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PEARL CULTURE IN JAPAN

By

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GENERAL HEADQUARTERS

SUPER COMMANDER FOR THE ALLIED POWERS

Natural Resources Section

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SUMMARY

1. Since ancient times, men of many countries have evolved theories on pearl formation. However, Japanese scientists, principally Mise and Nishikawa, produced the only tenable theory that has been used commercially for the culture of spherical pearls.

2. Nishikawa's experiments prior to 1909 resulted in the method used throughout Japan today in the commercial production of spherical pearls. His method is to cut into the body tissue of the oyster and an inorganic nucleus cut from clam shell. If the graft is successful, nacre produced by the introduced graft tissue covers the nucleus, and a pearl is formed. Only the mantle tissue can produce nacre, the material of which the pearl is composed.

3. Although almost any bivalve mollusk can produce a pearl of sorts, the Japanese pearl oyster, *Pinctada martensii*, is by far the most important species for the culture operations in Japan. Further south, the species next in importance are *Pinctada maxima* and *Pinctada margaritifera*.

4. The spat of the pearl oyster is the brood stock on which the pearl culture industry depends. Adult oysters are permitted to spawn in wire cages, and the spats are collected and reared in other specially designed cages. When about three years old and nearing maximum sizes and vitality, the oysters are brought to the laboratory for the nucleus insertion operation. After a brief convalescent period, during which the injured animals and those which fail to survive the operation are removed from the baskets, the oysters are returned to the sea in cages suspended from rafts. Except for periodic cleaning, the oysters remain undisturbed for a three-year period, after which they are returned to the laboratory, and the pearls are recovered.

5. The entire product of the culture pearl industry now is sold to occupation personnel or exported to the United States. By-products of the industry are seed pearls used in making cheap jewelry, pearl and pearl medicines, and fertilizer and chicken feed ground from the oyster shells.

6. Before World War II, about 350 pearl farms were in active production, mostly near Ago-wan. In the peak year, 1938, Japan produced 10,883,512 cultured pearls valued at ¥1,376,325.00. At that time, 306 culture leases covered an underwater area of 13,351.2 acres. During World War II, the Japanese Government reduced pearl culture to a minimum as an industry non-essential to the war effort. The pearl industry has not yet recovered. About 105 farms were producing in 1948 but on a greatly reduced scale because of lack of funds, materials, and brood stock. Mikimoto Farm is the only large-scale producer at present, and even this practically self-sufficient organization is operating on an almost skeleton basis. Mikimoto Farm is in Mie Prefecture, the center of the pearl culture industry. During 1926-46, 63.8 percent of all cultured pearls were produced in this prefecture.

7. Experiments in fresh water pearl culture, using the clam *Hyriopsis schlegelii,* have been conducted for about 20 years at Biwa-ko, Shiga Prefecture. Early experiments failed to produce marketable pearls, but since 1945, improvements in techniques have resulted in the production on non-nucleated pearls of fine color and luster but irregular shape. Nucleated spherical pearls can be produced, but their small size precludes competition with marine culture pearls.

This report was prepared by Dr. A. R. Cahn, aquatic biologist, Fisheries Division. Notes made by Lt J.A Tubb, Australian Army, while assigned to Fisheries Division, have been incorporated. The drawings are the work of Saburo Satouchi and Tatsuyuki Kita, technical consultants, Fisheries Division. So many Japanese pearl culturists and pearl scientists cooperated in supplying information that individual acknowledgment is impossible. Personal mention is made in the text where feasible. The writer is indebted to Mr. T. Ino for translating and briefing many Japanese publications.

INTRODUCTION

Until World War II, Japan was internationally famous for production of such luxury items as silk and pearls. The name of Mikimoto was known in every land as that of the 'inventor' of a new commercial pearl, a gem so lovely that it immediately captured the eye of the world, yet produced in such quantities that its market value was far below that of the natural pearl of the Orient. The appearance of this commercially produced pearl inevitably set off an argument as to whether it was a "natural" or "artificial" pearl. The argument resulted in the establishment of a new category to identify the new product, which became known as the "cultured" pearl.

