The History of Horseshoe Crab Research and Conservation in Japan

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Abstract Scientific studies of the Japanese horseshoe crab, *Tachypleus tridentatus*, from the Seto Inland Sea have been published for nearly a century, beginning with the pioneering work of Owhatari (1913). Studies by Matsunari, Asano, Oka, Nishii, Sekiguchi, and many others established much of the basic reproductive biology of the species in the vicinity of Kasaoka City. Oe-hama beach was designated as a "Horseshoe Crab Spawning Ground Natural Monument" in 1928. In spite of this formal recognition, and in the face of opposition by various local conservation organizations, the Kasaoka Bay Land Reclamation Project began in 1969. Horseshoe crab abundance since then has declined, which has stimulated efforts to raise horseshoe crabs in captivity. The success of such projects, though small in scale, affords some hope that horseshoe crab populations might experience recovery.

1 Introduction

Until very recently, the majority of the articles about the Japanese horseshoe crab (*Tachypleus tridentatus*) have been published in Japanese, and consequently, the rich history of horseshoe crab research in Japan is little known to the rest of the world. In particular, Kasaoka City, on the Honshu coast of the Seto Inland Sea, has been a focal point for horseshoe crab science, public awareness, and formal conservation activities for nearly 100 years. More recently, it has been the location of several efforts which may someday re-establish horseshoe crab populations using captive breeding methods. The 2007 International Symposium on the Science and Conservation of Horseshoe Crabs, upon which this book is based, allowed me the opportunity to discuss some of these past and present research and educational activities with a broad audience.

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2 Horseshoe Crabs in Kasaoka and Vicinity up to 1961

2.1 Report of Professor Chutarou Owhatari

A report on "Habits of the Horseshoe Crab" was one of the articles in the July 1913 edition of the *Japanese Journal of Zoology* (no. 298); the author was Chutarou Ohwatari, at the time a teacher at the Dai-roku High School. The article is a summary of the results of on-site surveys and collection of horseshoe crab specimens carried out by Ohwatari during the summer of 1912 at several sites in Okayama prefecture. These locations included Katakami, Hinase, Hachi-hama, Banda, Kogushi, and Sanban along the Honshu coast of the Seto Inland Sea as well as in Marugame and Takamatsu in Kagawa prefecture on the Shikoku coast of the Seto Inland Sea. Thus, this report is extremely valuable in understanding the natural history of horseshoe crabs in the Seto Inland Sea.

At the time, many people believed that horseshoe crabs made good agricultural compost, and if a few horseshoe crabs were incidentally caught in fishing nets, they were brought home and added to the compost heap. Questioning local people in Banda in Kojima county and around Kogushi yielded the information that, until a few years previously, boats out of In-no-shima and Takashima would come every summer to specifically catch horseshoe crabs. Several hundreds to several thousands would be caught, and set out to dry. Local residents found it hard to bear the terrific stench from the rotting horseshoe crabs, and so they called for a halt to this practice.

Even assuming a demand for horseshoe crabs as compost, it was not easy to catch a large number of them at one time, and so there was really no fishery specifically aimed at catching them. On both the Honshu and Shikoku coasts, they were caught incidentally by hand trawl (Danish seine), sailing drag seine, and drift net fisheries aimed at catching small shrimp, ordinary crabs or finfish, but generally only one or two horseshoe crabs were caught per night per fisherman. Most crabs were caught between May and July, but by early September, they had moved into deeper water, where they were more difficult to catch.

On the night of August 30, 1912, Ohwatari contracted with 12 hand-trawl fishing boats working out of Sanban Bay in Jodo county to bring him all the horseshoe crabs incidentally caught in their nets; a total of 33 horseshoe crabs were collected with prosoma widths ranging from 9.2 to 28.7 cm. This averages out to a little less than three horseshoe crabs per boat per night. In waters off of Atsu and Kogushi in Kojima Bay, not a single horseshoe crab was caught by a boat fishing the bottom with a drag net from 10 pm on August 29 to 5 am the following morning. However, 10 juveniles with anterior shells measuring from 4.6 to 8.6 cm wide were found in the mud at low tide on the tideflat at the eastern extremity of Kogushi beach.

