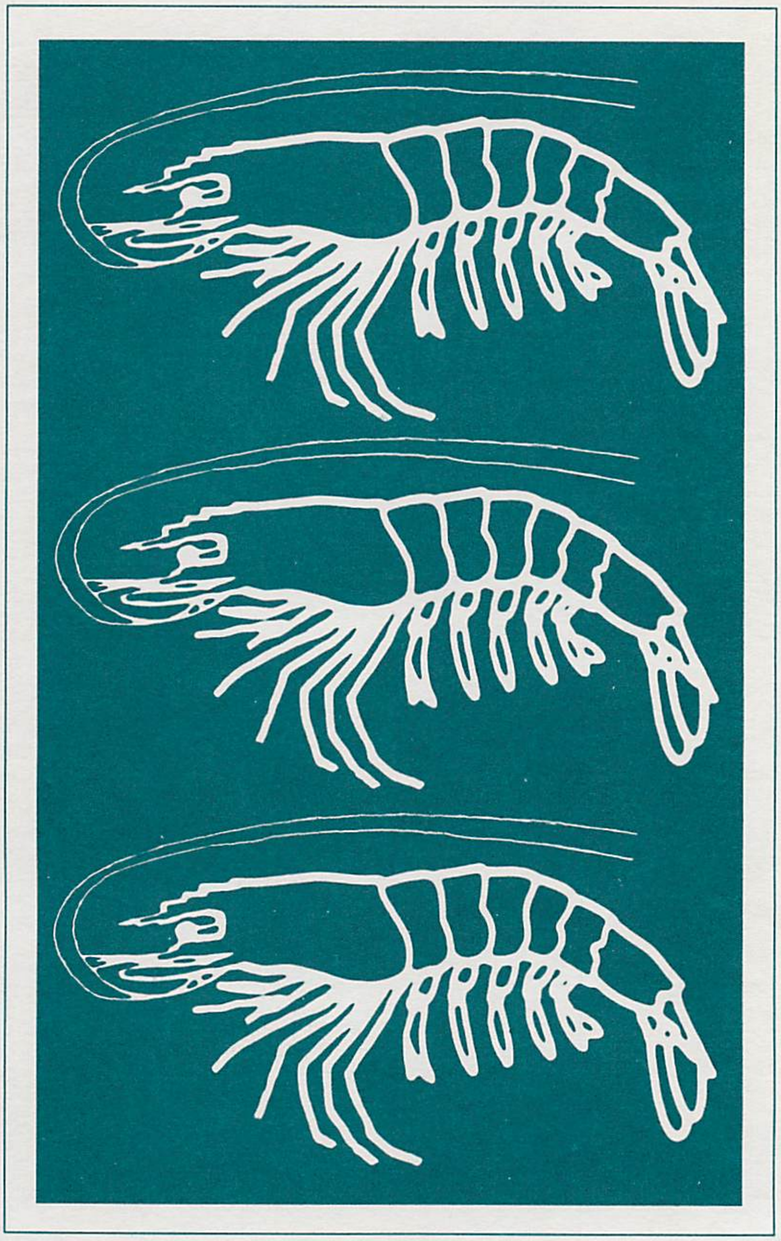
Handbook of Shrimp Diseases



Aquaculture

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Handbook of Shrimp Diseases

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This handbook is designed as an information source and field guide for shrimp culturists, commercial fishermen, and others interested in diseases or abnormal conditions of shrimp. It describes and illustrates common maladies, parasites and commensals of commercially important marine shrimp. Descriptions include information on the life cycles and general biological characteristics of disease-producing organisms that spend all or part of their life cycles with shrimp.

Disease is one of the several causes of mortality in shrimp stocks. Death from old age is the potential fate of all shrimp, but the toll taken by predation (man being one of the major predators), starvation, infestation, infection and adverse environmental conditions is much more important.

Although estimates of the importance of disease in natural populations are generally unreliable, the influence of disease, like predation and starvation, is accepted as important in lowering numbers of natural stocks whenever they grow to excess.

Disease problems are considered very important to successful production in shrimp aquaculture. Because high-density, confined rearing is unnatural and may produce stress, some shrimp-associated organisms occasionally become prominent factors in disease. Special measures are required to offset their detrimental effects.

Disease may be caused by living agents or other influences of the general environment. Examples of influences in the general environment that cause disease are lack of oxygen, poisons, low temperatures and salinity extremes. This guide concentrates on the living agents and on visual presentation of the structure and effects of such agents.

Shrimp Species

There are many shrimp species distributed world-wide. Important shrimp of the Gulf of Mexico catch are the brown shrimp, P*enaeus aztecus*; the white shrimp, *Penaeus setiferus*; and the pink shrimp; *Penaeus duorarum.*

Two exotic shrimp have gained importance in Gulf Coast aquaculture operations. These are the Pacific white (white leg) shrimp, *Penaeus vannamei*, and the Pacific blue shrimp, *Penaeus stylirostris*. These two species are used likewise throughout the Americas on both east and west coasts.

In Asia, the Pacific, and to some extent the Mediterranean, the following species are used: *Penaeus monodon, Penaeus merguiensis, Penaeus chinensis, Penaeus japonicus, Penaeus semisulcatus, Penaeus indicus, Penaeus penicillatus* and *Metapenaeus ensis. Penaeus monodon,* the giant tiger (or black tiger) shrimp is the world leader in aquaculture.

Shrimp Anatomy

A shrimp is covered with a protective cuticle (exoskeleton, shell) and has jointed appendages. Most organs are located in the head end (cephalothorax) with muscles concentrated in the tail end (abdomen). The parts listed below are apparent upon outside examination (Fig. 1).

1. Cephalothorax
2. Abdomen
3. Antennules
4. Antenna
5. Antennal scale
6. Rostrum (horn)
7. Eye
8. Mouthparts (several appendages for holding and tearing food)
9. Carapace (covering of cephalothorax)
10. Walking legs (pereiopods)
11. Abdominal segment
12. Swimmerets (pleopods)
13. Sixth abdominal segment
14. Telson
15. Uropod
16. Gills

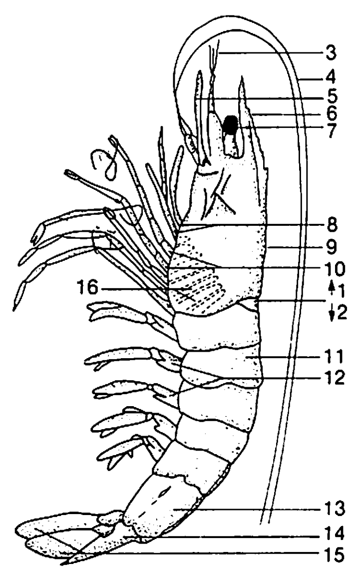


Fig. 1. External anatomy of shrimp. (Numbers conform to list.)

Inside structures include (Fig. 2)

1. Esophagus
2. Stomach
3. Hemocoel (blood space)
4. Digestive gland (hepatopancreas)
5. Heart
6. Intestine
7. Abdominal muscles

The "skin" or hypodermis of a shrimp lies just beneath the cuticle. It is functional in secreting the new exoskeleton that develops to replace the old at shedding. Shedding of the cuticle (also known as molting or ecdysis) occurs at intervals during a shrimp's life and allows for change in developmental stage and expansion in size.

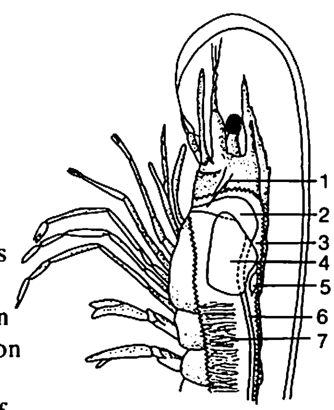


Fig. 2. Internal anatomy of shrimp. (Numbers conform to list.) Jagged line represents cutaway of cuticle to expose internal organs.

The reproductive organs of adults are particularly noticeable. When ripe, the ovaries of females may be seen through the cuticle to begin in the cephalothorax and extend dorsally into the abdomen. Spermatophores, a pair of oval structures containing the sperm in adult males, are also visible through the cuticle when viewed from the underside near the juncture of cephalothorax and abdomen. The principle nervous structure, the ventral nerve cord, is visible along the underside of the body between the swimmerets.

Obvious Manifestations of Shrimp Disease

Damaged Shells

Shrimp cuticle is easily damaged in aquaculture situations when hard structures are impacted or rubbed. (Fig. 3). Blood runs openly (outside of vessels) under the shell of shrimps, out through appendages and into tiny fringe parts. When injury occurs to the shell, the blood quickly clots and protects deeper parts (Fig. 4).

Shell damage may also be inflicted by the pinching or biting of other shrimp in crowded conditions. Parts of appendages such as antennae may be missing. Cannibalism has an important influence on survival in some phases of shrimp culture where stronger individuals devour weak ones (Fig. 5).

Shells may also be damaged because they become infected. A protective outer layer is part of the cuticle. If underlying portions are exposed opportunistic microbes will invade the shell and use it as a food base or portal for entry into deeper tissue. Larger marks darken and become obvious (Fig. 6).

Inflammation and Melanization

Darkening of shell and deeper tissues is a frequent occurrence with shrimp and other crustaceans. In the usual case, blood cells gradually congregate in particular tissue areas (inflammation) where damage has occurred and this is followed by pigment (melanin) deposition. An infective agent, injury or a toxin may cause damage and stimulate the process (Fig. 7). Gills are particularly prone to darkening due to their fragile nature and their function as a collecting site for elimination of the body's waste products (Fig. 8). Gills readily darken upon exposure to toxic metals or chemicals and as a result of infection by certain fungi (*Fusarium* sp.).

Less common but important are dark blotches that sometime occur within the tails of pond shrimp. This manifestation of necrosis (breakdown and death) of muscle portions followed by melanization degrades the product's market potential. It is possible that this condition results from deep microbial invasions that run through spaces between muscle bundles but its actual causes remain unknown (Fig. 9).

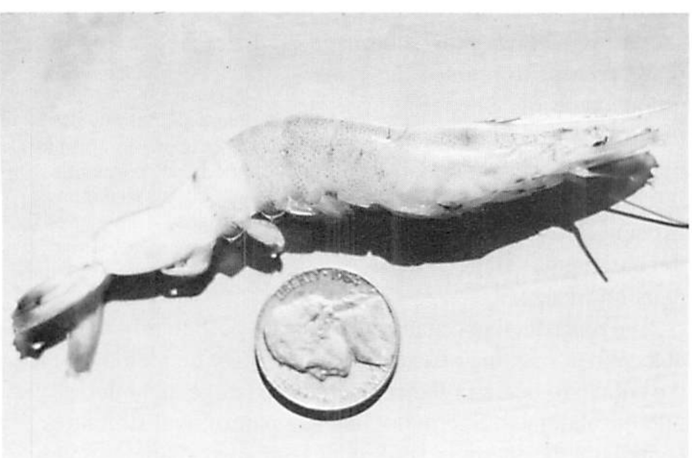


Fig. 5. Cannibalism usually begins as other shrimp devour the appendages.

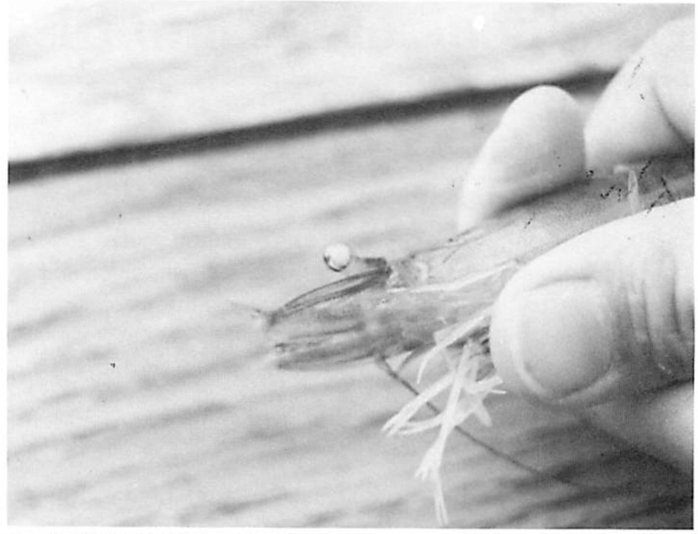


Fig. 3. Eyes of shrimp are normally black, but rubbing of a tank wall has caused this eye to appear whitish because of a prominent lesion.

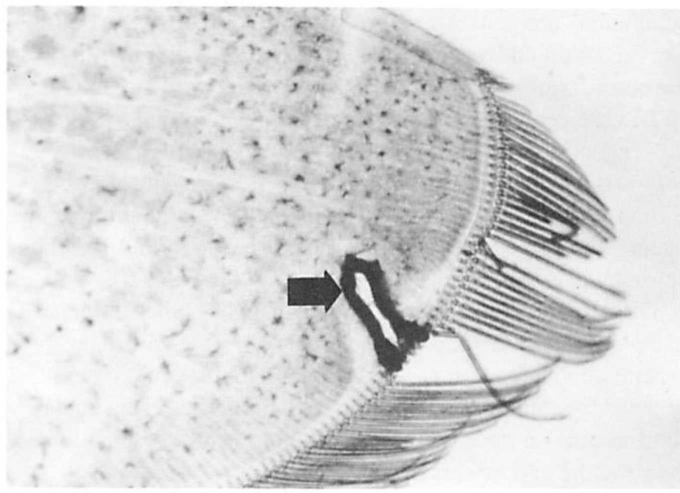


Fig. 4. Microscopic view of a lesion on a uropod (tail part). Note crease from bend in part and loss of fringe setae.

Fig. 6. Tail ends of two shrimp. The lower shrimp shows typical darkening of cuticle that involves microbial action. The darkening itself is considered a host response. The telsons of the upper shrimp are opaque because of dead inner tissue. Successful entry and tissue destruction by bacteria was accomplished only in those parts.