Nothing about the culture pearl is artificial except the origin of the stimulus which sets in action the mechanism of nacre deposition by the oyster. A natural pearl results when some irritant in the form of an organic or inorganic particle enters the oyster by chance and come to rest in spot from which it cannot be forced or washed out. This particle becomes the nucleus which the oyster envelopes in nacre secreted in response to the irritant, and the pearl is formed. The culture pearl in formed in the same manner, except that the irritating nucleus is placed in the oyster deliberately by man instead of reaching that location by chance. In either event the end product by the oyster is identical. The artificial pearl, however, is entirely different. It is usually a glass bead, sometime hollow and filled with wax, painted on the outside with a paste made of fish scales. Such a product has had no contact with an oyster, is not a pearl, and has no affinity with a pearl except in superficial resemblance. Only an oyster can make a pearl; so far, no man has succeeded in doing so. What man has succeeded in doing is to discover a method of introducing the stimulant irritant where and when wanted, and thus forcing the oyster to produce pearls in far greater abundance, under controlled conditions, than under the condition of chance provided by nature. Thus the Japanese have domesticated the oyster, and the places where pearls are produced are rightly called "pearl farms".

World War II had a profound effect on the production of culture pearls in Japan, an effect which will be felt throughout the world for many years to come. Because the pearl was a luxury items, its production during war years was controlled by the Government and reduced to almost nothing compared with prewar years. These pearls are already on hand or produced during the war years were used as barter and exchange items in occupied foreign territories, especially in China and Manchuria. The wartime restrictions forced most of the small producers out of business, and when hostilities caused only 105 pearls farms out of

prewar total of 350 still survived one reduced basis. Material shortages, especially of wire for rearing cages, together with lack of capital, have prevented the small-scale operations from resuming operations. A shortage of brood stock also exists, and it will be some years before pearl production can be resumed on a normal basis.

This report discussed the history and economic aspects of culture pearl production as practiced by the Japanese. The report also describes the biology and culture of the oysters which produce the pearls, as the Japanese have concerned themselves not only the oysters which produce the pearls but with all the associated problems of oyster farming.

HISTORY OF PEARL CULTURE

1. General

Since time immemorial man has been attracted by the beauty of pearls and probably from his first acquaintance with them has wondered how pearls are formed. Inquisitive and imaginative minds tried to explain pearl formation within the scope of limited horizons, and many theories were evolved.

In the first century AD man thought that when the weather was fine the shellfish came to the surface and opened its shell, whereupon a drop of dew fell into the shell and became a pearl. If the sun was warm, the dew was purified and the resulting pearl was of good quality; under adverse weather conditions, the pearl was poor. The scientists of ancient Rome believed the pearl to be the tear of the shell, or the crystallized tear of an angel. The ancient Greek scientists believed that the pearl was caused by lightning entering the sea. Columbus thought that dew on the mangrove dropped into the sea and became a pearl.

In 1554 Bowdelet said the pearl was the gallstone of the oyster. Anselmus de Boot in 1600 noticed the resemblance between the pearl and the shell and theorized that surplus shell "fluid", developed but not discharged by the shellfish, formed a pearl. Redi in 1671 claimed that a grain of sand got into the shell and formed a pearl. His suggestion was succeeded in 1673 by Sandius' theory that pearls represent undischarged egg of the mollusk. Beaumu, a French scientist, stated in 1717 that the surplus fluid described by de Boot was the result of the "ruptured organs" that built the shell.

In 1825 Sir Edward Hume cut a pearl in half and found a particle of a lustrous egg-like material. He concluded that a pearl was formed when an egg of the mollusk dies and was not discharged. Von Bear in 1830 discovered the egg of a parasite as the core of a pearl, and later many observers reported that parasites, parasite eggs, and other organic nuclei formed the core of pearls, illustrating the theory advanced so many years before by Redi. The followers of the two theories waged the battle of the pearl nucleus for many years before it was settled finally that both theories were correct: either a grain of sand or a particles of organic matter might become the nucleus around which the pearl is formed.