This information allows us to confirm that horseshoe crabs inhabited a wide area, not only on the Okayama (Honshu) side but also around Shodoshima Island, Takamatsu, and Marugame on the Shikoku side.

2.2 The"Horseshoe Crab Field Guide" (1929), by Tsurukichi Matsunari

Tsurukichi Matsunari (1851–1940) carried out long-term field studies of horseshoe crabs at Oe-hama beach in Kasaoka starting in 1917, and published the "Horseshoe Crab Field Guide" in 1929. This book includes an account of how the horseshoe crab spawning areas of Kasaoka came to be designated as a national "Natural Monument."

Matsunari's interest in the horseshoe crab followed a visit in March 1917 by Kotaro Amamori of the national Ministry of Agriculture, Forestry and Fisheries' Seafood Production Experimental Station, who had come to the Oe-hama Beach Fishermen's Cooperative to conduct surveys related to half-crenate ark shell (*Scapharca subcrenata*) aquaculture experiments. He happened to see a 1-year-old horseshoe crab juvenile and mentioned that this was an extremely mysterious creature seldom found anywhere in the world.

This motivated Ohwatari to visit the site repeatedly in order to carry out research. Professors Shouzaburo Watase and Seitaro Goto, as well as scientists from the United States and Russia, also visited the site. Starting in late June 1926, Osamu Hattori of Tokyo Teikoku University conducted surveys here for about 4 weeks. Matsunari provided information and served as a guide to all these visiting scientists, and this aroused his interest in the horseshoe crab.

Following surveys in 1927 by Yaho Atari (Ministry of Interior, Department of Geography) and Sei-ichi Inoue (Ministry of Okayama prefectural office), and a visit by the prefectural school inspector stationed at Tsuda, Okayama, the "Horseshoe Crab Spawning Ground Natural Monument" was created in March 1928, under the "Law for the Protection of Historic, Scenic and Natural Monuments" (1919). In Japan, both sites and species can be designated as natural monuments, and in this case a site, not the species, was designated.

Matsunari also detailed the methods and results of his independent observations of horseshoe crab habitat, spawning and feeding behavior, etc. He estimated that approximately 1500 horseshoe crabs were caught in hand-trawl nets between April and November every year and dried for use in compost.

2.3 Studies by Daigoro Moriwake, Eitsu Oka, and Uichiro Asano (1936–1945)

In the November 1936 issue of *Kagaku Toppiku* ("Science Topics") magazine, there appeared an article entitled "Horseshoe Crabs," by Yoshitaka Imai, Taito Kodama, and Daigoro Moriwake. This article noted how Moriwake, at the time a freshman at Tokyo University, stopped at Kasaoka on his way home to Iwakuni (Yamaguchi prefecture) to call on Osamu Hattori of Tokyo University's Department of Science, who was doing research at Kanaura Bay. Moriwake gives an account of horseshoe crab spawning events in sandy areas

along rock walls bordering Yo-nasu (literally "west beach") and Oe-hama in Kanaura Bay, although apparently these are not eyewitness accounts. He also described horseshoe crabs stuck into cracks in rock walls around fishermen's homes to dry, looking like "upside-down frying pans."

Also in 1936, Ikio Sato published a report on "A Naturally Deformed Horseshoe Crab with Two Tails." This document describes a mature male horseshoe crab caught in late July off of Yorishima-cho in Asaguchi county, Okayama prefecture that had a completely formed "second tail" growing out of the right side of the shaft of the telson.

Around that time, Eitsu Oka of Tokyo University's Department of Science spent every summer in Kasaoka to conduct experimental embryology studies using horseshoe crab eggs. Despite its dry title, his report of his experiences, "Collecting Horseshoe Crab Eggs" (1940), provides a lively, readable, and comprehensive account of the horseshoe crab situation at Oe-hama beach and Kasaoka at the time. It described overall horseshoe crab distribution and spawning behavior, reviewed the existing literature, provided a guide to spawning sites in the Kasaoka area, and even listed horseshoe crab-related souvenir items available at the time. Particularly relevant was his comment that, "...Okayama prefecture in particular is a major spawning area. Within Okayama, Kanaura Bay is especially famous as horseshoe crab breeding habitat. Thus, when collecting horseshoe crab eggs, one invariably heads for Kanaoka Bay or its environs."