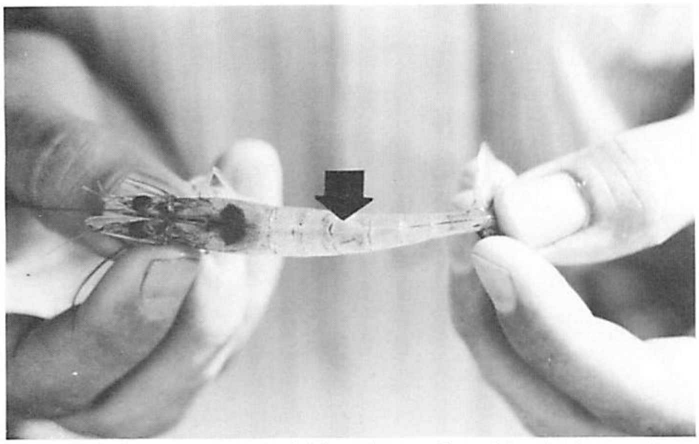


Fig. 7. A shrimp photographed (above) near time of back injury and (below) hours later. Injury by a toxin or disease agent will usually trigger a similar response of inflammation and melanization.

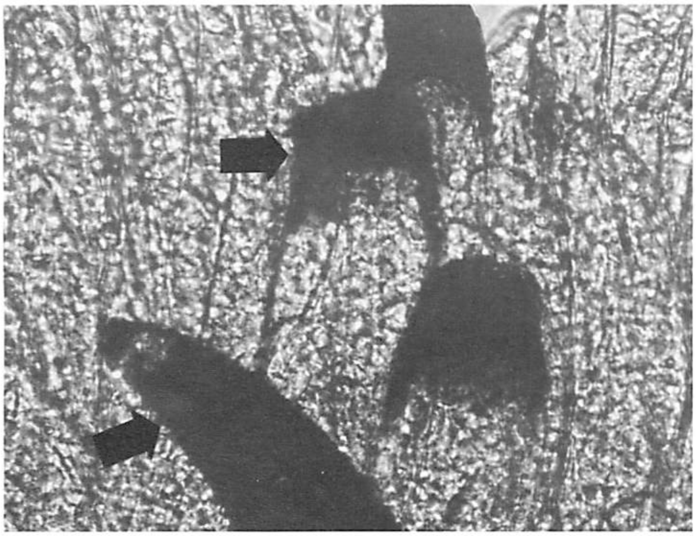


Fig. 8. Microscopic view of damaged and melanized gill tips.

Emaciation and Nutritional Deficiency

Unfed shrimp lose their normal full and robust appearance and exhibit emaciation. The shell becomes thin and flexible as it covers underlying tissue such as tail meat that becomes greatly resorbed for lack of nutrients. Molting is curtailed and shell and gills may darken in time (Fig. 10). Emaciation may also follow limited feeding behavior during chronic disease conditions or an exposure to unfavorable environmental conditions. Empty intestines are easily observed through transparent cuticle and flesh.

Prepared diets deficient in necessary constituents may predispose or cause disease. Vitamin C deficiency, for example, will initiate darkening of gills or certain tissues associated with the cuticle and eventually result in deaths.

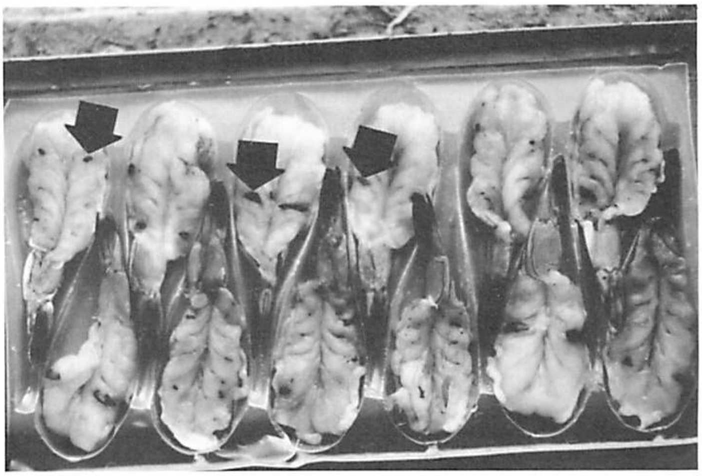


Fig. 9. Areas of melanized necrotic tissue in tail musculature.

Fig. 10. Emaciated shrimp. Gills and body fringes have become obviously darkened and the soft tail is covered with a thin and fragile cuticle.

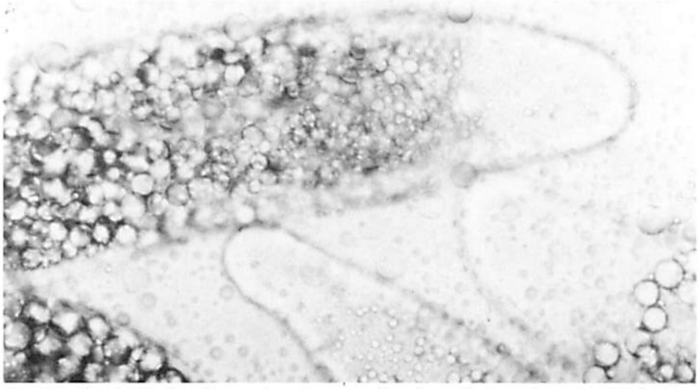


Fig. 11. Lipoid (fat) spheres in microscopic view of digestive gland tubule.

Digestive glands sometimes will become reduced in size. Among other things, this is an indication of poor nutrition. Well-fed shrimp will have an abundance of fat globules within storage cells of the digestive gland tubules that provide bulk to the gland (Figs. 11 and 12).

Muscle Necrosis

Opaque muscles are characteristic of this condition. When shrimp are exposed to stressful conditions, such as low oxygen or crowding, the muscles lose their normal transparency and become blotched with whitish areas throughout. This may progress until the entire tail area takes on a whitish appearance (Fig. 13).

If shrimp are withdrawn from the adverse environment before prolonged exposure, they may return to normal. Extremely affected shrimp do not recover, however, and die within a few minutes (Fig. 14). In moderately affected shrimp, only parts of the body return to normal; other parts, typically the last segments of the tail are unable to recover and are prone to bacterial infection (Fig. 15). These shrimp die within one or two days (Fig. 5). Shrimp muscles with this condition are known to undergo necrosis (death or decay of tissue).

Tumors and Other Tissue Problems

Conspicuous body swellings or enlargements of tissues have been reported in shrimp. In most cases, affected individuals were captured from polluted waters. Occurrence of shrimp with evident tumors is rare in commercial catches. Miscellaneous irritations experienced by captive shrimp in tank systems will sometimes result in focal areas of tissue overgrowth (Fig. 16).

A particularly vulnerable tissue of captive juvenile and adult shrimp is found on the inner surface of the portion of carapace that covers the gills. When microbes invade this tissue, it and the adjacent outer shell may completely disintegrate exposing the gills. In other cases a partial loss of the tissue distally may result in an outward flaring of the exposed cuticle. A hemolymphoma or fluid-filled blister also forms sometime in this

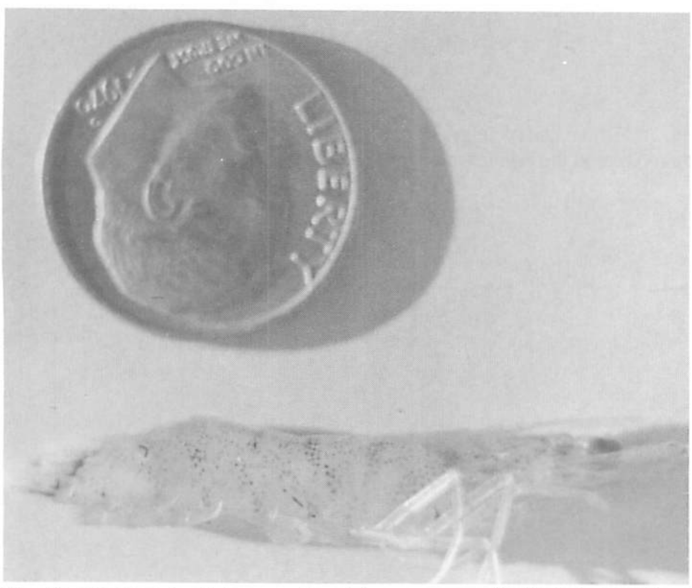


Fig. 15. Damage to abdomen of a shrimp as a result of *Vibrio* infection.

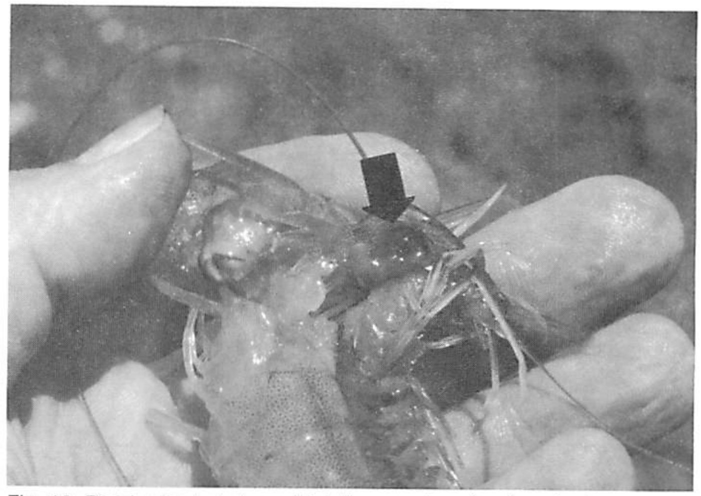


Fig. 12. Pond-raised shrimp with full, normal and reduced, abnormal digestive gland. Arrow points to abnormal gland.

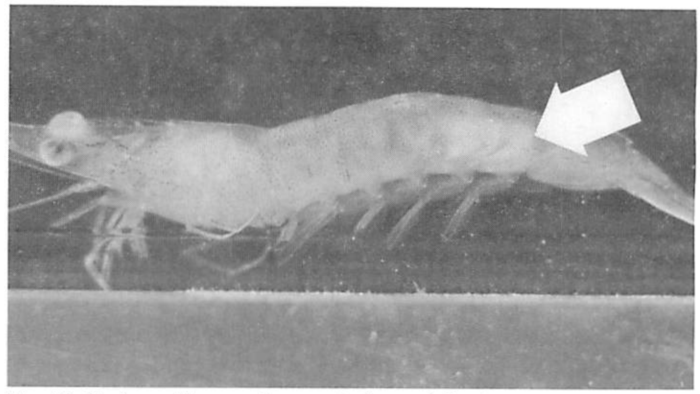


Fig. 13. Shrimp with necrotic muscle tissue following exposure to stressful environment. Affected tissue at arrow.

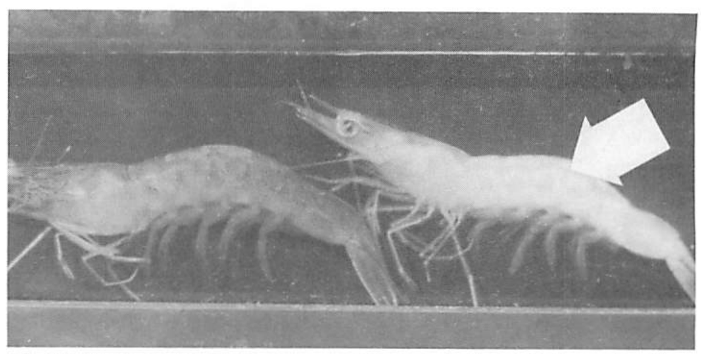


Fig. 14. Shrimp with advanced muscle necrosis (arrow) shown beside normal shrimp.

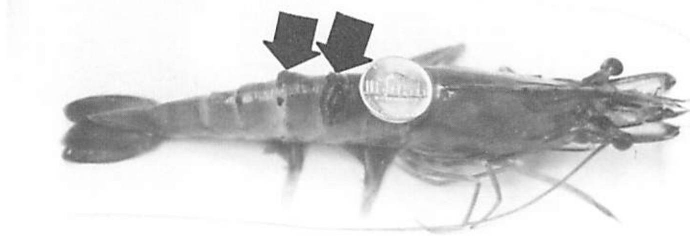


Fig. 16. Tumorous growth on an adult shrimp from a tank system.

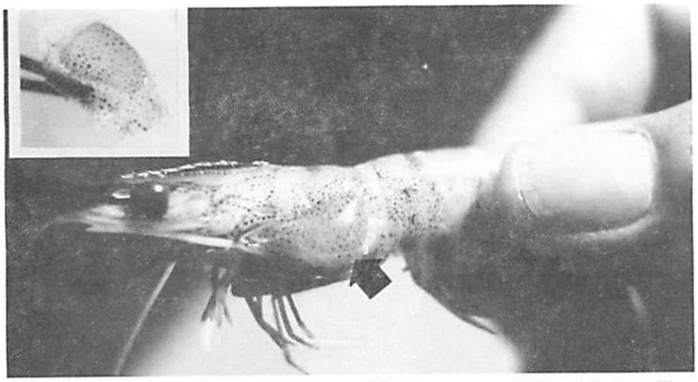


Fig. 17. Blister condition. Inset shows blister removed. The blister will darken upon death of shrimp degrading marketability of heads-on product.

portion of the carapace in pond shrimp (Fig. 17). Primary causes of these manifestations are not understood.

A degeneration of male reproductive tracts occasionally occurs in captive adults of certain penaeid species. A swelling and darkening of the tubule leading from the testes to the spermatophore is readily apparent when viewed through the translucent body (Fig. 18).

Surface Fouling

The surfaces of shrimps are prone to an accumulation of various fouling organisms. Heavy infestations can interfere with mobility or breathing and influence marketability (Fig. 19).

Cramped Shrimp

This is a condition described for shrimp kept in a variety of culture situations. The tail is drawn under the body and becomes rigid to the point that it cannot be straightened (Fig. 20). The cause of cramping is unknown, but some research points to mineral imbalance.

Unusual Behavior

Diseased shrimps often display listless behavior and cease to feed. In the case of water quality extremes such as low oxygen, shrimp may surface and congregate along shores where they become vulnerable to bird predation. Cold water may cause shrimp to burrow and an environmental stimulation such as low oxygen, thermal change or sudden exposures to unusual chemicals may initiate widespread molting.

