USE OF THE TADPOLE SHRIMP (*TRIOPS* SPP.) AS A BIOLOGICAL AGENT TO CONTROL PADDY WEEDS IN JAPAN

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ABSTRACT

Tadpole shrimps, Triops spp., are aquatic crustaceans which appear in paddy fields a few days after flooding and puddling. The shrimps have been used by some farmers in Japan as a biological agent for weed control. The weeding mechanisms of the shrimps are discussed, from the viewpoint that the shrimps have ecological characters typical of r-strategic pioneer organisms similar to those of annual plant weeds found in paddy fields, even though they belong to quite different taxonomic groups. To maintain the stability of Triops populations in rice paddies, the environment must be repeatedly disturbed to maintain fluctuating conditions.

INTRODUCTION

Tadpole shrimps, *Triops* spp., are aquatic crustaceans belonging to the Subclass Branchiopoda. This includes many species which appear in paddy fields a few days after they are flooded and puddled (Table 1).

For many years, Japanese farmers have recognized the effectiveness of tadpole shrimps in removing weeds from paddy fields. The name they are called in Japanese means "weed picking bugs in rice fields". The Hyogo Agricultural Experiment Station confirmed this in work carried out between 1923 and 1925 (Katayama 1973a). However, only relatively few farmers have been using tadpole shrimps for weed control, and then only in limited parts of Japan, such as in Kawachi-Nagano City in Osaka Prefecture from 1977, and in Kawabe-cho, Wakayama Prefecture, from 1978 (Katayama 1973, 1978).

Studies of the biology and effectiveness of the shrimps are now under way to determine whether this method of weeding could be used more widely, and whether it is suited to the ecology of the modern paddy field.

DISTRIBUTION OF TADPOLE SHRIMPS

The tadpole shrimp is a name commonly given to many types of Triopsidae, including the genera *Triops* and *Lepidurus.* Since they are also present in the fossil record, there are a number of reports on their past and present distribution, as well as their morphology and reproduction (Longhurst 1955, Akita 1976, Hempel-Zawitkowska 1967, Katayama 1973, Igarashi 1970 etc.).

The genus *Triops* comprises four species (Table 1). The distribution area of the American tadpole shrimp, *T. longicaudatus*, is North America and Oceania, while the Asian tadpole shrimp, *T. granarius*, is found from South Africa to the Eurasian Continent. The European tadpole shrimp, *T. cancriformis*, is found in Europe, North Africa, and Middle East to India, while the Australian tadpole shrimp, *T. australiensis*, is found in Australia, and in parts of Madagascar.

Only *T. australiensis* is not found in Japan. Since there are no *Lepidurus* spp. (Table 1), the three *Triops* species found in Japan are assumed not to be endemic, but to have been introduced by means of human activity (Katayama and Takahashi 1980). *T. longicaudatus* was first described in

Key words: Tadpole shrimp, *Triops* spp. biological control, paddy weeds, pioneer organisms, r-strategist, desertic conditions, natural farming.

Table 1. Taxonomy and distribution of tadpole shrimps and related species

Arthropoda
- Crustacea
  - Branchiopoda
    - Notostraca
      - Triopsidae: tadpole shrimps
        - *Triops* spp.
        - *Lepidurus* spp.
    - Anostraca
        - *Branchinella* spp.
    - Conchostraca
        - *Caenestheriella* spp.
    - Cladocera
        - *Daphnia* spp.

Species	Distribution	Reproduction
Triops longicaudatus (Le Conte) The American tadpole shrimp (2 subspecies)	North America (south of 50°N), Central - South America, West Indies, Galapagos Islands, Hawaii, New Caledonia, and Japan	Bisexual Hermaphroditism in the west of North America, Galapagos Islands, Hawaii, and Japan
Triops granarius (Lucas) The Asian tadpole shrimp	South Africa, Middle East, India, China (30 - 50°N), and Japan	Bisexual
Triops cancriformis (Bosc.) The European tadpole shrimp (3 subspecies)	Europe (south of 60°N), North Africa, Balkans, Middle East to India, and Japan	Bisexual in south Europe Hermaphroditism in Northern Europe and Japan
Triops australiensis (Spencer & Hall) The Australian tadpole shrimp (2 subspecies)	The drier regions of Australia and Madagascar	Bisexual

Source: Longhurst 1955, Katayama 1973, and others

Japan by Ueno (1925) and is widely distributed from the Kanto District to the middle of Kyushu (Fig. 1). *T. granarius* has a local distribution in some estuaries near large harbors in Shizuoka, Osaka, Hyogo, Kyoto, Shimane, Tottori, Tokushima, Kagawa, Ohita, and Fukuoka Prefectures. It is sometimes sympatric with *T. longicaudatus* in the same locality and even in the same paddy field (Katayama *et al.* 1974, Tanimoto 1975). *T. cancriformis* is found only in Yamagata Prefecture, far from the other two species.