Uichiro Asano, a teacher at Kasaoka Girl's High School, also carried out long-term field studies of horseshoe crab spawning and embryology, and his "Natural History of the Horseshoe Crab" (1942) can be regarded as a summary of nearly a decade of effort. In particular, its section on the growth process remains an extremely valuable work even today.

2.4 Studies by Hiroyuki Nishii (1945–1961)

The next person to become deeply involved with the horseshoe crabs of Kasaoka was Hiroyuki Nishii, M.D. After graduating from Okayama University School of Medicine, he took a post at what was at the time the Okayama Prefecture/Kanaura Township/Oda County Hospital in June 1934. On his daily trips by Jinrikisha to and from the hospital, Nishii passed the stone monument at Oe-hama beach marking the "Horseshoe Crab Spawning Grounds Natural Monument," which aroused his interest in horseshoe crabs. Most local people, however, were not only uninterested in horseshoe crabs but in fact also treated them as a nuisance. The sight of people drying horseshoe crabs by sticking them tail-first into cracks in stone walls and other cruel treatment astounded Nishii and aroused his righteous indignation. He became acquainted with Matsunari (see Section 2.2), who became his guide, and in time Nishii started his own studies of horseshoe crab ecology and embryology during the scarce moments when he was not busy seeing patients.

After the long hiatus of the war, Nishii returned to his studies in Kasaoka, and by virtue of his strong leadership and outspoken commitment, a major movement to protect horseshoe crabs grew up in the Kasaoka area. When the Ministry of Agriculture, Forestry and Fisheries proposed the Kasaoka Bay Land Reclamation Project, Nishii worked to obtain funds earmarked for horseshoe crab protection, and his success led to the construction of a globally unparalleled horseshoe crab protection center. Nishii also organized the existing literature, both Japanese and foreign, which he published together with his own research results as the "Horseshoe Crab Encyclopedia" (first edition 1973, expanded edition 1975). This work remains an essential source for understanding the literature, in particular on the history of horseshoe crab protection.

Nishii also put considerable effort into training the next generation, including the author. Soon after starting my job as a science teacher at East Kasaoka Municipal Middle School in 1961, I was introduced to Dr. Nishii and, inspired by his enthusiasm, I began my continuing involvement in the horseshoe crab protection movement, the history of which is dealt with in the next section.

3 Surveys by the East Kasaoka Middle School Horseshoe Crab Research Club (1961)

The East Kasaoka Middle School Horseshoe Crab Research Club was established in 1961, and, guided by Dr. Nishii, immediately embarked on surveys of horseshoe crab spawning.

In the 2 years following the Club's establishment, its work included studies of horseshoe crab spawning and embryology. Dissection of adults revealed that females have about 13,000 eggs in the subfrontal area of the prosoma. It was found that spawning occurred from mid-June to the end of August, generally in the middle of the night during spring tides, from about midnight until 3 am. On average, each pair of horseshoe crabs spawned at five to six sites in succession along an arc-like path and each nest contained about 500 eggs. After about a month, embryos started to rotate, and hatching took place on about the 50th day. It appeared that juvenile (third molt) hatchlings hibernate in the sand from about October to about March of the following year.

In the Club's third year (1963), spawning surveys confirmed an increased number of nests all along the eastern shore, and also that horseshoe crabs spawned at sites located progressively eastwards, starting at Oe-sawa and moving to Irie, Koh-no-shima inlet, Ohshima beach, and so on.

In 1964, the club organized the results of its 4 years of research to enter in the annual Japan Student Science Awards, sponsored by the Yomiuri Shimbun newspaper, and won first prize for Okayama prefecture. The work of the Horseshoe Crab Study Club continued, and I devoted myself to protection activities as well as field studies with my students, literally, in the mud. The result of these efforts was the publication of my book "The Horseshoe Crab of

Seto." Excerpts of this book appeared nationwide in Japanese textbooks for fourth graders under the titles "The Horseshoe Crab" and "Protecting the Horseshoe Crab" for 22 years.