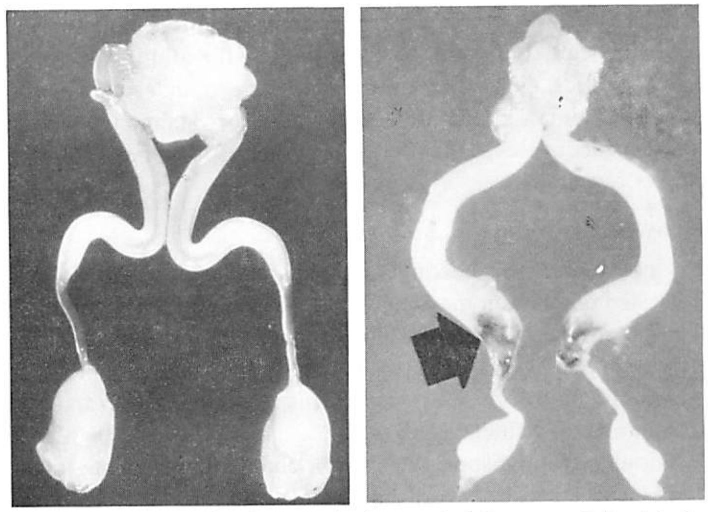


Fig. 18. Darkening of male reproductive tract of *Penaeus stylirostris*. A. Normal tract. B. Initial darkening. Darkening will advance until spermatophores and testes become affected. (Photos courtesy of George Chamberlain.)

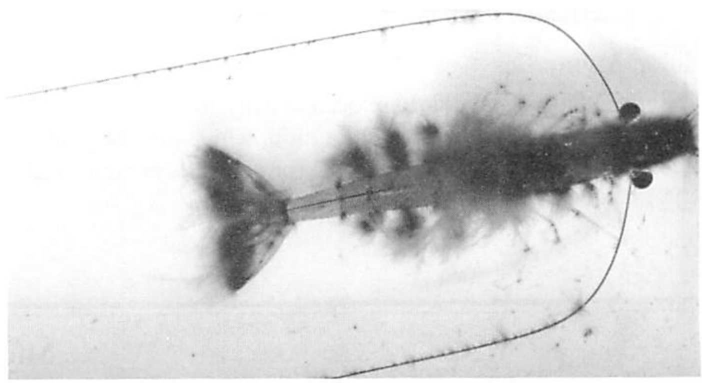


Fig. 19. Algal overgrowth on shrimp exposed to abundant light. (Photo courtesy of Steve Robertson.)

Developmental Problems

Deformities are quite prevalent in some populations. They arise from complex interactions that involve environment, diet and gene expression. Bodies may be twisted or appendages misshaped or missing. Deformities are less prevalent in wild-caught larvae than hatchery populations probably because wild shrimp have more opportunity for natural selection and exposure to normal developmental conditions (Fig. 21).

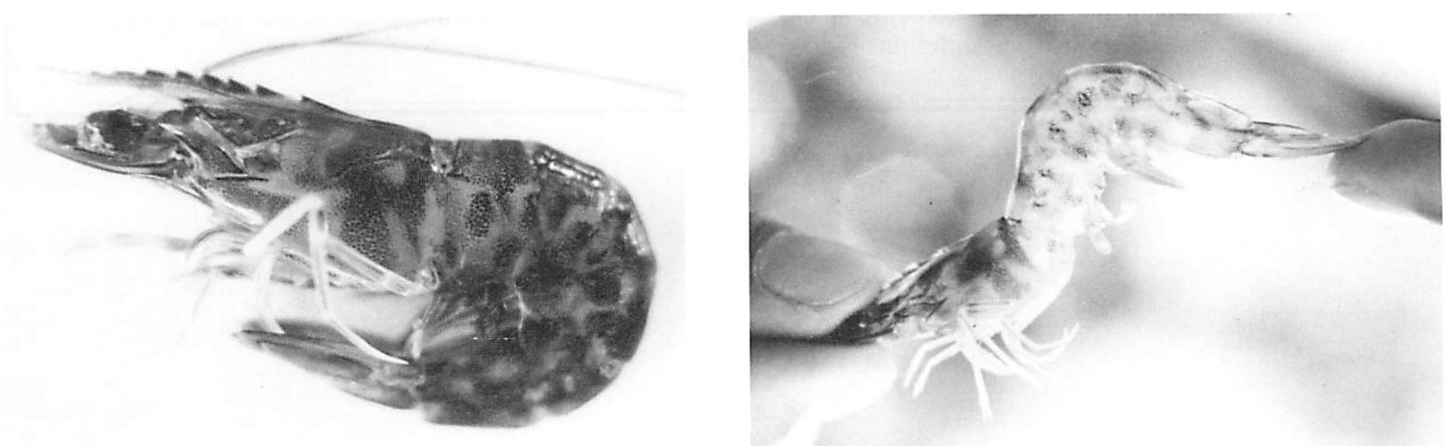


Fig. 20. Cramped shrimp condition. Full flexure (A). Flexure maintained when pressure applied (B).

Molt arrest occurs in affected animals of some populations. Animals begin, but are unable to complete the molting process. In some cases, there is abnormal adherence to underlying skin, but most animals appear to lack the necessary stamina. Nutritional inadequacies and water quality factors have been identified as causes.

Growth Problems

Growth problems become obvious in aquaculture stocks. A harvested population may show a larger percentage of runting than expected. Some research has connected viral disease with runting in pond stocks and it is generally held that variable growth may result from disease agents, genetic makeup and environmental influences.

For unknown reasons, the shell or cuticle may become fragile in members of captive shrimp stocks.

Shells are normally soft for a couple of days after molting, but shells of those suffering from soft-shell condition remain both soft and thin and have a tendency to crack under the slightest pressure. Some evidence of cause suggests pesticide toxicity, starvation (mentioned above) or mineral imbalance.

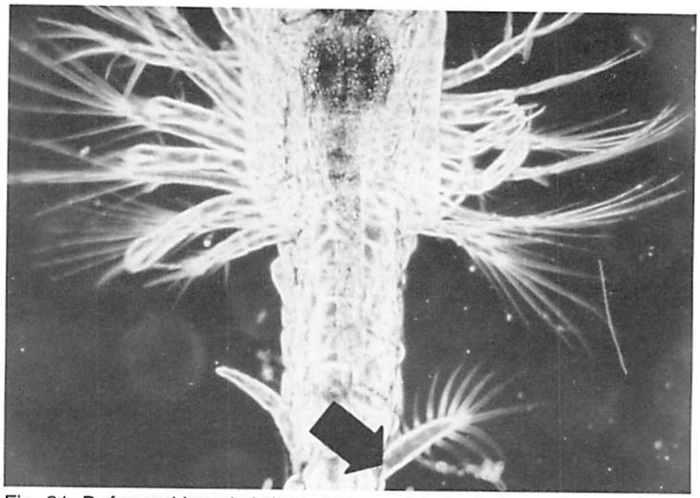


Fig. 21. Deformed larval shrimp. Arrow points to deformed appendage. (Photo courtesy of George Chamberlain.)

Color Anomalies

Shrimp of unusual color are occasionally found among wild and farm stocks. The striking coloration, which may be gold, blue or pink, appears throughout the tissue and is not confined to the cuticle or underlying skin. A genetic cause is suspected. Transformation to blue coloration from a natural brown is known for some captive crustaceans and has been linked to nutrition. Pond-cultured, giant tiger shrimp sometime develop a condition where digestive gland degeneration contributes to a reddish coloration.

Microbes

Microbes are minute, living organisms, especially viruses, bacteria, rickettsia and fungi. Sometimes protozoa are considered microbes.

Protozoa are microscopic, usually one-celled, animals that belong to the lowest division of the animal kingdom. Normally, they are many times larger than bacteria. The typical protozoa reproduce by simple or multiple division or by budding. The more complex protozoa alternate between hosts and produce cells with multiple division stages called spores.

Fungi associated with shrimp are microscopic plants that develop interconnecting tubular structures. They reproduce by forming small cells known as spores or fruiting bodies that are capable of developing into a new individual.

Bacteria are one-celled organisms that can be seen only with a microscope. Compared to protozoans, they are of less complex organization and normally less than 1/5,000 inch (1/2000 cm) in size.

Rickettsia are microbes with similarity to both viruses and bacteria and have a size that is normally somewhat in-between. Most think of them as small bacteria.

Viruses are ultramicroscopic, infective agents capable of multiplying in connection with living cells. Normally, viruses are many times smaller than bacteria but may be made clearly visible at high magnification provided by an electron microscope.

Microbes

Viruses

Our knowledge of the diversity of shrimp viruses continues to grow. Viruses of shrimp have been assigned explicitly or tentatively to six or seven categories. Several shrimp viruses are recognized to have special economic consequence in aquaculture:

Baculoviruses

Baculovirus penaei — a virus common to Gulf of Mexico shrimp. It damages tissue by entering a cell nucleus and subsequently destroys the cell as it develops (Fig. 23). An occlusion is formed (Fig. 24). This virus has become a constant problem for many shrimp hatcheries where it damages the young larval animals. Occlusions of the same or closely related viruses are seen in Pacific and Atlantic Oceans of the Americas. At least ten shrimp species are known to show disease manifestations in aquaculture settings.

Monodon-type baculovirus — one that forms spherical occlusions (Fig. 25) and whose effects are seen mostly in the culture of the giant tiger prawn, *Penaeus monodon*. Damage of less importance has been seen in *Penaeus japonicus*, *Penaeus merguiensis* and *Penaeus plebejus*.

Midgut gland necrosis virus — a naked baculovirus harmful to the Kuruma prawn, *Penaeus japonicus*, in Japan.

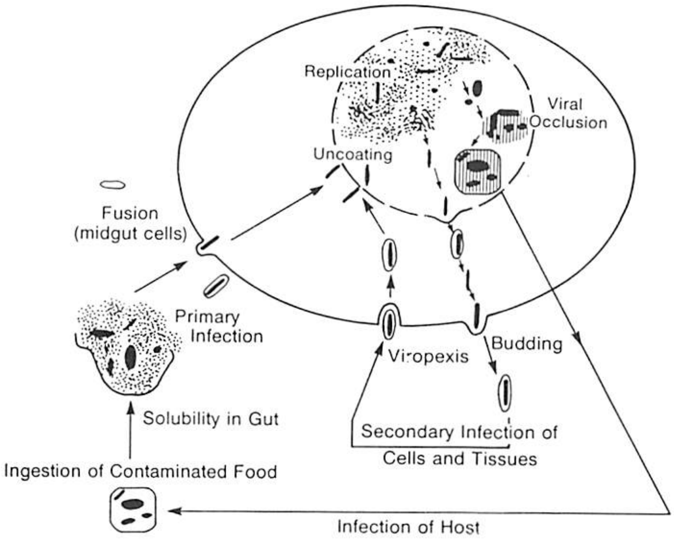


Fig. 23. Baculovirus life cycle. Transmission of the virus is thought to be initiated as a susceptible shrimp ingests a viral occlusion. Virus initially enters cell cytoplasm either by viroplexis (cell engulfs particle with surrounding fluid) or by fusion where viral and cell membranes fuse and viral core passes into cell. Secondary infection occurs as extracellular virus continues to infect. (Redrawn by Summers and Smith, 1987. Used with permission of author and Texas Agricultural Experiment Station, The Texas A&M University System.)

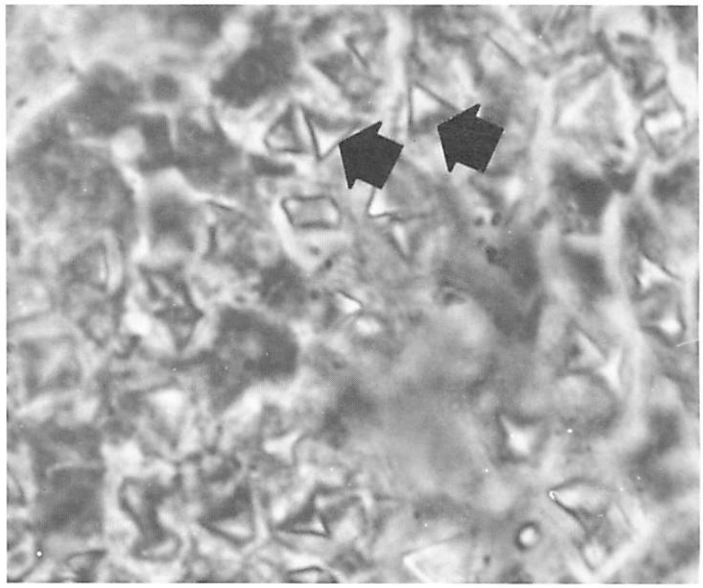


Fig. 24. Occlusion bodies of *Baculovirus penaei*. These bodies, visible to low power of a light microscope, are characteristic of this virus. The occlusions and those of other baculoviruses are found mainly in the digestive gland and digestive tract.

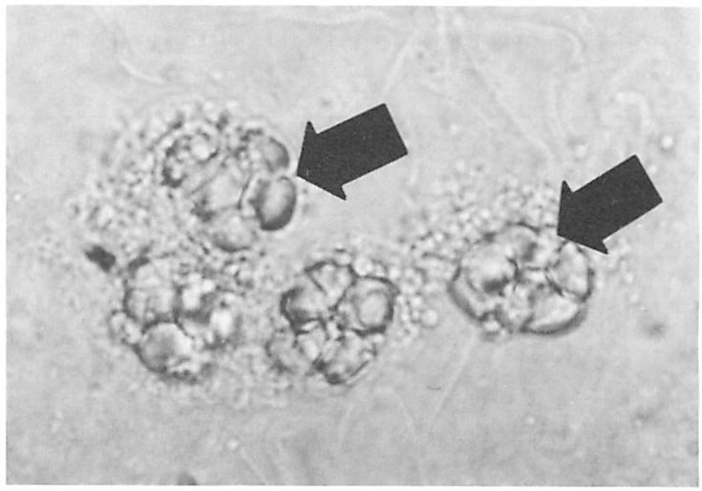


Fig. 25. Monodon baculovirus in a tissue squash showing groups of spherical occlusions. Light microscopy.

Parvoviruses

Infectious hypodermal and hematopoietic necrosis virus — a virus affecting several commercially important shrimp and, particularly, the Pacific blue shrimp, *Penaeus stylirostris*.

Hepatopancreatic parvo-like virus — a virus causing disease in several Asian shrimp. Transmission to *Penaeus vannamei* did not result in disease to that species.