TADPOLE SHRIMPS IN WEED CONTROL

Weeding Mechanisms

Tadpole shrimps control weeds by three mechanisms. Firstly, they agitate the soil surface so that young seedlings of paddy plants are uprooted. They scratch the soil surface while searching for benthic food, as well as burrowing into the soil for oviposition. They deposit their eggs in the soil at a depth about 1-3 cm, depending on their body size, and then cover the eggs with soil and level the soil

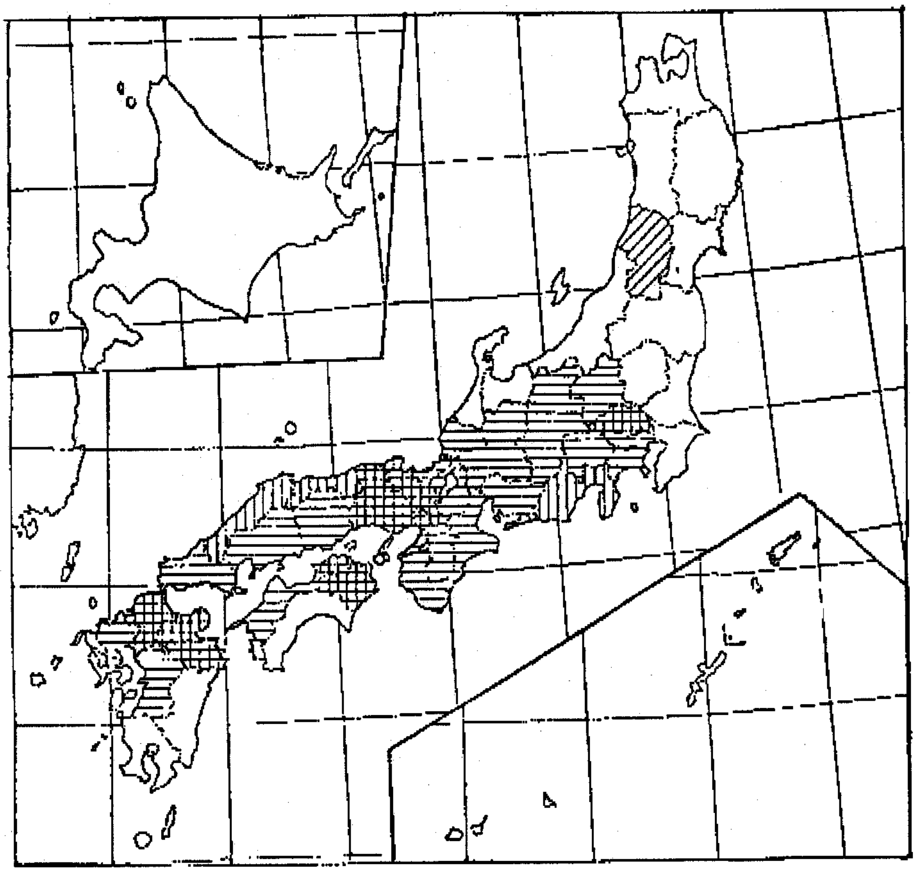

Fig. 1. Distribution of tadpole shrimps in Japan

: *Triops cancriformis,*

: *Triops granarius,*

: Coexistence of *T. longicaudatus* and *T. granarius,*

: *Triops longicaudatus.*

Source: Katayama and Takahashi (1980)

surface.

Secondly, they eat the young buds and roots of newly germinated plant seedlings. Tadpole shrimps are basically detritus filter feeders, but they eat omnivorously many kinds of living and dead organisms in the soil and water.

Thirdly, when they are active in feeding and oviposition, fine soil particles are disturbed and the water becomes muddy. As a result, sunlight cannot pass through the water, so that the photosynthesis of young plants under water is inhibited by what could be called a biological mulching effect. However, muddy water does not inhibit photosynthesis if it is very shallow.

Tadpole shrimps have an influence, not only on the seedlings of paddy weeds, but also on rice plants when they are direct seeded. In California, where rice is sown by direct seeding, tadpole shrimps are considered a pest (Grigarick *et al.* 1961). However, if rice is transplanted, as is usual in Japan, the shrimps do not have any harmful effect because the transplanted rice seedlings are too big to be damaged by their activity.