It should also be noted that in 1964, an abnormal proliferation of the naticid gastropod *Neverita didyma*, a bivalve predator, occurred along a stretch of coast where the concentration of juvenile horseshoe crabs was the greatest, centering on the tideflats at Natsume and Torinoe beach on western Ohshima Island and extending about 6 km from Yokoshima to Nagahama. No direct link between this snail and juvenile horseshoe crabs was identified, but it seems unlikely that horseshoe crabs would not be affected by this event's impact on the local food chain.

4 Surveys for the Kasaoka Bay Land Reclamation (1966)

Major construction work on the Kasaoka Bay Land Reclamation Project was to have commenced in 1966, but because this project involved landfilling the Horseshoe Crab Spawning Ground Natural Monument site at Oe-hama beach, surveys were required to identify an alternative site. Professor Shiro Kawaguchi of Okayama University carried out surveys of adult spawning density and the characteristics of adult and juvenile habitat from 1966 to 1971.

Most of these field surveys were performed by the main research team members, assisted by five field researchers and many graduate and undergraduate students. Because they were conducted just before the land reclamation project began, their results constitute an extremely valuable reference for understanding the status of horseshoe crab habitation in Kasaoka Bay before it was reclaimed. The reports based on the 1966 surveys in particular describe a landscape that is unimaginable now. Thus, at the risk of waxing long-winded, I would like to quote from these reports at some length here.

4.1 The Oe-Hama Beach Area in Kasaoka City

Habitation status: Rather extensive areas of tidal flats extended along both the east and west shores of Kanaura Bay including the area at the mouth of the bay, most of this was fine, silty mud so deep that one sank in to the thighs even when wearing rubber-soled boots. Many juvenile horseshoe crabs with prosoma widths from 2–3 to 7–8 cm were found at low tide on these areas of fine, silty mud. Because it was so difficult to walk here, it was nearly impossible to measure numbers of individuals distributed over a wide area, but concentrations of several individuals per square meter were frequently observed. Thus, we can surmise that quite a considerable number of horseshoe crabs inhabited this area. However, large individuals with shells wider than 10 cm were very seldom seen on the areas of tidal flat exposed at low water, but rather were seen in the

shallowest parts of boat channels running through the area. The mud flat area where the greatest numbers of horseshoe crab juveniles were seen was located on the east side of the mouth of Kaneura Bay. The juveniles, including some very small individuals less than 1 cm wide, were normally found completely submerged in the fine, silty mud. Horseshoe crab juveniles were also found on tidal flats on the Oe-hama side and at other locations around the mouth of the bay, but not quite as many as on the east side of the bay entrance.

Spawning sites: Going eastwards from the mouth of Kanaura Bay there was a sandy beach 20–30 m long near Kanazaki, but otherwise the bottom is muddy right up to the seawall. Every time we visited this beach to determine the presence of nesting, we invariably failed to find any nests. However, on the west side, that is, on the Oe-hama beach side, some sandy areas remained in the Kanaura-hashizume area, and the more landward beaches provided particularly suitable spawning sites. Here we were able to observe adult pairs engaged in spawning, and we also found many indentations in the sand where spawning had taken place. Numerous horseshoe crab juveniles were observed on the mud flats in the Oe-hama beach area, and the larger adults were also observed in boat channels there. Of particular significance was our observation of adults spawning on the sandy areas of the beach, because it had been said that no more horseshoe crabs were to be found on Oe-hama beach due to various construction projects that had been going on, including a seawall, a bridge, and a road. It was thought that the Oe-hama beach area had lost its practical value as a Horseshoe Crab Spawning Ground Natural Monument, and for this reason as well as in reference to the land reclamation project, it was said that an alternative site needed to be designated. Another spawning site was thought to have existed toward the south side of Oe-hama beach, but this survey was unable to confirm any spawning at this site.