Nodavirus

Taura virus — a virus causing obvious damage to various tissues and in the acute phase, to the hypodermis and subsequently the cuticle of *Penaeus vannamei* (Fig. 26). It is an important problem for both production and marketing. During the 1995 growing season, this virus caused large losses to aquaculture stocks in Texas. Damage was great in Central and South America beginning in 1992.

Other viruses

Yellow head virus — a virus causing serious disease of the giant tiger prawn, P*enaeus monodon*. Large losses have been experienced in Asian aquaculture units. Gills and digestive glands of infected shrimp are pale yellow.

White spot diseases — viruses of similar size and structure have been shown to cause a similar manifestation and heavy losses to P*enaeus japonicus*, *Penaeus monodon* and *Penaeus penicillatus* in Taiwan and Japan. Advanced infections show development of obvious white spots on the inside of the cuticle (Fig. 27).

Several other viruses with relatively little known importance are considered as members of the reoviruses, rhabdoviruses, togaviruses.

Fig. 26. Advanced stage of infection with Taura virus showing damage to cuticle. Smaller shrimp with acute infection do not show such damage but do show reddish telson and uropods.

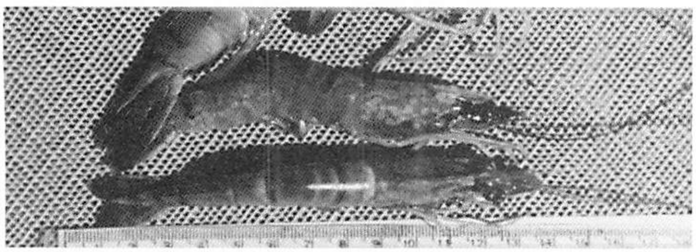


Fig. 27. Asian shrimp showing signs of white spot disease. (Photo courtesy of R. Rama Krishna.)

Viruses

Viruses cause disease as they replicate within a host cell and thereby cause destruction or improper cell function. A virus is essentially a particle containing a core of nucleic acids, DNA or RNA. Once inside a proper host cell, the viral nucleic acid interacts with that of a normal cell to cause reproduction of the virus. The ability to parasitize and cause damage may be limited to a single species or closely related group of hosts, a host tissue and usually the place within a cell in which damage takes place.

The cause and effect for all shrimp virus disease needs careful attention. Some viruses cause disease only after exposure to unusual environmental conditions. Also, impressions about virus identity are often based on results of routine examinations that give presumptive results. Certainly viruses cause important disease in particular circumstances but key understandings of most shrimp viruses are largely unknown: longevity within systems, source of infection, method of transmission, normal and unusual carriers, and potential to cause damage.

Our ability to detect shrimp viruses is ahead of our ability to evaluate their importance or to implement controls. For viral identification, scientists have employed the recent technology that detects characteristic nucleic acids. This is augmented by careful microscopical study of tissues to detect characteristic damage to cells. Use of electron microscopy to determine size and shape of virus particles has also been helpful (Fig. 22).

A peculiar feature of some baculoviruses of shrimp and other invertebrate animals is to occurrence of the occlusion bodies within infected cells. These are relatively large masses of consistent shape that contain virus particles embedded within. Other "naked" baculoviruses do not show formation of occlusions.

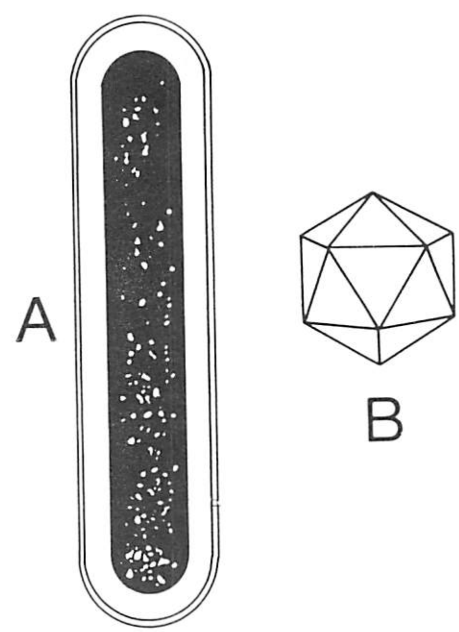


Fig. 22. Structure of viruses reported from shrimps. A. Baculoviridae. Size range is about 250 to 400 nanometers in length. B. Basic structure of most of the other shrimp viruses: Parvo-like viruses—20 to 24 nm in diameter containing DNA; Reo-like viruses—55 to 70 nm diameter, RNA; nodavirus—30 nm diameter, RNA; toga-like virus 30 diameter, RNA, enveloped. Rhabdoviruses are elongated like baculoviruses but a blunt end provides bullet-shapes—150 to 250 nm, RNA.

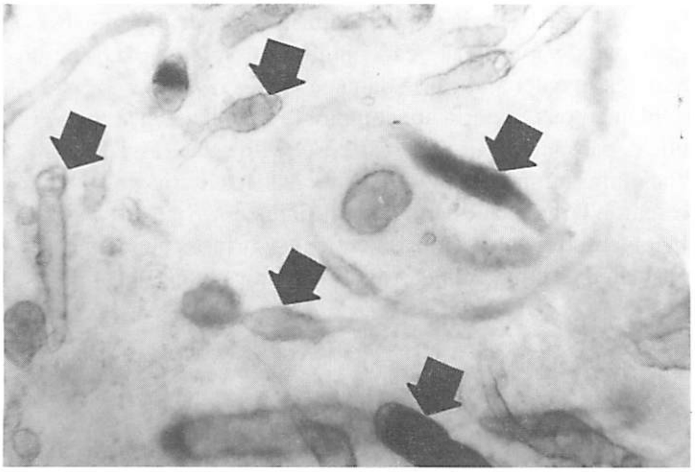


Fig. 28. View with light microscope of a tissue squash of infected digestive gland. Note dark necrotized tissue of tubules (arrows).

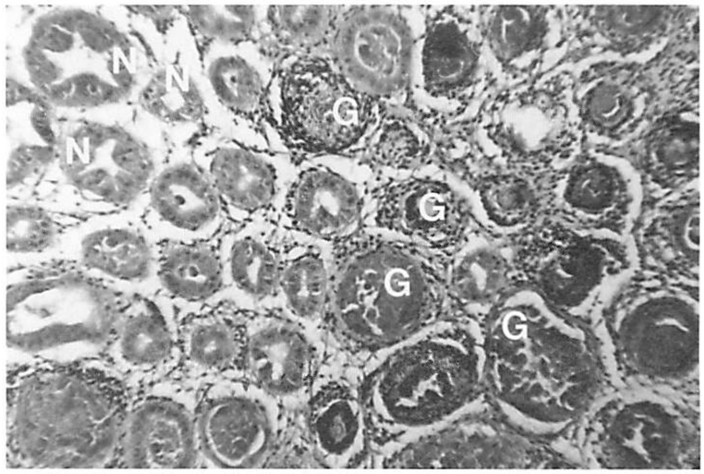


Fig. 29. Transverse section of digestive gland tubules showing progression of granuloma formation. Normal tubules are to the left (N) and affected tubules are to the right (G.).

Bacteria and Rickettsia

Bacterial infections of shrimp have been observed for many years. Scientists have noticed that bacterial infection usually occurs when shrimp are weakened. Otherwise normal shrimp also may become infected if conditions favor presence and abundance of a particularly harmful bacterium.

Shrimp body fluids are most often infected by the bacterial group named *Vibrio*. Infected shrimp show discoloration of the body tissues in some instances, but not in others. The clotting function of the blood, critical in wound repair, is slowed or lost during some infections. Members of one group of *Vibrio* have the characteristic of luminescence giving heavily infected animals a "glow-in-the-dark" appearance.

Bacteria also invade the digestive tract. A typical infection in larval animals is seen throughout the digestive system. In larger animals, infection becomes obvious in the digestive gland after harmful bacteria gain entry to it, presumably via connections to the gut.

Digestive gland tissues are organized as numerous tubular structures that ultimately feed into the digestive tract. Pond-reared shrimp occasionally die in large numbers because of diseased digestive glands. The specialized cells that line the inside of the tubules are particularly fragile and are easily infected. Tubules progressively die and darken (Figs. 28 and 29). This kind of disease manifestation is seen in recent reports of rickettsial infection. Cells of the digestive gland tubules are severely damaged as rickettsiae invade and develop therein (Figs. 30 and 31).

If infected by bacteria capable of using shell for nutrition, the exoskeleton will demonstrate erosive and blackened areas

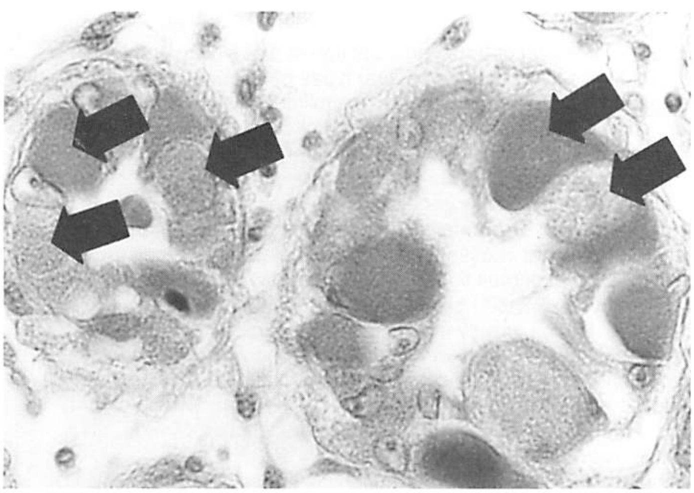


Fig. 30. Histological cross section of a digestive gland tubule. Rickettsial microcolonies are shown at arrows. Rickettsiae will exhibit constant brownian motion and color red with Giemsa stain, but electron microscopy is needed for definite diagnosis. (Specimen courtesy of J. Brock)

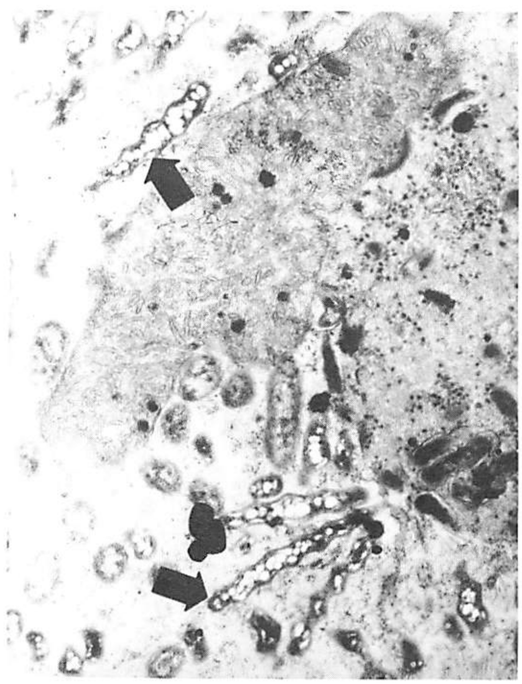


Fig. 31. Electron microscope view of tissue infected with rickettsia organism (arrow). (Photo circa 1987 from *Penaeus vannamei* on Texas coast.)

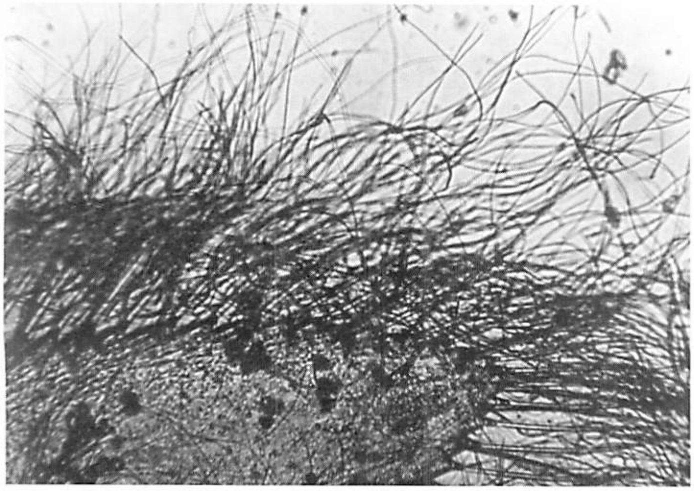


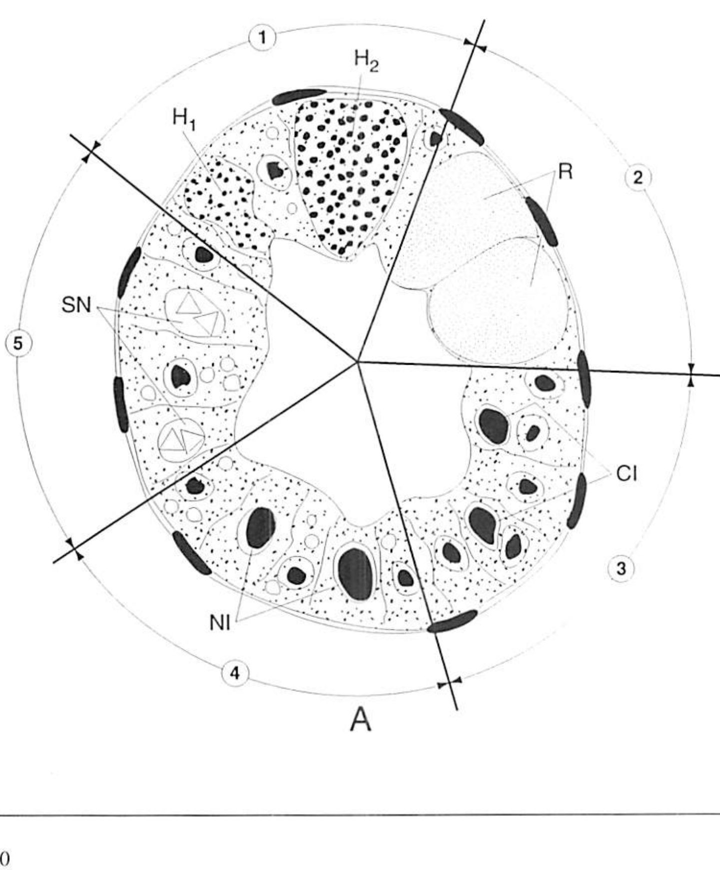
Fig. 32. Microscopic view of filamentous bacteria on a shrimp pleopod.