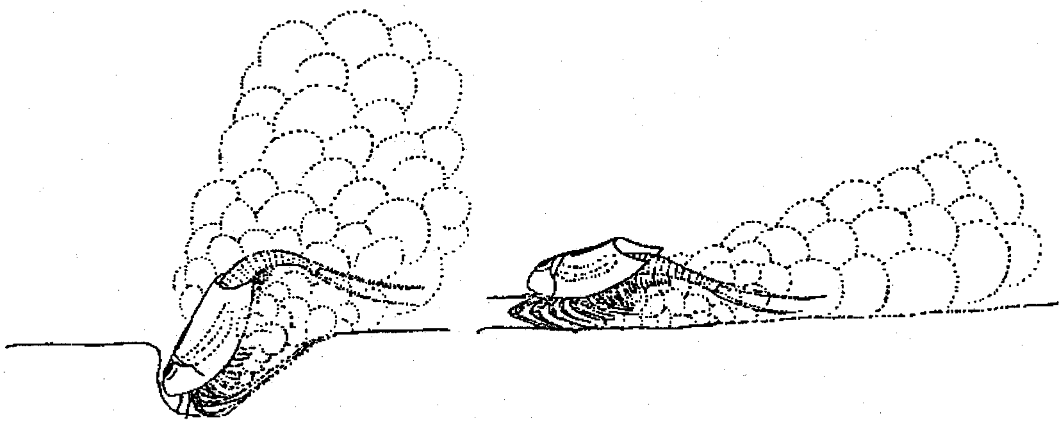

Fig. 2. Tadpole shrimps scratching the soil surface for oviposition (left) and in gathering food (right)

Effectiveness of Weeding by the Shrimps

The mechanism of weeding by tadpole shrimps is mostly mechanical and depends on their omnivorous behavior so it is not selective against particular plant species. The weeds observed in Japanese paddies cover more than 200 species, of which about 30 are considered to be particularly harmful to rice. About 20 species are annual weeds and are injured by the shrimps because they usually germinate in paddy fields just as the shrimps are developing. On the other hand, the action of the shrimps may have little effect on perennial weeds.

Katayama *et al.* (1974) examined the weeding effect experimentally during the growing season of rice plants, and observed only a few weeds when tadpole shrimps were present at a density of more than 25 individuals/m^2. The weeding effect continued until the rice harvest, even though the shrimps by then had already disappeared.

Yonekura (1979) studied the relationship between shrimp population density and the control of selected weed species in experimental paddy fields (Fig. 3), and found that a density of more than 80/m^2 could effectively suppress weeds. Matsunaka (1976) estimated that it needed about 500 man-hours of work to weed 1 ha of paddy field by hand in the traditional way, but only 90 hours if herbicides are used, and only 20 hours to remove by hand weeds left behind after the action of the shrimps.

THE LIFE-STYLE OF THE TADPOLE SHRIMP

The effectiveness of weed control by tadpole shrimps is related to their density, their body size, and the time of their appearance in paddy fields. They appear just after paddy fields are flooded. Their eggs lie dormant in the soil, and can survive in a dormant state for many years. They are resistant to severe drought and temperature extremes, rather like the seed banks of annual weeds.

Most eggs hatch within a few days after being submerged, but some remain unhatched in the soil (Fig. 4, Takahashi 1977a). This is an effective way for the shrimps to maintain their populations under unpredictable fluctuations in environmental conditions (Takahashi 1977c).

The young shrimps develop rapidly to maturity, when their weeding activity becomes effective, just as many weed seeds are germinating (Fig. 5). In the case of *T. granarius*, the shrimps begin oviposition on the 10th day after submergence, while their body size is still increasing, and they lay many eggs during their short life span (Fig. 6).

Under laboratory conditions they can survive more than three months, but in the field they usually disappear within a month. Water management in most paddy fields is not suitable for the survival of the shrimps, and they have many natural enemies including birds, fishes, frogs and insects. However, once oviposition is accomplished, even after they disappear, their descendants are left safely dormant in the soil.