Louis Boutan in 1904 announced that if a parasite gets into the shell, settles in an indentations in the mantle, and there dies, that portion of the mantle separates from the main portion and become a pearl. At last, an observer was getting very close to the truth.

In 1907, T. Nishikawa announced the results of his experiments on pearl formation. He reported that a pearl is formed when the living, pearl-secreting cells of the mantle get into the body of the oyster under the stimulus of a foreign body and, by cell division, form a pearl sac which covers the nucleus with nacre to form the pearl. In 1913 Alverdes confirmed Nishikawa's work by his experiments if his own.

Although many fantastic theories on pearl formation existed in early times, few experiments to produce pearls were attempted. The production of pearls cultured apparently originated in China about the 13th century AD when crude semispherical pearls were produced by introducing a foreign substance between the mantle and the shell. For several centuries the Chinese have been inserting tiny images of Buddha under the mantle of the fresh water mussel *Cristaria plicarta*, which deposits a thin coating nacre on the images. Such pearl-covered images still are produced in China and sold to devout Buddhists.

The Swedish Naturalist, Carl von Linne, reported in 1761 that he had completed successful experiments in pearl culture. He wrote, "...in the course of five years I am able to produce in any mother-of-pearl shell the size of one's hand, a pearl as large as the seed of the common vetch". He kept his process secret while trying to sell it to the Swedish Government. When this attempt failed, he sold his process to a German named Bogge. The correspondence relating to the method was made public in 1859. Linne's method was to drill a hole in the shell from the outside and insert throughout a silver wire with a small particle of limestone attached to the tip. This particle was detached between the mantle and the shell and left there. Five years later a semispherical pearl would be found in its place. Linne

stated that the shellfish is able to close the hole in its shell, after which it coats the stone with pearl material. However, some observers claimed semispherical product was a water blister, not a pearl.

The Chinese technique was employed successfully in 1859 by Kelaat, using the Ceylon pearl oyster *Pinctada vulgaris.* At Tahiti culture experiments using the local pearl oyster were made in 1844, and at various times attempts were made in the Red Sea, the Mediterranean Sea, the Gulf of California and elsewhere to increase pearl production, either by direct action on the oyster or by cultivating the oysters and protecting them from predators.

Several theories which attempt to explain the phenomenon of pearl formation within the tissue of the mollusks have been advances, but only the theory of the pearl sac formation thus far has stratified experimental tests. On the theory the Japanese culturists based their successful experiments in the commercial culture pearls. [*1]

[*1] This pearl sac theory will be discussed in detail (see page 32).

2. Pearl culture in Japan

Several Japanese research scientists, among them K. Mitsukuri, K. Kishinoue, C. Sasaki, and the brothers S. and M. Fijita had been interested in the academic aspects of pearl production for many years, but not until late 1890's was any attempt made to produce culture pearls commercially

The early history of the cultured pearl in Japan already is so beclouded by conflicts of personalities and so confused by petty jealousies that reaching conclusions as to the exact origin of the spherical culture pearl is difficult. Although the name of Mikimoto has come to be almost synonymous with culture pearls, other name, already almost lost, should be recognized as of paramount importance in the early history of pearl culture. In writing this report every effort has been made to trace the facts and to record this early history. Much of the information summarized below was obtained from Dr. Y. Matsui, director of Nippon Institute for Scientific Research on Pearls (Nippon Shinju Kenkyu Sho).

Tatsuhei Mise: Tatsuhei Mise was born 16 March 1880 at Watakano, Mie Prefecture, and died 3 August 1924. A carpenter by profession, he became interested in pearls when his stepfather returned from an oyster inspection trip to Australia. Although he had no scientific

training, he began working on an idea that occurred to him and produced his first spherical pearls at his home on Watakano-Shima in Matoya-wan. [*2]

[*2] Watakano Island in Matoya Bay. See glossary for Japanese generic terms.

Available information points to the conclusion that he was the first person to develop a spherical culture pear. The exact date cannot be established, but it was before 1904, as in that year he showed his cultured pearl to Dr. Kishinoue, a leader among Japanese marine scientists. This pearl was developed in *Pinctada martensii* by a tissue-graft around tiny nucleus.