(Fig. 6). These bacteria typically attack edges or tips of exoskeleton parts, but if break occurs in the exoskeleton the bacteria are quick to enter and cause damage.

Filamentous bacteria are commonly found attached to the cuticle, particularly fringe areas beset with setae (Fig. 32). When infestation is heavy, filamentous bacteria may also be present in large quantity on the gill filaments. Smaller, less obvious bacteria also settle on cuticular surfaces but are not considered as threatening as the filamentous type.

Microbial Disease and Digestive Glands

Digestive glands are routinely searched by pathologists for signs of disease. This is done after chemical preservation, microsection, slide-mounting and staining the tissue. Transverse sections of the tubules are then examined with a light microscope. General damage is seen when bacteria such as *Vibrio* species invade tubules. Rickettsiae, viruses, microsporans and haplosporans are more selective. They invade cells and progressively cause damage from within. For comparative purposes, a drawing of a normal tubule is compared with a tubule showing a variety of typical manifestations (Fig. 33).



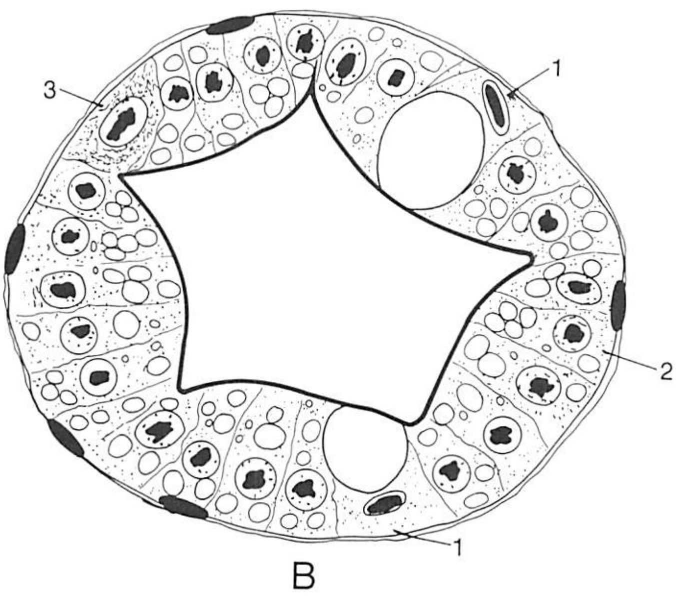


Fig. 33. A. Drawing of transverse section of digestive gland tubule with bold lines that separate several types of disease conditions. 1. Haplosporan parasite (microsporans similar but may show fully developed spores, see Figs. 42 and 43). 2. Rickettsiae. 3. Virus infection with manifestation of inclusion in cytoplasm. 4. Virus infection with inclusion in nucleus. 5. Virus with occlusions in swollen nucleus. As cells are destroyed, more general lesions are formed from viruses. Inclusions of viruses normally show distinctive shape and staining features. Particular viruses will infect particular tissue types (not always hepatopancreas tissue) and cell locations (nucleus or cytoplasm) within preferred hosts. Cells enlarged by haplosporans and rickettsiae may be initially distinguished by comparing larger internal components of the pre-spore units of haplosporans with almost submicroscopic particles of microcolonies of rickettsiae. H_1 = early haplosporan stage, H_2 = later stage; R = rickettsial microcolony; CI = cytoplasmic inclusion of virus; NI = nuclear inclusion of virus; SN = swollen nucleus with occlusions within.

B. The normal tubule. Toward the digestive tract, secretory cells (1) predominate and fibrous cells (3) become more numerous. Absorptive cells (2) contain varying amounts of vacuoles according to nutritional status.

Fungus

Several fungi are known as shrimp pathogens. Two groups commonly infect larval shrimp, whereas another attacks the juvenile or larger shrimp. The most common genera affecting larval shrimp are Lagenidium and Sirolpidium. The method of infection requires a thin cuticle such as that characteristic of larval shrimp (Figs. 34 and 35).

The most common genus affecting larger shrimp is *Fusarium*. It is thought that entry into the shrimp is gained via cracks or eroded areas of the cuticle. *Fusarium* may be identified by the presence of canoe-shaped macroconidia that the fungus produces. Macroconidia and examples of fungal infections are shown in Figures 36, 37 and 38.

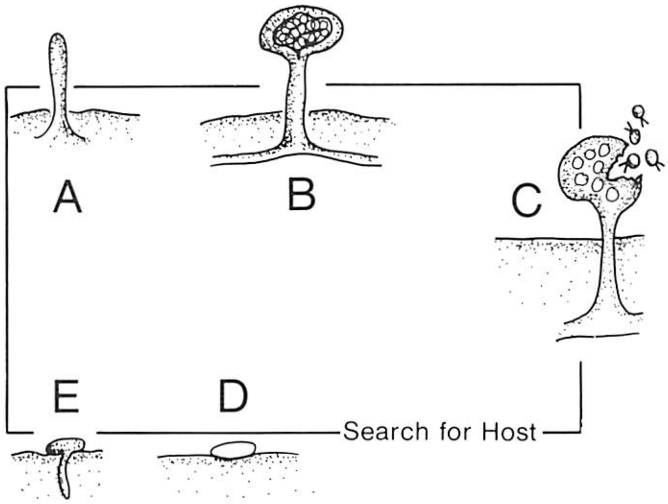


Fig. 34. Transmission of *Lagenidium*. A. Fungus sends out discharge tube from within shrimp body. B. Vesicle forms. C. Vesicle produces motile spores that are released. D. Motile spores contact shrimp and undergo encystment. E. Germ tube is sent into the body of the shrip and fungus then spreads throughout.

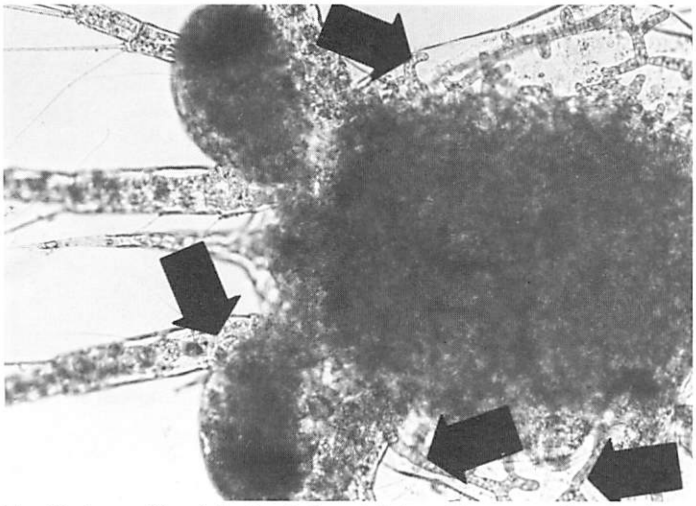


Fig. 35. *Lagenidium* infection in larval shrimp. Note extensive development of branchings of fungus throughout the body. (Photo courtesy of Dr. Don Lightner, University of Arizona.)

Fig. 36. Canoe-shaped macroconidia of *Fusarium*. These structures bud off branches of the fungus and serve to transmit fungus to shrimp.

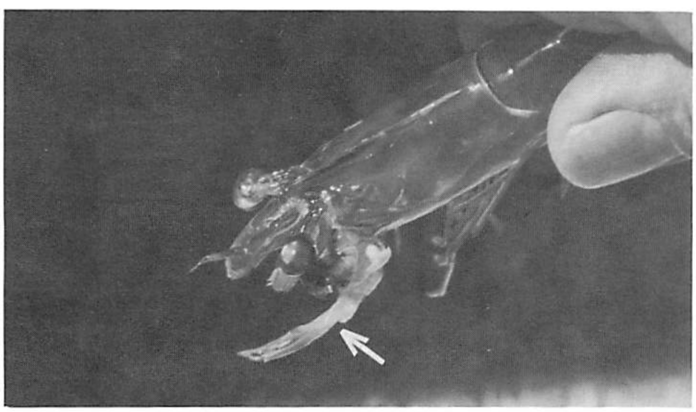


Fig. 37. Shrimp photographed immediately after mole: Old appendage (arrow) is not shed due to destruction of hypodermis by active fungal infection.

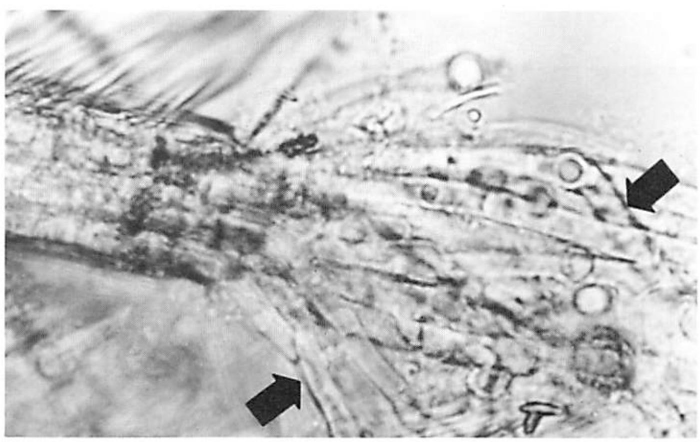


Fig. 38. Microscopic view of fungus at tip of antenna.

Protozoa

Protozoan parasites and commensals of shrimp will occur on the inside or outside of the body. Those on the outside are considered harmless unless present in massive or burdensome numbers. Those on the inside can cause disease and are representative of several groups of protozoan parasites: Microspora, Haplospora and Gregarina. Members of these groups are known or believed to require that some animal besides shrimp be present in order to facilitate completion of their life cycles. A few protozoa are known to invade weakened larval animals directly and contribute to disease.

Microspora parasitize most major animal groups, notably insects, fish and crustaceans. In shrimp, microsporan infections are best known locally as cause of a condition known as "milk" or "cotton" shrimp (Figs. 39, 40 and 41). Microsporans become remarkably abundant in the infected shrimp and cause the white appearance of muscle tissues. A typical catch of wild shrimp will contain a few individuals with this condition. These shrimp are usually discarded before processing. Depending on the type of microsporan, the site of infection will be throughout the musculature of the shrimp or, in particular organs and tissues.

Microsporans are present in the affected shrimp in the form of spores. Spores are small cells that can develop into a new individual. They are very minute and detection requires examination with a microscope (Figs. 42 and 43).

Infected shrimp are noted to be agile and apparently feed as normal shrimp. However, tissue damage occurs and no doubt affects many life functions. No eggs have been found in "milk" shrimp and it is suspected that all types of microsporan infections can render shrimp incapable of reproduction (Fig. 44).

The life cycles of shrimp microsporans have not been satisfactorily worked out. However, examination of the cycles of related species and miscellaneous facts contained in literature indicate that the cycle presented in Figure 45 is representative of microsporans.

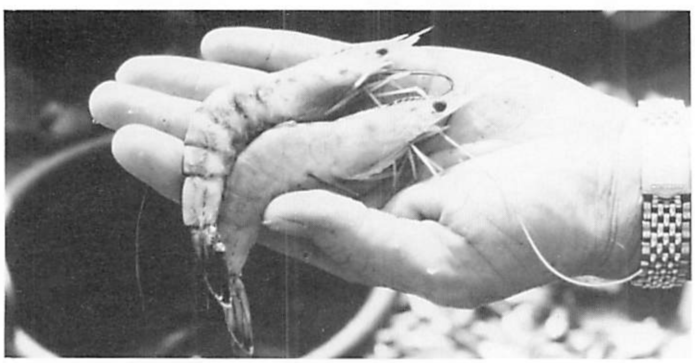


Fig. 39. Infected or "milk" shrimp (upper) in comparison to normal shrimp (lower). (Photo courtesy of Dr. R. Nickelson.)

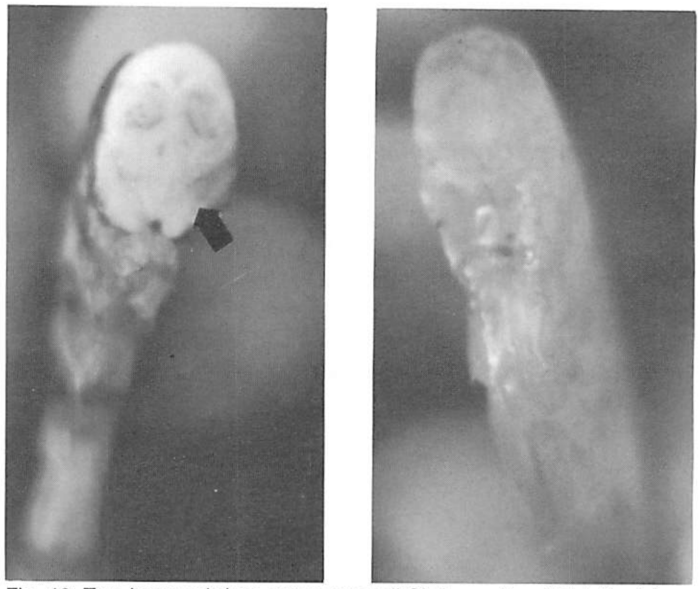


Fig. 40. Two brown shrimp cut across tail.Shrimp with whitish flesh has microsporan infections throughout muscle tissue.

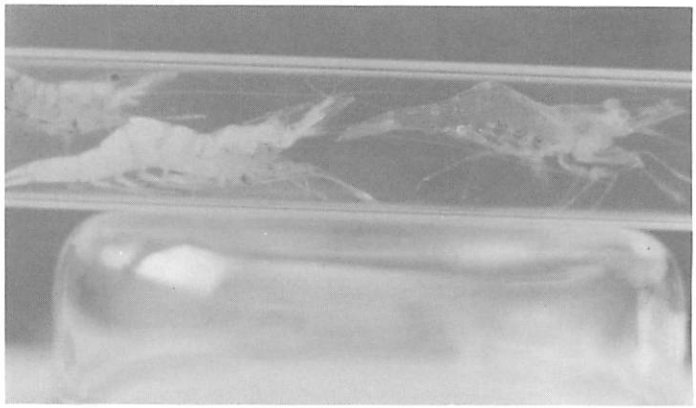


Fig. 41. Grass shrimp with "milk" shrimp condition. The normal shrimp in the figure is transparent.