4.2 Katashima and Vicinity

An extensive horseshoe crab habitat site was found in Katashima and vicinity; in particular, it was confirmed that great numbers of horseshoe crabs inhabited a large muddy/sandy area on the north side of the site. Spawning was confirmed over an extensive area of sandy beach even during the 1968 surveys.

4.3 The Yokoshima Coast

Yokoshima had an extensive area of tidal flat, and large numbers of juveniles were found. There were also large, sandy spawning sites, and the area was well known as a place where numerous pairs came to spawn, but in fact during this survey spawning was confirmed at only two spots.

4.4 The Irie Vicinity and the Natsume Coast

There was a deep inlet in the vicinity of Irie, with an extensive area of tideflats inhabited by a large number of horseshoe crab juveniles. There were sandy areas between the small boat harbor and Ohdonsu, and numerous instances of spawning were confirmed, especially in sandy pools. Although there was no sand along the seawall at Shinden in west Ohshima, between the Ohshima River and the Natsume coast there were sandy areas along the road embankment, and many instances of spawning were confirmed here. The presence of horseshoe crabs was also confirmed along the shoreline continuing southwards from the Natsume coast; also, although the beach was rather narrow, the presence of many horseshoe crab juveniles and spawning was confirmed along Ohdonsu beach near the Youth House.

4.5 The Koh-No-Shima/Uchiura Vicinity and the Furue Coast

There were extensive tidal flats in the vicinity of Koh-no-shima/Uchiura, at Katashima and in the Tenjin area. Many horseshoe crab juveniles were also found on these tidal flats, and many rather large horseshoe crabs were also seen in the small boat channels and along the edge of the tidal flats. The seawall built for the land reclamation project extends to a considerable distance into the muddy area at this site, and almost no sandy areas were seen along the coast here. Even so, many nests were found in the small areas of sand still remaining and in spaces among the gravel and rocks. Along the Furue coast south of here there are also sandy beaches and extensive tidal flats, where the presence of horseshoe crab juveniles was also confirmed.

5 The Kasaoka Bay Land Reclamation Project (1969) and Formation of the "Kasaoka Association for the Protection of Horseshoe Crabs" (1970)

These surveys by Kawaguchi and his group gave additional credence to the research carried out by Nishii, Tsuchiya, and the East Kasaoka Middle School Horseshoe Crab Research Club. However, in September 1969, while Kawaguchi's studies were still under way, an opening ceremony was held to commemorate the start of construction on the Kasaoka Bay Land Reclamation project, slated for completion in 1975. Taking his warning from this, Nishii submitted a statement to the Mayor of Kasaoka that clearly and concretely explained the need to take measures to conserve the horseshoe crabs and secure funds specifically for this purpose. While calling on the government for a swift resolution to this issue, by putting pressure on the Kasaoka Rotary Club, Lion's Club, Jaycees, Women's Association, Parent/Teacher Organization (PTA), Youth Organization, and other

groups, Dr. Nishii gained the agreement of about 13,000 Kasaoka residents in favor of horseshoe crab conservation. With their support, the "Kasaoka City Association for the Protection of Horseshoe Crabs" was formed, and a "Horseshoe Crab Emergency Declaration" was published on December 1, 1970, calling on the relevant authorities to expedite protection measures. Dr. Nishii also submitted a statement to the Ministry of Agriculture suggesting that an opinion on horseshoe crab protection measures by Dr. Koichi Sekiguchi of Tokyo University of Education should be sought, and based on this suggestion, in May of the following year (1971) Sekiguchi provided the detailed and practical "Opinion Statement on Measures to Protect the Horseshoe Crab." Based on this statement, in May 1972, the ministry elected to provide a subsidy of 24.8 million yen to Kasaoka City earmarked for horseshoe crab protection measures.

In the meantime, the Mayor of Kasaoka had submitted an application for a supplementary "Horseshoe Crab Breeding Site Natural Monument" including the entire Koh-no-shima channel; based on this application, then Culture Minister Sakata Michita designated this site in 1971.

In July 1971, the "Kasaoka Horseshoe Crab Protection Youth Group" was set up on the suggestion of the Kasaoka City Board of Education, and the activities of the East Kasaoka Middle School Horseshoe Crab Research Club were taken over by this group, which included 54 students from 3 middle schools. All the surveys and research noted above were continued by this new group.