Mise applied for a patent on his spherical culture pearl method 13 May 1907, but the Japanese Patent Office refused to grant him a patent (see Appendix A). On 1 March 1907, he had applied for a patent on the needle used in his method; this application was granted 27 April 1907 as Patent No. 12590, apparently the first patent issued relative to actual spherical pearl culture. In this patent is found the first mention of the deliberate introduction into the oyster of mantle epithelium in order to produce a pearl. Here Mise states that his needle is used to insert a nucleus "together with pieces of epithelium from the mantle..... into the connective tissue and leave it inside the body of the oyster" (see Appendix H). It is clear, therefore, that for sometime Mise had a clear understanding of the three basic requirements for the production of spherical pearls: (a) a spherical nucleus (b) introduced into the connective tissue of an oyster (c) along with pieces of mantle epithelium.

Mise never published the results of his work, but on his death he left a letter, written in February 1923, giving details of the story. Considerable confusion of dates and some mistakes of fact appear in this letter, and Dr. Matsui who now has the document, is attempting to determine its reliability for historical purposes.

Tokichi Nishikawa: Tokichi Nishikawa was born 17 March 1874 at Osaka and died at the early age of 35 on 22 June 1909, leaving a son, Shinkichi Nishikawa, who inherited his father's inventions.

Graduated from College of Science, Tokyo University, in 1897 with a major in zoology, Tokichi Nishikawa became a technologist in Japanese Bureau of fisheries. He was sent to Australia, where he investigated marine products with special attention to the oyster fishing grounds. On his return to Japan he resigned from the Bureau in 1905 to devote his time to

research on pearls.

Nishikawa, it seems certain, was the first person to produce a spherical culture pearl by scientific methods, with the finished product resulting from planned experiments. Again the exact date of production of this first pearl is lost, but it must have been after his resignation from the Bureau of Fisheries, as the work was done at Marine Biological Laboratory of Tokyo University at Misaki, Kanagawa Prefecture. In as much as he died in 1909, the time limits are rather well fixed. Dr. Iljima, a noted scientist, exhibited Nishikawa's spherical culture pearls to the Emperor at the graduation exercises at Tokyo University on 10 July 1909, less than three weeks after Nishikawa's death.

Nishikawa married Mineko Mikimoto, eldest daughter for Kokichi Mikimoto, but he and his father-in-law were not on friendly terms. On his death, his rights reverted to his son Shinkichi and to his two able assistants, the Fujita brothers, Sukeyo and Masayo. These brothers completed Nishikawa's studies and long after Nishikawa's death, obtained the patent known as "the Nishikawa patent". This method used tiny silver and gold nuclei.

Nishikawa applied for a patent on his method of producing spherical pearls on 23 October 1907, five month after Mise's application. Though Mise's application was ruled as an "infringement" on Nishikawa's method (see Appendix A), Nishikawa, on 2 September 1908, signed an agreement with Mise and the latter's patron, Toraichiro Yokoyama, which made the use of the Mise and Nishikawa methods among them. This was done, apparently, because Mise's application of 13 May 1907 (which was rejected) and Nishikawa's application of 23 October 1907 (not granted until 20 June 1916) covered almost the exactly same method. Though Mise obtained a patent on his instruments, Nishikawa's heirs got the patent on the pearl culture method itself – but not until after Kokichi Mikimoto had entered picture. The agreement signed in 1908 would seem to be a recognition by Nishikawa of the priority of Mise's discovery and helps to establish Mise as the first person to produce a spherical culture pearl. [*3]

[*3] For details of the Mise-Nishikawa complex, see Appendix A.

Nishikawa published brief notes on his pearl investigations from time to time in the Japanese Journal of Zoology but never published a detailed summary of his work. His notes finally were collected and compiles by Tamiji Kawamura and were published in book form in 1914 under the title "Pearl", the authorship being credited to Nishikawa (Nishikawa 1914).