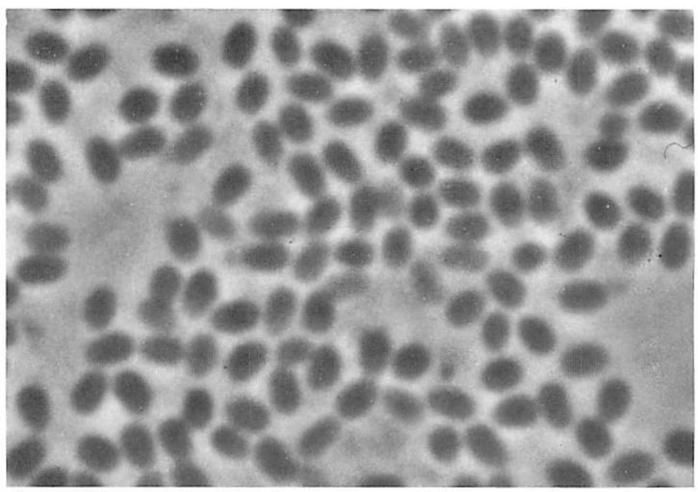


Fig. 42. Microscopic view of many spores of *Ameson (=Nosema)* sp. The spores are free or unenveloped. Parasitic microsporans of commercially important shrimp with enclosing envelopes are assigned to genera *Pleistophora, Thelohania* and *Agmasoma*. The latter two differ from *Pleistophora* in that their membranes retain a constant spore number of eight per envelope. *Pleistophora* sp. have more than eight spores per envelope.

Haplospora

A member of the Haplospora, another spore forming protozoan group, was recently recognized in as important to shrimp health when researchers found infected animals in an experimental population that had been imported into Cuba from the Pacific Coast of Central America. The parasites invaded and destroyed tissues of the digestive gland (Fig. 32). Such infections are not common in aquaculture.

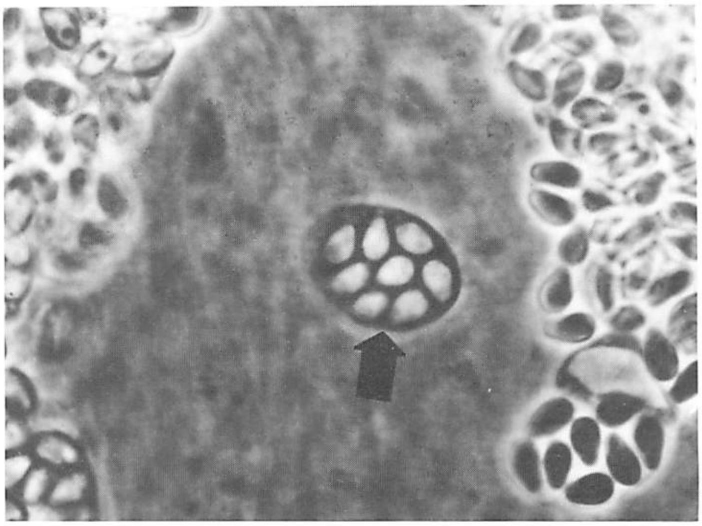


Fig. 43. Microscopic view of many spores of *Thelohania* sp. Note envelope (arrow).

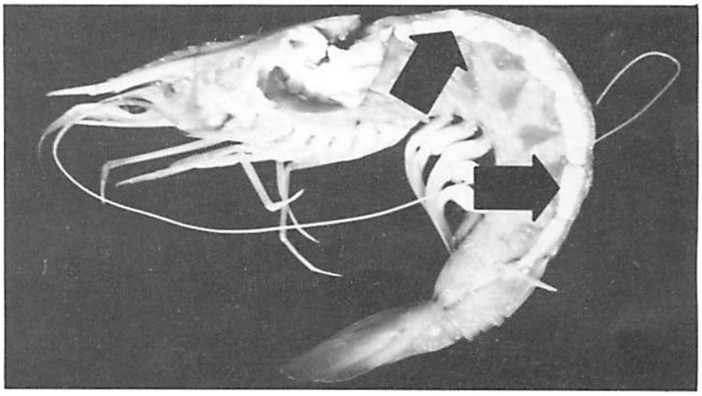
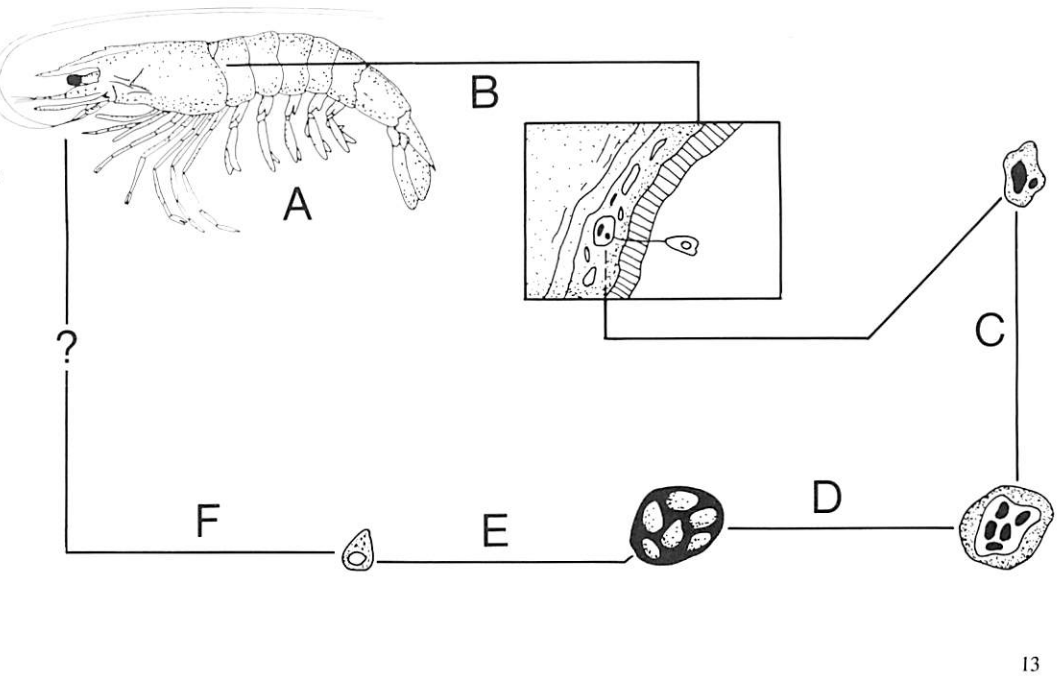
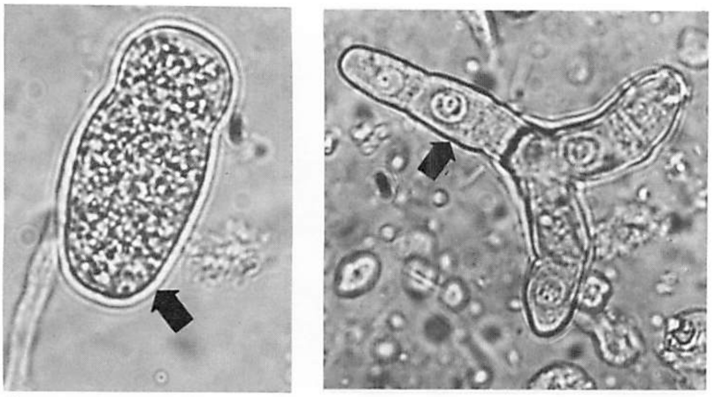


Fig. 44. *Agmasoma penaei* in white shrimp. This parasite is always located along the dorsal midline (arrows). Advanced infections can be seen through the cuticle with the unaided eye.

Fig. 45. Life cycle of microsporan of shrimp. A. Ingestion of spores by shrimp. B. In gut of shrimp, the spore extrudes a filament that penetrates gut wall and deposits an infective unit. A cell engulfs this unit. C. Infective unit enters the nucleus of the cell, undergoes development and then divides to form schizonts. D. Schizonts then divide and develop into spores. E. By the time spores are formed, they are located in a specific tissue (muscle, tissues around intestine, etc.). The spores are either discharged from the shrimp while living or after death, but the method of release and the pathway taken is not known. F. Experiments designed to transmit infection by feeding infected shrimp to uninfected have been unsuccessful. It is assumed particular events such as involvement of another host may be required to complete passage from one shrimp to the next. Successful transmission has been reported when infected shrimp were fed to fish (speckled trout) and fish fecal material was then fed to shrimp.





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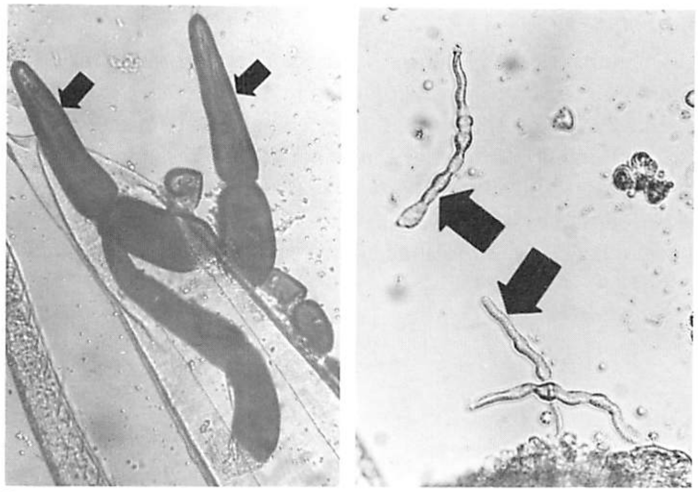

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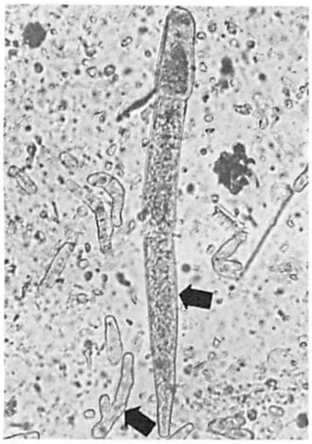


C

Fig. 46. Microscopic views of gregarines. A. and B. *Nematopsis* sp. tropohzoites. C. *Nematopsis* sp. gametocyst. D. Trophozoites of *Cephalolobus* sp., a gregarine that attaches to the base of the terminal lappets of the shrimp stomach rather than the intestinal wall (photo courtesy of Dr. C. Corkern). E. Trophozites of *Paraophioidina* sp., a gregarine found recently in Pacific white shrimp larvae.

Fig. 47. Microscopic view of gametocyst of *Nematopsis* sp.

Gregarina

Gregarine are protozoa that occur within the digestive tract and tissues of various invertebrate animals. They occur in the digestive tract of shrimp and are observed most often in the form of a trophozoite (Fig. 46) or occasionally a gametocyst (Fig. 47). The life cycle involves other invertebrates such as snails, clams or marine worms as diagrammed in Figure 48.

Minor damage to the host shrimp results from attachment of the trophozoites to the lining of the intestine. Earlier study suggested that absorption of food or intestinal blockage by the protozoa is perhaps detrimental but that pathological damage was relatively unimportant. Recent study indicates that when trophozoites of Nematopsis species are present in large numbers, damage to the gut lining occurs that may facilitate infection by bacteria.

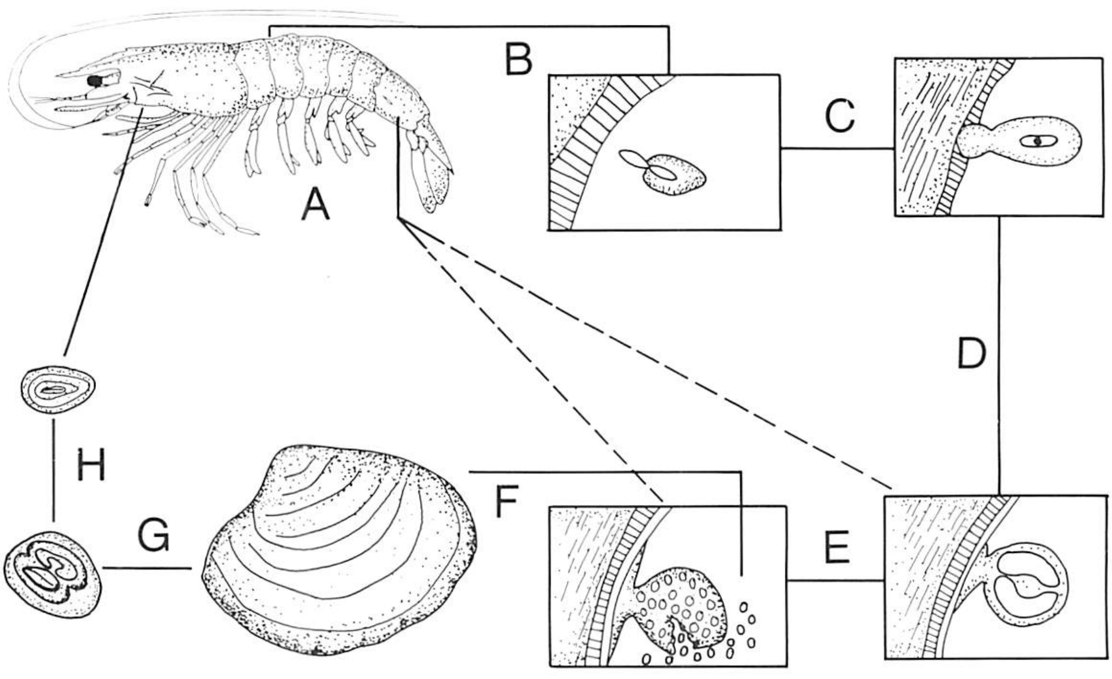


Fig. 48. Life cycle of a gregarine of shrimp. A. Shrimp ingests spores with bottom debris. B. Sporozoite emerges in the gut of the shrimp. C. Sporozoite attaches to the intestinal wall and grows into a delicate trophozoite; other trophozoites do not attach to the wall but onto each other and form unusual shapes (See Fig. 47). D. The unusual forms develop and attach to the end of the intestine (rectum) to form gametocysts. E. Gametocyst undergoes multiple divisions to produce "gymnospores" that are set free with rupture of the gametocyst. F. Gymnospores are engulfed by cells at the surface of the flesh of clams. G. They develop to form spores in the clam. H. Then the spores (with sporozoite inside) are liberated from the clam in mucous strings (slime).