At about this time, a new problem arose, namely how to save the horseshoe crabs living in and around Oe-hama beach once construction started in earnest on the Kasaoka Bay Land Reclamation Project. One problem was the fine, silty, and very deep mud of the tideflats off of this beach; there was a lot of excited discussion about the best way to gather the horseshoe crabs on these flats, for example, by using platform-type geta clogs, rowing out on the flats in large tubs, or even by utilizing special frequency electromagnetic waves. However, none of these methods actually ended up being implemented before construction began. The desperate efforts of the Horseshoe Crab Youth Group from Kanaura Middle School only managed to save several hundred horseshoe crab juveniles, which were released mainly at Natsume and Torinoe beaches.

Professor Sekiguchi, who had been using horseshoe crabs collected in Kasaoka Bay in his research at the Tokyo University of Education Shimoda Marine Research Facility (now the University of Tsukuba Shimoda Marine Research Center), became concerned that the Kasaoka Bay Land Reclamation Project and other factors would deprive Kasaoka Bay of its value as horseshoe crab habitat. He released about 20,000 artificially inseminated eggs and hatchlings at Koh-no-shima in September 1969. This activity was repeated annually for some years afterwards, though the release site was changed to Natsume beach, and in recent years has been continued by Professor Tomio Itow of Shizuoka University.

6 Breeding and Raising Japanese and American Horseshoe Crabs in Captivity

6.1 Rationale

As detailed above, the Oe-hama shore in Kasaoka was designated as a protected breeding place of horseshoe crabs in 1928. Unfortunately, the shallow sea was increasingly reclaimed after World War II, and the horseshoe crabs disappeared. Efforts to propagate horseshoe crabs through captive breeding have been conducted as one possible measure to protect the species from the threat of extinction.

6.1.1 Studies by Tokiko Mitsueda

Ms. Tokiko Mitsueda directs the horseshoe crab breeding program at the Kasaoka Municipal Horseshoe Crab Museum. She has successfully raised both American and Japanese horseshoe crabs from the egg stage to adulthood.

On September 1, 1998, Ms. Mitsueda started raising fertilized eggs of American horseshoe crabs that she received from Dr. Sekiguchi. The fertilized eggs were spread upon a plastic frame ($30 \times 20 \times 7$ cm). Eggs were placed on the top of the tray and the seawater was changed twice a day. Four days later, all the eggs hatched, and these newly hatched horseshoe crabs began to develop into the first molting stage. During the first stage, these larval horseshoe crabs do not need to feed because they have their embryonic yolk sacks. From the second stage, juveniles were raised in sand and fed mixed food such as brine shrimp, TetraMin, and Tetra Krill-E in a laboratory dish up to the fifth stage. They were returned to their containers after being fed. From the sixth stage, worms (tubifex) were added as live food. It was noted that these juvenile horseshoe crabs habitually molted during the night.

On November 30, 1990, these juvenile *Limulus* attained the full length of 16.2 cm of the 13th stage. They were moved to a water tank of $45 \times 30 \times 20$ cm. The bottom of the water tank was spread with coral sand, which doubled the height. On March 10, 1991, they reached the 14th stage of larval horseshoe crabs after molting for the 13th time. On June 18, 1991, they matured to the 15th stage and preferred to eat live food such as polychaetes (lugworms), littleneck clams, and ark shells. After eating in a separate container for about an hour, they were returned to the water tank.

On September 6, 1991, these horseshoe crabs molted for the last time, and finally became adult male horseshoe crabs, 3 years since they were raised from the egg stage. These male horseshoe crabs had been bred to study how many years they could live afterward; however, they died in 2006.

Ms. Mitsueda has also had success in raising the Japanese horseshoe crab in captivity. In 1998, eggs were gathered from the spawning pond of the Horseshoe Crab Protection Center and hatched in the laboratory. A selectivity experiment

determined that young horseshoe crabs preferred mud rather than sand, therefore mud was gathered from the tidal flats and put on the bottom of the containers.