Kokichi Mikimoto obtained first pearl culture patent, 2670, in 1896 on his method of producing the semispherical or blister pearl. This patent was the first issued in Japan on pearl culture. In time this patent was interpreted to include any insertion of nucleus into the pearl oyster from the exterior, thus apparently protecting Mikimoto from infringement from anyone introducing a nucleus of any kind by any method, even though at the time he had not the slightest idea of how to produce a spherical pearl. This patent granted in 1896 was nullified in 1912. The first Mikimoto patent dealing with the method of producing spherical culture pearls by deposition of nacre from graft mantle tissue was No. 29407, granted 1 May 1916. All previous Mikimoto pearl patents dealt either with the production of blister pearls or with phases of pearl culture other than the production of spherical pearls.

T. Nishikawa and K. Mikimoto: Mikimoto applied for a patent on his own method of spherical pearl culture on 16 October 1914, and his application was granted 1 Mat 1916 as patent No. 29409. Although Nishikawa applied for his patent 24 October 1907, seven years before Mikimoto applies for his patent, Nishikawa's request apparently lay dormant in the patent office for nine years and was finally granted as Patent No.29629, 20 June 1916, seven week after the patent was granted to Mikimoto.

The actual inventor of the Mikimto method, according to Dr. Matsui, was Otokichi Kuwabara, formally a dentist, later as employee and close friend of Mikimoto. Kuwabara is now 82 years old and is too feeble to recall this early history. He is said to have originated many devices and inventions while working for Mikimoto. The "Mikimoto method" was the so-called "all-lapped system" by which a nucleus was wrapped and tied with a fine silk thread in a tissue sac made from the mantle of an oyster, prior to its insertion within the body, where it was attached "by pressing". However, the use of this graft mantle tissue was also the key to Nishikawa method, which is the insertion of bits of living mantle tissue into the body of the oyster as the lining of a pocket to receive the introduced nucleus. It is Nishikawa (or Mise) method which is used exclusively in producing spherical culture pearls today, not Mikimoto method, which proved too delicate and difficult, and which yielded no better results than the much simpler Nishikawa technique.

Through the efforts relatives and friends of late Tokichi Nishikawa, a reconciliation was effected between the son, Shinkichi Nishikawa, who, with Fujita brothers, controlled the patented Nishikawa method, and his grandfather, K. Mikimoto. Permission to use Nishikawa method at Mikimoto's Pearl Farm was arranged between them. From 1921-24, Masayo

Fujita was in charge of Mikomto Farm as technical superintendent.

3. Pearl Culture on South Pacific Areas

In Ryukyu Islands and among the Mandated Islands further south, the Japanese, before World War II, experimented with pearl culture, using much larger native forms of pearl oysters, *Pinctada margaritifera* and *P. maxima*.

Ryukyu Islands: Ryukyu Island chain is a semicircular group of hundreds of small islands reaching from Kyushu, the southern island of Japan proper, southwest toward Formosa. The pearl culture activities in this chain, which centered in Yaeyame-retto Islands, particularly on Ishigaki-shima, apparently were initiated by Mikimoto in 1912. The local form of the Japanese pearl oyster, Akoya-gai (*Pinctada martensii)*, and the Black-lipped pearl oyster (*P. margaritifera*) or Kurocho-gai were used here with considerable success. Black lipped oyster produced pearls of large size and fair quality, and Akoya-gai produced many-colored pearls. The Ryukyu form of *P. martensii* is thick-bodied, with a thin, papery shell. The nacreous layer of the shell is varied in color, and pearls produced by this oyster are rarely white. The common colors produced are black, gold yellow and silver.

Butong: Dr. M. Fujita began a series of experiments on the artificial production of pearls in 1921 at Butong, the southeastern extremity of Celebes. He used the golden pearl oyster (*Pinctada maxima* Jameson), locally called Shirocho-gai. These experiments resulted, in 1928, in the production of culture pearls, gold in color and luster. The enterprise was financed by Mitsubishi Co. and finally was incorporated as South Sea Pearl Co., Ltd (Nanyou Shinju KK). The stock used at this station was collected by pearling luggers from the great pearl oyster grounds of the Arafura Sea between New Guinea and Australia, especially around Aroe Island (Figure 1).