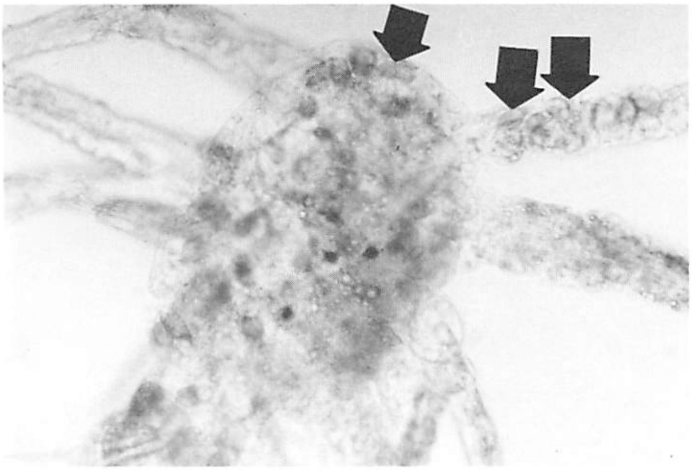


Fig. 49. Weakened larval shrimp invaded by ciliated protozoans (arrows).

Body Invaders

Several protozoa have been noted to invade a shrimp body and feed on tissues as they wander throughout. Tentative identifications name Par*auronema*, *Leptomonas*, *Paranophrys* and an amoeba. Adverse effects of these protozoa are not fully understood, but they are usually found associated with shrimp that have become weakened or diseased (Fig. 49).

Surface Infestations

Ectocommensal Protozoa

Several kinds of protozoa are regularly found on surfaces, including gills, of shrimp. Apparently, shrimp surfaces are a favored place to live within the water environment. Common on the surfaces of shrimp are species of Z*oothamnium*, *Epistylis*, *Acineta*, *Ephelota*, and *Lagenophrys* (Fig. 50A-E).

Zoothamnium is a frequent inhabitant of the gill surfaces of shrimp, and in ponds with low oxygen content, heavily infested shrimp can suffocate. Surface-settling protozoa occasionally cause problems in shrimp hatcheries when larval shrimp become overburdened and are unable to swim normally. As protozoa continuously multiply in numbers, shrimp acquire an increasing burden until shedding of the cuticle provides relief.

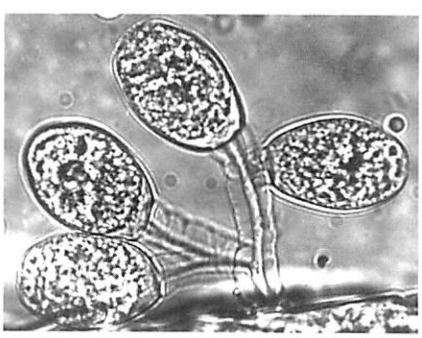
Members of one unique group of protozoa, the apostome ciliates, have a resting stage that will settle on shrimp surfaces. When the crustacean molts, the protozoan releases and completes the life cycle within the shed cuticle before entering a resting stage on a new crustacean (Fig. 51).

Other Surface Infestations

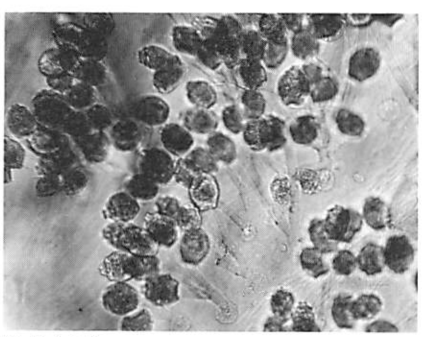
A variety of other organisms attach to shrimp surfaces. Their abundant presence on gills and limbs can interfere with breathing and mobility. Small, single-cell plants called diatoms are often found attached to larval shrimp in hatcheries. (Fig. 52). Shrimp from aquaculture facilities that are exposed to an unusual amount of sunlight often will have over-growths of algae of mixed variety (Fig. 19).

Occasionally, one will find barnacles, leeches and the colonial hydroid *Obelia bicuspidata* affixed to body surfaces (Fig. 53). These organisms are probably quite common in the vicinity of the shrimp and select surfaces of infrequently molting, older shrimp as spots to take up residence. Insects will sometimes lay eggs on shrimp (Fig. 54).

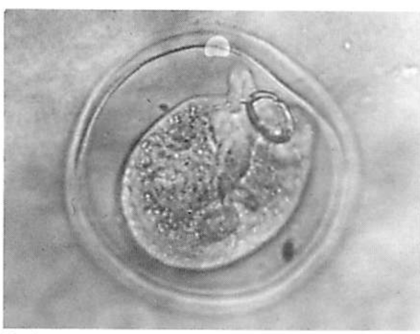
Some members of the crustacean group called isopods are parasitic on shrimp of commercial importance. Commercially important shrimp of the Gulf of Mexico are apparently not parasitized. However, smaller shrimp of the family Palaemonidae are often seen infested along our coastline. Commercial shrimp of the family Penaeidae are parasitized in Pacific areas (Fig. 55A and B).



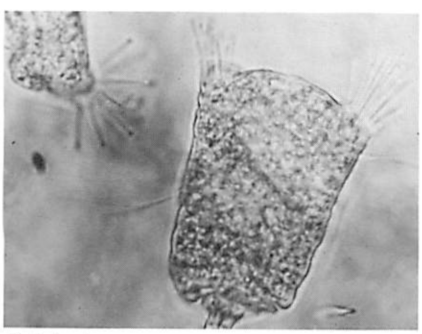
A. Zoothamnium



B. Epistylis

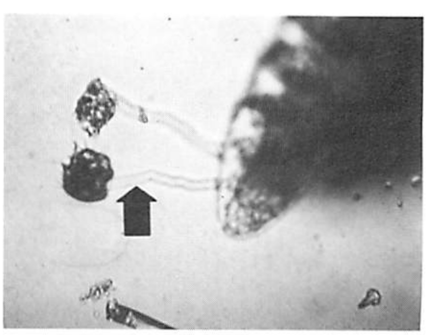


C. Lagenophrys



D. Acineta

Fig. 50. Microscopic views of common surface dwelling protozoa.



E. Ephelota

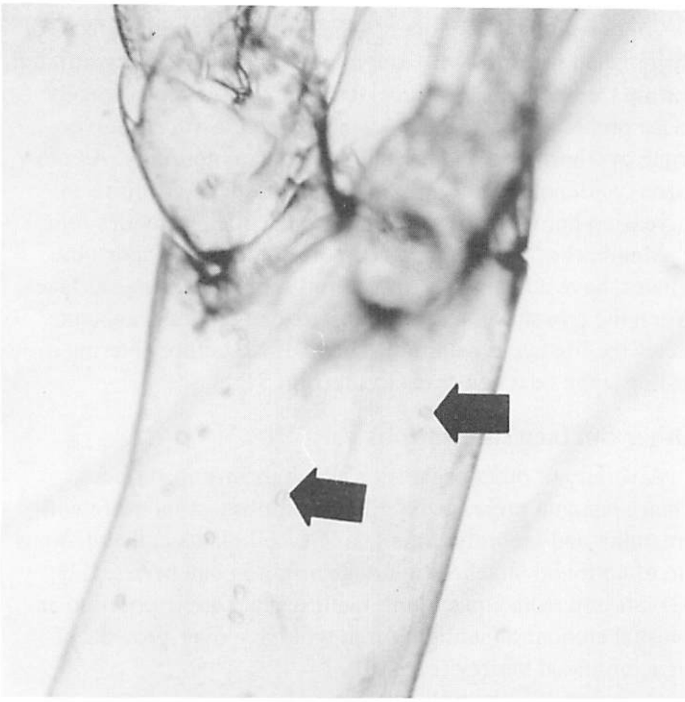


Fig. 51. Microscopic view of several apostome ciliates inside grass shrimp molt. Proper identifiation of genus cannot be determined from living animal. Staining with a technique called silver impregnation is required.

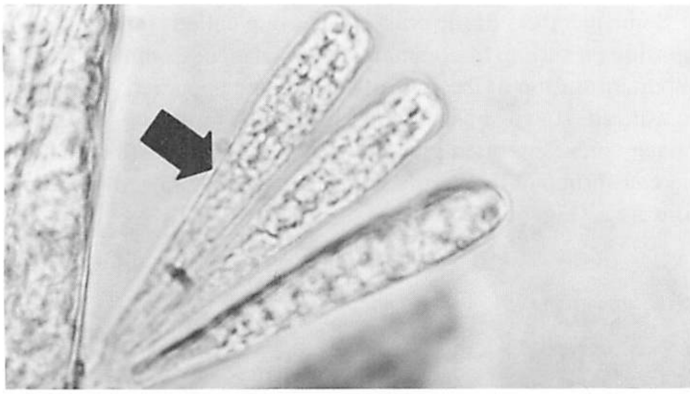


Fig. 52. Microscopic view of diatoms (arrow) attached to gill surfaces of larval shrimp.

Fig. 53. Grass shrimp with leech attached.

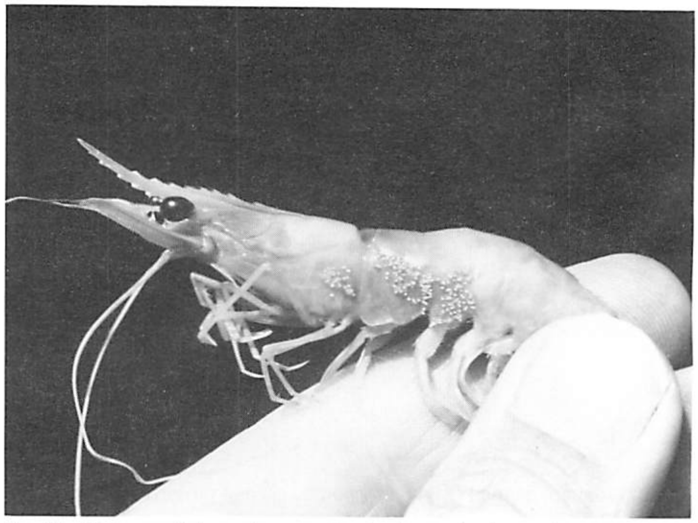


Fig. 54. Shrimp with insect eggs attached to cuticular surface.

Fig. 55A. Asian shrimp infested with parasitic isopods (gill cover flared open to expose parasites).

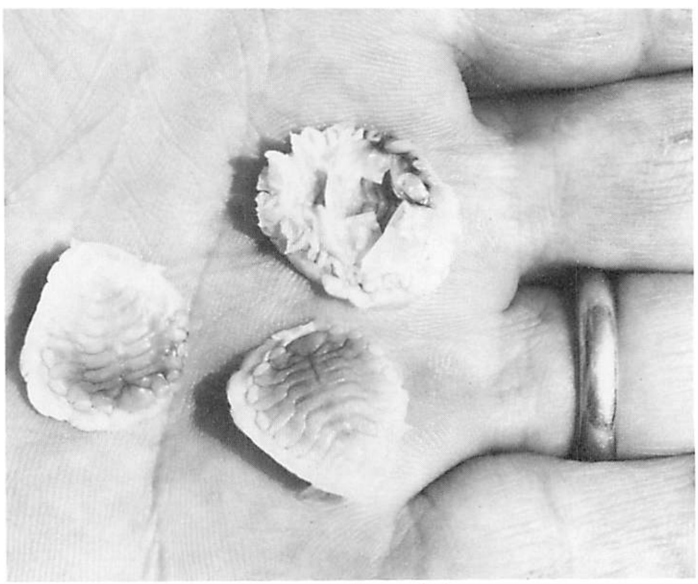


Fig. 55B. Parasitic isopods removed from shrimp.

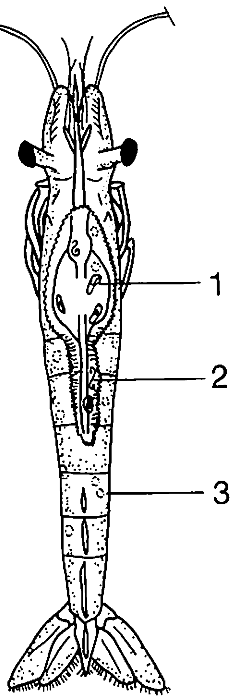


Fig. 56. Common sites of infestation by worms. 1. Tapeworms; usually associated with tissues covering digestive gland. 2. Roundworms; in and outside organs in cephalothorax, but also along outside of intestine. 3. Flukes; commonly encysted in tissues adjacent to organ in cephalothorax, but also in abdominal musculature and under cuticle.

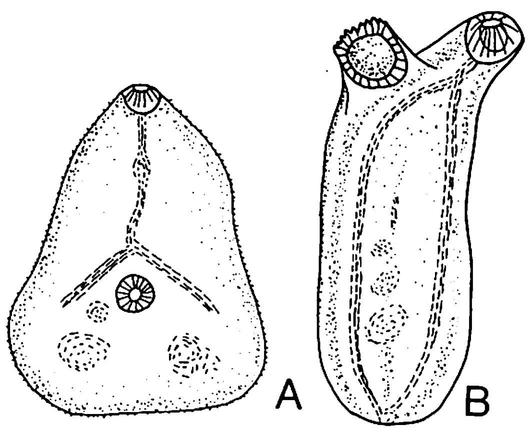


Fig. 57. Drawing of microscopic view of common flukes of shrimp (excysted). A. *Microphallus* sp. B. *Opeocoeloides fimbriatus.*

Worms

Worm parasites of shrimp are categorized as trematodes (flukes), cestodes (tapeworms) and nematodes (roundworms). Some species are more common than others and, as yet, none have been known to cause widespread shrimp mortality. Worms may be found in various parts of the body (Fig. 56).

Trematodes

Trematodes (flukes) are present in shrimp as immature forms (metacercariae) encysted in various body tissues. Metacercariae of trematodes of the families Opecoelidae, Microphallidae and Echinostomatidae have been reported from commercial species of penaeid shrimp (Fig. 57). One species, *Opecoeloides fimbriatus*, has been noted to be more common than others along our coast, and the hypothetical life cycle of this species is illustrated in Figure 58.