A review of the literature on the biology of *Triops* spp. suggests that tadpole shrimps have r-strategic pioneer ecological characters similar to those of annual paddy weeds, even though they belong to quite different taxonomic groups (see Table 2). Our laboratory experiments have confirmed this similarity in their ecological

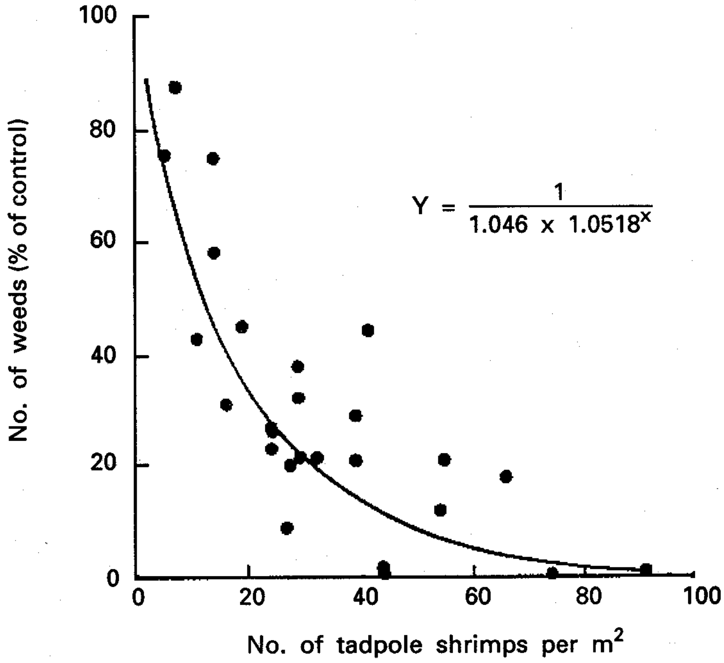

Fig. 3. Weeding effect of tadpole shrimps at different population densities

Source: Yonekura (1979)

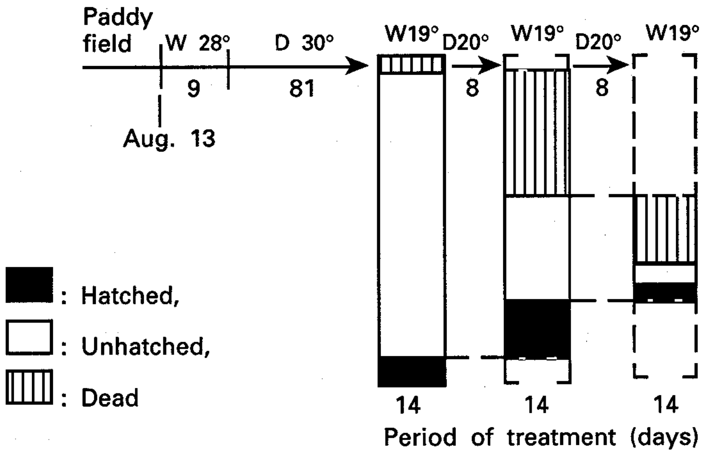

Fig. 4. Effects of repeated desiccation and water submergence on the hatching of *T. longicaudatus* eggs.

Treatment: alternate water submergence (W) and desiccation (D) of eggs

Source: Takahashi (1977a)

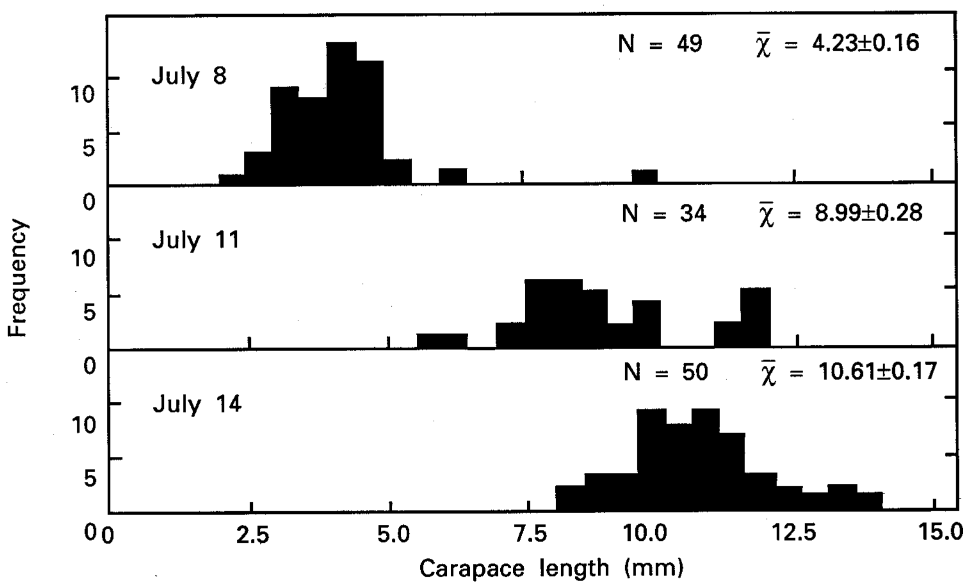

Fig. 5. Growth of tadpole shrimps in paddy fields in Kyoto

Cultivation program:
Flooding on July 1, puddling on July 2.
Transplanting of rice seedlings on July 3 - 5.