Palau: The success achieved in the culture of pearls in the Japanese pearl oyster prompted Mikimoto to extend his field of investigation, and he established an experimental station at Palau in 1920. Beginning with his experiments with the Black lipped pearl oyster (*Pinctada margaritifera*), the Kurocho-gai, which was readily available at Palau, he later extended his work to include the Yellow-lipped pearl oyster (*P. maxima*) or Shirocho-gai, importing live Shirocho-gai from the Arafura Sea. In 1935 and 1936 Mikimoto successfully transported *P. martensii,* the Japanese pearl oyster, to Palau. The experiments were fairly successful, and some excellent pearls of fine luster and color were produced.

The other companies began operations at Palau, South Seas Pearl Co. in 1936 and Horiguchi Pearl Trading Co. (Horiguchi Shinju Boeki KK) in 1937. The activities of these farm continued until 1941, when the outbreak of World War II put an end to all such work.

The Palau pearl enterprises were not highly successful commercially, apparently because of unfavorable environmental conditions, and the projects now are regarded failures.

4. Development of Pearl Farm

Pearl culture was practiced in 15 prefectures in Japan and in Okinawa during the late prewar years. In 1935, the last prewar year for which detailed data are available, 357 pearl farms totaling 13,509 areas were under lease for pearl culture purposes. As of 1 September 1948, 160 pearl farms with a leased acreage of 10,540 were in some stage of operation in nine prefectures (Table 1). All except the farm in Shiga Prefecture were also active in the prewar period. Prefectures engaged in pearl culture in 1935 but inactive are: Ishikawa, Kumamoto, Yamaguchi, Aichi, Saga, and Shizuoka, one each. The present field of pearl culture thus is reduced considerably compared with the prewar era.

The number of active pearl farms and their cultured acreage during 1926-48 are given in Table 2. Presentation of an annual breakdown for this period similar to that in Table 1 is impossible because statistics, as gathered and compiled by Japanese Government are not consistent. Some reports deal in "farmers", "leases", or "lease holders"; there being no common denominator, the reports are not comparable. A "lease" represents a water area rented without cost from the Government exclusively for pearl culture by a "lease holder", who may hold a number of leases which may be active or dormant so far as producing pearls or pearl oysters is concerned. Furthermore, a lease holder may subdivide his lease among any number of individuals, each acting independently, and each thus becoming a "farmer".

During the World War II, the pearl industry declined rapidly (Table 2) as war efforts increased. Not until after hostilities ceased did the industry slowly begin to regain some of its lost ground. Its recovery has been retarded because of shortage of many critical materials and because of the depletion of the oyster stock, which the industry needs in tremendous numbers. Thus many of the smaller operators have not been able to reestablish themselves,

and all but the larger organizations have had to begin again with practically nothing. Most of the farms were still in the early stage of their redevelopment at the end of 1948.

The distribution of the pearl farms in operation in Japan in 1948 is shown in figure 2. Mie Prefecture, as always, is the center of the culture pearl industry. Its five major bays (Figure 3) afford anchorage for 3,002 culture rafts on leased areas totaling 5,788 acres. Ago-wan is by far the most important and is the heart of the present pearl culture industry. The bays of Kagamiura, Matoya, and Ago are the center of the summer culture activities. In the winter the waters of Gokasho and Nie bays average 3℃ warmer than those of Kagamiura, Matoya, and Ago; before the minimum temperature is reached in these summer anchorages, the culture rafts are towed to Gokasho and Nie bays foe winter anchorage and protection against excessive cold. The remaining pearl culture areas of Mie Prefecture (Table 1) are relatively small and insignificant at this time.

Mikimoto Pearl Farm: Because of his tremendous success in the cultured of pearls, the name of Mikimoto is known to all who know anything of pearls. Although he cannot be credited with having produced the first spherical cultured pearl nor with originating the method he has used to successfully to produce them, his contribution to the culture of the pearl oyster and his great business acumen have made him the father of the industry. Today, nearly 92 years old, he is still an active and powerful figure in the industry. His farm represents the selected results of 55 years of systematic investigation and embodies the story of pearl culture. Unless otherwise indicated, the technical sections of this report are based on operations at the Mikimoto Farms.