Cestodes

Tapeworms in shrimp are associated typically with the digestive gland. They are usually found imbedded in the gland, or next to it, in the covering tissue. In shrimp, tapeworms are present as immature forms (Fig. 59), while adult forms are found in rays. Species of the genera *Prochristianella, Parachristianella* and *Renibulbus* are common. Other tapeworms from wild shrimp include a relatively common pear-shaped worm of the intestine and a less common worm of the cyclophyllidean group. Tapeworms are most often encountered in wild shrimp.

Differentiation between the tapeworm groups is made in general body form and tentacular armature. A hypothetical life cycle for *Prochristianella penaei* is presented in Figure 60.

Nematodes

Nematodes occur more commonly in wild shrimp than in cultured shrimp. The degree of infection is probably related to the absence of appropriate alternate hosts in culture systems. Nematodes will occur within and around most body organs, as

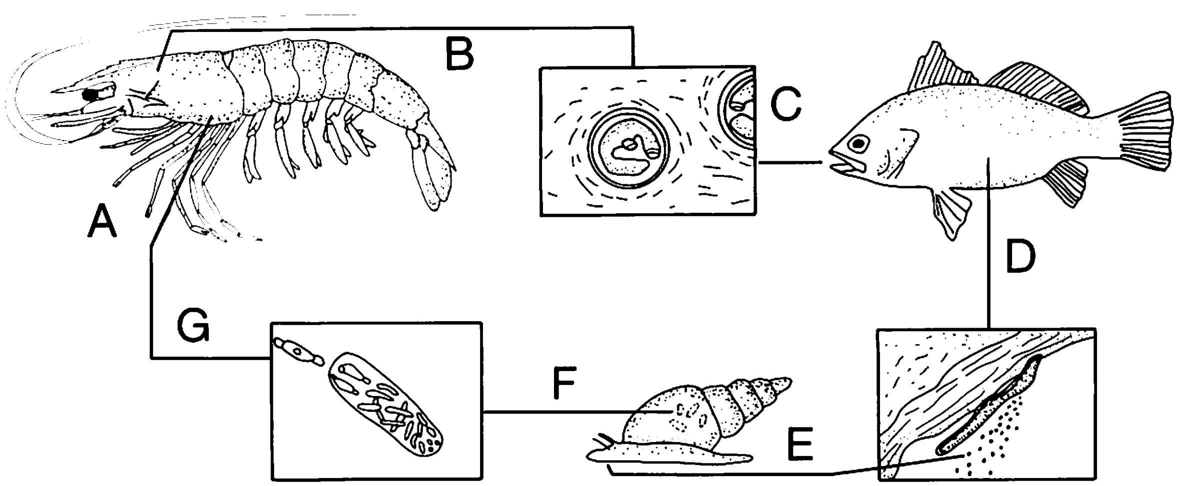


Fig. 58. Hypothetical life cycle of a shrimp fluke, *Opecoeloides fimbriatus.* A. Infective stage or cercaria penetrates shrimp. B. Cercaria migrates to the appropriate tissue and encysts forming a stage called metacercaria. C. Shrimp infected with metacercaria is eaten by fish (silver perch, red drum, sheepshead, several others). D. Shrimp is digested. This releases metacercaria. Metacercaria stage undergoes development until it forms an adult. E. Eggs laid by adult fluke pass out of fish with wastes. Egg hatches and an infective stage known as a miracidium is released. The miracidium penetrates a snail and multiplies in number within sporocysts. F. Cercariae develop within sporocysts. When fully developed, cercaria leaves the sporocyst and snail and swims in search of a shrimp. If contact is made with a shimp within a short period, the cycle is completed.

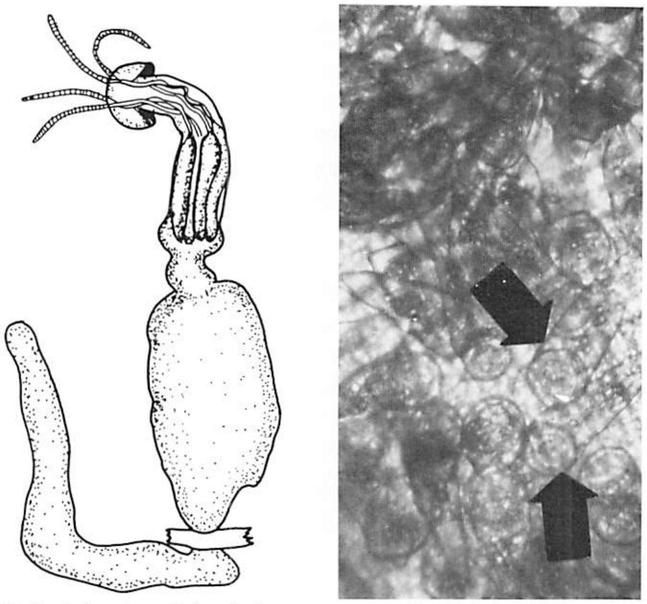


Fig. 59. A. A drawing of the shrimp tapeworm, *Prochristianella penaei* as it would appear in a microscopic view after removal from its cyst. B. Unnamed pear-shaped tapeworm larvae in gut. (Photo courtesy of Dr. C. Corkern.)

well as in the musculature. Nematodes of shrimp include *Spirocamallanus pereirai* (Fig. 61), *Leptolaimus* sp. and *Ascaropsis* sp. The most common nematode in Gulf shrimp is *Hysterothylacium reliquens* (Fig. 61).

It is the juvenile state of nematodes that infects shrimp with the adult occurring in fish. An illustrated life cycle thought to represent *Hysterothylacium reliquens* is depicted in Figure 62.

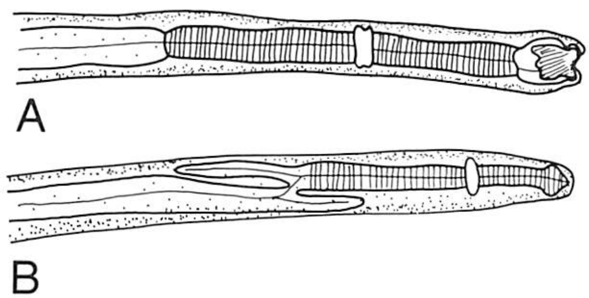


Fig. 61. Drawing of microscopic view of head end of (A) *Spirocamallanus pereirai* and (B) *Hysterothylacium* sp. common roundworms found in penaeid shrimp.

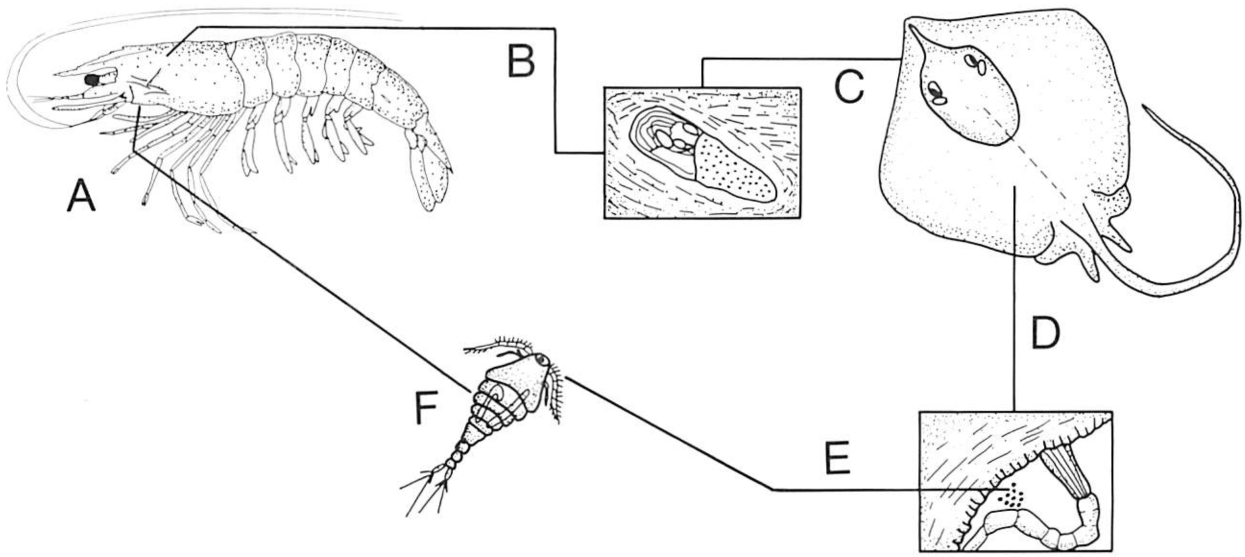


Fig. 60. Hypothetical life cycle of the tapeworm, *Prochristianella penaei* Kruse. A. Shrimp eats a copepod or other small crustacean infested with larval tapeworm. B. Tapeworm develops into advanced larval stage in tissues of shrimp. C. Stingray ingests infested shrimp. D. Tapeworm develops into adult in gut (spiral valve) of ray and begins to release eggs. E. Eggs pass out of the fish with feces and are eaten by copepod. Eggs hatch and larval worm develops inside copepod.

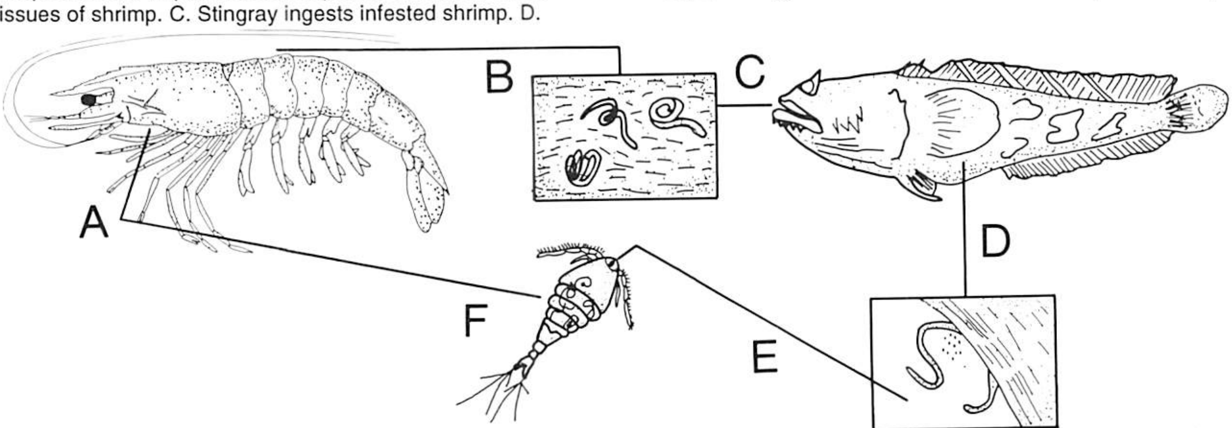


Fig. 62. Hypothetical life cycle of *Hysterothylacium relinquens*, a roundworm of shrimp. A. Shrimp eats a copepod or other small crustacean infested with larval roundworm. B. Roundworm develops into advanced larval stage in tissues oi snrimp. C. Toadfish ingests infested shrimp. D. Roundworm devleops into adult in gut of fish with feces and are eaten by copepod.

Environment

Environmental Extremes

Temperature, irradiation, gas saturation, hydrogen ion content (pH), oxygen content and salinity all have appropriate tolerable ranges for sustaining life of various shrimp species and life stages. If these ranges are exceeded or extremes combine for an interactive effect, shrimp will become diseased. Besides the direct effect from these noninfectious agents, exposure may result in predisposal to effects of opportunistic infective agents.

Gas bubbles will form in the blood of shrimp if exposed to waters with large differences in gas saturations. If a large amount of bubbling occurs in the blood, death will result.

In the presence of acidic water, minerals will often precipitate on cuticular surfaces. Usually the precipitant is iron salt (Fig. 63).

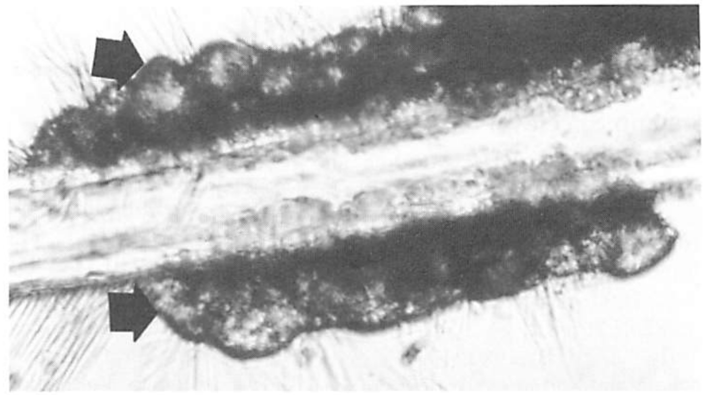


Fig. 63. Precipitant of iron salt on a shrimp's fringe hair (setule).

Toxicity

Poisoning can result from toxic substances absorbed from the water or consumed food. Water may accumulate excessive concentrations of ammonia, nitrite, hydrogen sulfide or carbon dioxide, all of which can have a toxic effect on shrimp. Some metals also may cause a toxic effect when present in excess. Both presence and toxicity of these chemicals are influenced by the changeable environmental conditions. They may act singularly or have combined effects.

Certain microbes and algae will excrete poisonous materials. Examples of algal release are the occasional red tides that occur along our coast. Aside from survival loss, affected animals behave in a disoriented manner. Microbes such as bacteria become concentrated in high density rearing systems. When microbial species with potential for toxic release greatly increase therein, stocks may be damaged.

Pesticides can be harmful if they occur seasonally in surface water supplies affected by agricultural practice. Because of migrations into estuaries or near effluent disposal sites, wild shrimp populations are more susceptible than cultured stocks to the variety of pollutants released.

There are reports of toxicity caused by the food shrimp consume. Toxins from microbes are known to build up in feeds stored in unfavorable conditions. Some food stuffs and live larval food, such as brine shrimp, can contain pesticides. Perhaps more common are undesirable effects of feeds that have aged and become rancid.

Breakdown of lining tissues (necrosis) of the intestine have been associated with consumption of certain algae. Because cultured shrimp feed both on prepared feeds and bottom materials, it is suspected that the occasional occurrence of detrimental irritants and toxins contained within bottom surfaces could cause tissue breakdown when such sediments are consumed. ■

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