Source: Takahashi (1977a)

charactors (Takahashi 1975, 1977a, b, Takahashi *et al.* 1980).

Paddy fields are a habitat which is artificially disturbed when the fields are ploughed or sprayed with chemicals. The development of tadpole shrimps is adapted to a temporary water pool and unstable environmental conditions. Tadpole shrimps are frequently observed in paddies where the drainage system is efficient in producing dry conditions during the off season, while other common aquatic animals are unlikely to survive. For this reason, they are often found in paddy fields which have been converted from rice to upland crops for a few years, and then returned to flooded rice cultivation, and in paddy fields separated from other paddies by roads and houses. These conditions seem to inhibit the invasion of natural enemies.

ADAPTING RICE CULTIVATION TO THE TADPOLE SHRIMP

As pioneer animals, tadpole shrimps are characterized by their wide fluctuations in population density. This process can be clearly demonstrated by the sharp peak in their reproduction curve, as shown in Fig. 7 (Takahashi and Gohda 1981). When their density becomes very high, they can barely find enough food, and they become very active in searching for food such as newly germinated weeds. This is good for weed control, but food shortage inhibits their development and reduces fecundity, while mortality increases as a result of cannibalistic behavior. As a result, their population declines in the next generation. This instability in population density is not desirable from a practical point of view. For good weed control, shrimp populations should be maintained at the required level every time a rice crop is cultivated.

In Japan, conventional farming using chemical fertilizers and pesticides is widely practiced. Although tadpole shrimps are fairly resistant to agricultural chemicals, chemicals do still reduce the population densities in paddy fields (Takahashi and Kuroiwa 1982). Recently, however, some farmers have been carrying out natural farming without any chemical pesticides or fertilizers, and even without tillage. Hidaka (1990) reported a change in the abundance of tadpole shrimps related to the number of years in which natural farming has been carried out after changing from conventional farming (Fig. 8). The abundance of *Triops* spp. increased at first over time when chemicals were discontinued.