Sea water was exchanged about once a month, but depending on water temperature and the number of feedings, about half of the sea water was replaced about every 20 days after the crabs reached the second instar stage. Fresh water was added as needed to maintain the salinity.

Ms. Mitsueda developed a method of feeding that reduced the fouling of the aquarium. Horseshoe crabs were taken out of their aquarium and moved to another container in which they were allowed to feed. After feeding, the horseshoe crab was washed with sea water, and returned to its aquarium. In this way, the water in their aquarium remained clear and less susceptible to rotting. The sea water in the aquarium was replaced with 50% new sea water during feeding.

Tachypleus juveniles were fed a similar regimen to *Limulus* as described previously, i.e., brine shrimp for second instars, brine shrimp and TetraMin for third and fourth stages, brine shrimp, TetraMin, and tubifexes for fifth stages, and TetraMin, chopped clams and worms for sixth stages and beyond.

Unfortunately, there was only surviving horseshoe crab left by 1997. On September 28, 1999, it finally became an adult female crab after the last molting. This individual became an adult female in its 11th year.

6.1.2 Studies by Oshige Yoshinori

Mr. Oshige Yoshinori, a junior high school science teacher, began to raise 50 Japanese horseshoe crab eggs from the Kasaoka Municipal Horseshoe Crab Museum in September 1993. He also obtained another 50 larval horseshoe crabs the following year which he raised and studied with his students at Konoshimasoto Junior High School. In April 1995, he was transferred to another school, yet he was able to take 38 of the original 100 horseshoe crabs to continue raising and studying by himself at home. The following report is based on the progress of that group of 38 crabs beginning in April 1995 until the present time.

Mr. Yoshinori's method of raising the crabs was to spread mud from a tidal flat at the bottom of a water tank. The mud contains plentiful natural food for horseshoe crabs; in nature, the mud also provides a protective refuge from enemies and predators. Also, in captivity, the bacteria in the mud help to purify the seawater to the benefit of the young horseshoe crabs. Eleven larval horseshoe crabs were placed in a water tank ($30 \times 90 \times 40$ cm). The sea water is changed once every half year. The tank is placed next to a bright window which receives plentiful sunlight, and under these conditions the water remains clear.

From the first stage to the fifth stage, the larval horseshoe crabs are fed brine shrimp and those larval horseshoe crabs past the sixth stage are moved to another container and fed. Despite the fact that there are individual differences, these larval horseshoe crabs generally molt three times following the year when they hatch and become the fourth stage of larval horseshoe crabs. Furthermore,

in the second year, these larval horseshoe crabs molt again and attain the sixth developmental stage of larval horseshoe crabs, and after the third year, they molt once a year. After that, these larval horseshoe crabs molt only once a year, and assuming they become adult horseshoe crabs when they reach the 15th stage, they become adults 11 years after they hatch.

It is likely that the growth rates under these conditions are faster than those experienced by natural individuals. Conditions in artificial breeding are thought to be better than nature, and the survival rates of bred crabs are high as well. Additionally, when water temperature is high, horseshoe crabs in tanks move aggressively and can consume all their food in around 30 min. In contrast, in the case of wild populations, individuals must search for food and are adversely affected by their predators and competitors. In all likelihood, then, both growth rates and survival may be higher among horseshoe crabs raised in laboratory aquaria.

7 Future Directions

The projects conducted by Ms. Mitsueda and Mr.Yoshinori are small-scale successes, but for future larger scale projects on captive breeding, some refinements and additional data will be necessary. As they grow, horseshoe crabs increasingly require larger aquaria and this is a problem that may constrain aquaculture facilities. It is extremely difficult to breed horseshoe crabs from egg to adulthood, because of the slow growth rate and the importance of providing juveniles with the proper nutrition at each stage. Additional studies should be conducted on influence that sediment type (e.g., mud vs. sand) has on the frequency of molting and growth increment. If the bred horseshoe crabs are released at a relatively small size, we must be able to clarify their survival relative to natural horseshoe crab populations. Follow-up investigations should include studies of post-release survival, and whether these individuals survive to breeding age.