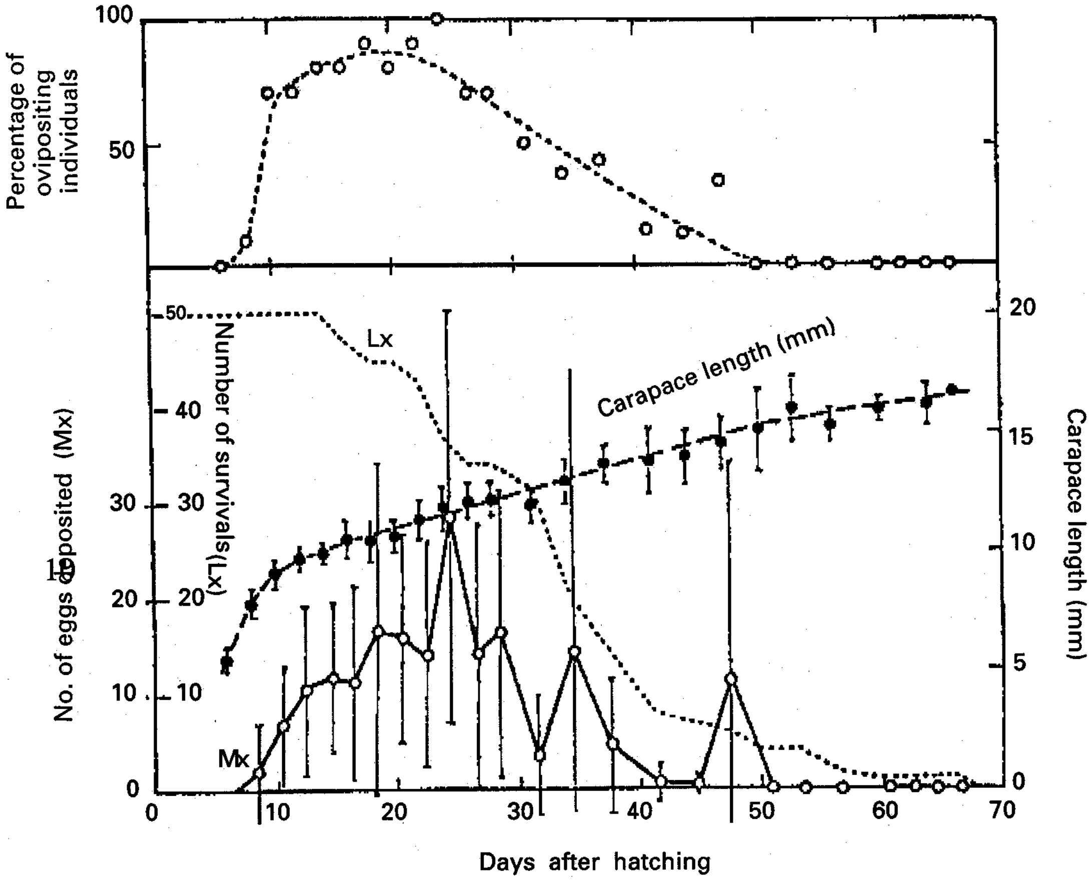

Fig. 6. Survivorship curve (Lx), fecundity curve (Mx), percentage of ovipositing individuals, and growth of carapace length in *T. granarius.*

Vertical bars indicate the S.D.
Source: Takahashi *et al.* 1980

However, the biotic community then stabilized and the *Triops* population declined, while populations of the parasitic nematode *Agamermis unka* (Mermithidae) increased. This nematode is an important biological agent for controlling the brown planthopper, *Nilaparvata lugens.* The character of this parasitic nematode is K-strategic, and its presence shows that the natural farming field has become an environment suitable for K-strategic organisms. Again, it is clear that tadpole shrimps are pioneer animals adapted to unstable environmental conditions.

The use of biological agents to control pest insects and weeds sometimes involves a contradiction, in that factors which promote one agent may damage another if they have different ecological characters, such as being of r- or K-strategists. To maintain stable *Triops* populations in paddy fields, the environment must be repeatedly disturbed to create conditions suitable for r-strategic organisms.

REFERENCES

Akita, M. 1976. Classification of Japanese tadpole shrimps. *Zoological Magazine* 85: 237-247.

Grigarick, A.A., W.H. Lange, and D.C. Finfrock 1961. Control of the tadpole shrimp, *Triops longicaudatus,* in California rice fields. *Journal of Economic Entomology* 54: 36-40.

Hempel-Zawitkowska, J. 1967. Natural

Table 2. Comparisons of biology of annual weeds and tadpole shrimps in paddy fields

<table>
<tr><th>Annual weeds</th><th>Tadpole shrimps</th></tr>
<tr><td colspan="2">• Life cycle adapted to a habitat disturbed annually or irregularly, such as paddy fields where ploughing, flooding, and drying occur repeatedly
• High level of persistence of seeds or eggs during long periods of severe soil conditions (dry, cold, hot etc.).
• Germination or hatching sensitive to stimulation by light, osmotic pressure or atmospheric conditions, when seeds or eggs are floating on the soil surface after flooding, ploughing and puddling.
• Prompt germination of seeds or hatching of eggs, and rapid development when environmental conditions become favourable, irrespective of photoperiodic conditions.
• Seeds or eggs do not all germinate or hatch at once: some persist in a dormant state in the soil.</td></tr>
<tr><td>• Development and growth under a wide range of nutritional and soil conditions.</td><td>• Omnivorous food habit, eating living and dead organisms, both animals and plants.</td></tr>
<tr><td colspan="2">• Broad overlap of growth and reproductive stages.
• High reproductive power, producing many seeds or eggs which are small in size.</td></tr>
<tr><td>• Self-compatibility in fertilization</td><td>• Some strains are hermaphroditic and are able to produce eggs unisexually</td></tr>
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Source: Takahashi 1975, 1977

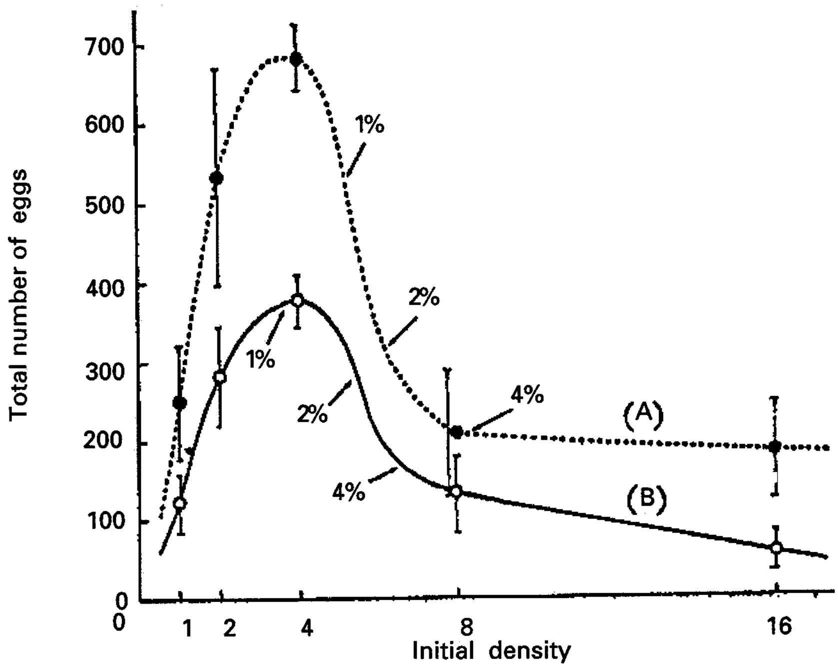

Fig. 7. Egg production curve observed in the population of *T. cancriformis*

The dotted line (A) indicates the total number of eggs deposited and the solid line (B) indicates that until 26th day. The vertical bars on each point show the S.E. of the averages. The arrow marks indicate the equilibrium points when the rate of survival from egg to young is 1, 2, or 4%.

Source: Takahashi and Gohda (1981)

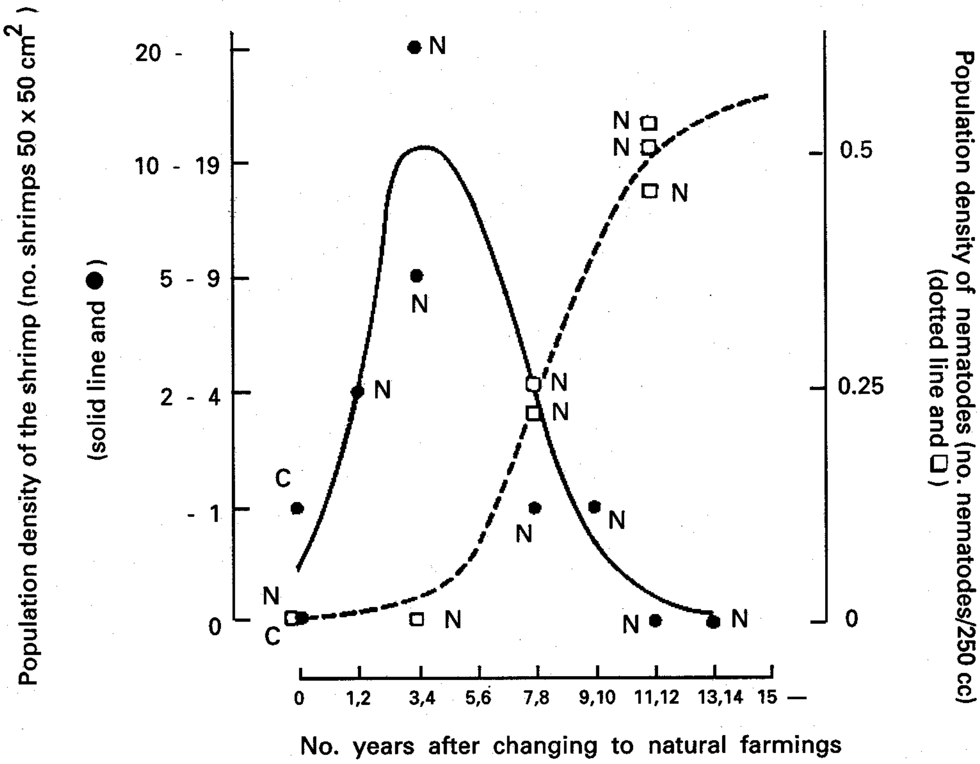

Fig. 8. Abundance of American tadpole shrimps and nematodes parasitic on the brown planthopper after a change from conventional to natural farming

Source: Hidaka 1990

history of *Triops cancriformis* (Bosc.). *Zoologica Poloniae* 17: 173-239.

Hidaka, M. 1990. Searching for a new farming technology, neither extensive nor intensive: Comparisons of the structure and function of the biotic community in rice cultivation between the natural farming and the conventional intensive farming. In: *Pest Insects in Natural and Organic Farming*, F. Nakasuji and K. Hidaka. Tojusha, Tokyo, pp. 10-265. (In Japanese).

Igarashi, K. 1970. Ecological studies of *Triops longicaudatus* [Notostraca] inhabiting Shonai district, Japan. 2. *Journal of Yamagata Agriculture and Forestry Society* 27: 34-39. (In Japanese with English summary).

Katayama, H. 1973a. The species of *Triops* and their distribution in Osaka district. *Nature Study* 19: 62-67. (In Japanese).

Katayama, H. 1973b. Biological control of weeds by tadpole shrimps in paddy fields 1, 2. *Nogyogijutu* (*Journal of Agricultural Technology*) 28: 161-163, 208-213. (In Japanese).

Katayama, H. 1978. The progress of a practice association utilizing tadpole shrimps in Kawachi-Nagano City. *Nogyogijutu* (*Journal of Agricultural Technology*) 33: 226-229. (In Japanese).

Katayama, H. and F. Takahashi. 1980. Tadpole shrimps—Their invasion and ecology. In: *Fresh Water Organisms in Japan: Ecology of Invasion and Disturbance*. T. Kawai *et al.* (eds.). Tokai University Press pp. 133-146. (In Japanese).

Katayama, H., K. Ueki, M. Soga, and H. Matsumoto. 1974. Studies on effect of tadpole shrimp on biological control of weeds in paddy field. 1. Field experiment of effect of *Triops granarius* (Lucas). *Weed Research* (*Journal of Weed Science Society, Japan*) 17: 55-59. (In Japanese with English summary).

Longhurst, A.R. 1955. A review of the Notostraca. *Bulletin of the British Museum (Natural History) Zoology* 3: 3-57.

Matsunaka, S. 1976. Tadpole shrimps: A biological tool of weed control in transplanted rice fields. *Proceedings of the Fifth Asian-Pacific Weed Science Society Conference, Tokyo*, 1975: 439-443.

Takahashi, F. 1975. Effect of light on the hatching of eggs in *Triops granarius* (Notostraca: Triopsidae). *Environmental Control in Biology* 13: 29-33. (In Japanese with English summary).

Takahashi, F. 1977a. Pioneer life of the tadpole shrimps, *Triops* spp. (Notostraca: Triopsidae). *Applied Entomology and Zoology* 12: 104-117.

Takahashi, F. 1977b. *Triops* spp. (Notostraca: Triopsidae) for the biological control agents of weeds in rice paddies in Japan. *Entomophaga* 22: 351-357.

Takahashi, F. 1977c. Generation carryover of a fraction of population members as an animal adaptation to unstable environmental conditions. *Research on Population Ecology* 18: 235-242.

Takahashi, F. and M. Gohda. 1981. The type of egg production curve with respect to population preservation: Ecological studies of tadpole shrimps (Branchiopoda: Triopsidae) for the biological control of weeds in rice paddies. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewande Limnologie* 21: 1531-1540.

Takahashi, F., M. Gohda, and A. Akayama. 1980. Comparison of life tables among the three species of tadpole shrimps. *Japanese Journal of Applied Entomology and Zoology* 24: 229-233. (In Japanese with English summary).

Takahashi, F. and Y. Kuroiwa. 1982. The influence of pesticide spray and manuring on the occurrence of tadpole shrimps useful for the biological control of weeds. *Studies on Natural Farming—The Memorial Issue of the Interdisciplinary Research Institute of Environmental Sciences, Kyoto* 101-108. (In Japanese with English summary).

Tanimoto, C. 1975. Ecological surveys of tadpole shrimps. (1). In Sanuki Plaine. *Heredity (Tokyo)* 29: 18-24. (In Japanese).

Ueno, M. 1925. *Apus* from eastern Asia. *Zoological Magazine* 37: 423-435. (In Japanese with English summary).

Yonekura, M. 1979. Weeding efficiency of the tadpole shrimp (*Triops* spp.) in transplanted rice fields. *Proceedings of the 7th Asian-Pacific Weed Science Society Conference, Tokyo*, 1979, pp. 237-240.

DISCUSSION

Dr. Takahashi was asked whether tadpole shrimps were harmed by the levels of pesticide and fungicide commonly applied to rice fields in Japan. He replied that he had observed abundant shrimp eggs after insecticides had been applied, but that there tended to be higher shrimp populations in fields where herbicides had not been applied than in fields where they had. Although this difference was statistically significant, it was not very marked. He added in reply to another question that it is not yet known whether tadpole shrimps are particularly sensitive to some kinds of herbicides or insecticides.

Dr. Shibayama commented on the strong interest among Japanese consumers in organic farming without any use of pesticides. He suggested that tadpole shrimps may be a promising means of weed control where transplanted rice is grown with shallow flooding. In organic farming, chemical herbicides cannot be used and hand weeding is difficult, so that tadpole shrimps might be a suitable solution. Dr. Takahashi agreed, and referred to his paper in which fields with high populations of tadpole shrimps needed only 20 man-hours/ha for manual weeding, a lower labor cost than the application of chemical herbicides. However, he emphasized that the weeding effect from tadpole shrimps is unstable, because there are wide fluctuations in their populations.