Kokichi Mikimoto was born 25 January 1858 at Toba, Mie Prefecture, the eldest of 11 children. He spent his youth on the shores of Ago-wan, a bay long famous for the production of the Japanese pearl oyster, *Pinctada martensii*. Because of over-fishing and the lack of conservation measure, the output of these shellfish had decreased steadily year by year almost to the point of extinction, while the world demand for pearls constantly increased. Familiar with the Japanese methods of shellfish and fish farming, Mikimoto decided to apply the same principle to the cultivation of the pearl oyster.

In 1890 he sought information from Professor Kakichi Mitsukuri of Tokyo University, then the foremost marine zoologist in Japan, regarding scientific techniques of artificially stimulating oysters to produce pearls. Professor Mitsukuri gave him a resume of the subject and encouraged him to put his ideas into effect.

Mikimoto had established his first pearl farm at Shinmeiura in Ago-wan in 1889, and his first experimental station on a small island off Toba in September 1890. For several years he groped blindly in the field of oyster culture, trying to find the answer to the riddle of pearl formation. In January 1893, the *akashio* or red tide wiped out his oyster crop at Shinmeinoura and he withdrew to Toba. Here on 11 July 1893 he obtained his first success, a semispherical blister pearl. In January 1896 he obtained a patent on his method of producing blister pearls.

In 1905 the red tide again practically destroyed his crop, killing about 800,000 oysters under cultivation in bamboo baskets. Examination of this lot showed five spherical pearls, all located near adductor muscle. Up to this time Mikimoto had been inserting granules of Mother-of-pearl between the mantle and the shell, producing blister pearls. The pearl-muscle relationship of the five pearls gave him the final clue as to how spherical pearls could be produced: inserting the granule within the tissue of the oyster. In the meantime both Mise and Nishikawa had discovered the secret.

To increase his supply of oysters, Mikimoto undertook extensive experiments on spats collecting and rearing. He invented and patented many devices which eventually became the basis of pearl oyster culture.

In October 1893, Mikimoto established his second pearl farm on a small, uninhabited island in Ago-wan which was known as Tatoku-jima or "land of many virtues". It was on this island that most of the work on pearl cultured was accomplished, and it remained the headquarters of Mikimoto until the completion of his present (third) pearl farm 1n 1919 (Figure 3).

The appearance of the cultured pearl on the world market started a dispute as to whether it was a "real" or "artificial" pearl. However, studies by such scientists as Lister in England and Boutan in France convinced the public that the "Cultured" pearl was no different from the "natural" pearl except in the origin of the initial irritant.

THE PEARL OYSTERS

1. Species and Distribution

Although many bivalve mollusks can produce a pearl of sorts under stimulus of an irritant and under suitable physical or environmental conditions, the production of pearls of quality is confined to a relatively small group of species. An outline of the distribution of the mote important pearl-producing species of the Pacific area is shown in Table A, page 20.

TABLE A. DISTRIBUTION OF MORE IMPORTANT PEARL PRODUCING MOLLUSKS, PACIFIC AREA

Species	Distribution
Pinctada martensii (Dunker)	Japan (Ise, Kii, Tosa Hizen, Mie)
Pinctada margaritifera (Linne)	Japan (Kii, Tosa), Ryukyu Island, Formosa, South Seas in general
Pinctada margaritifera zanzibarensis (Jameson)	Madagascar, Seychelles Island
Pinctada margaritifera mazatlanica (Hanley)	Bay of California, Panama Bay
Pinctada margaritifera erythrensis (Jameson)	Red Sea
Pinctada margaritifera persica (Jameson)	Persian Gulf
Pinctada margaritifera cumingii (Reeve)	Eastern Polynesia, Society Island (Tahiti), Hawaii Island
Pinctada maxima (Jameson)	Ryukyu Island (rare at Amami-Oshima), New Guinea, Celebes, Arafura Sea
Pteria marcroptenia (Lamarck)	Ryukyu Island (north to Amami-Oshima), Formosa, South Seas in general
Atrina japonica (Reeve)	Japan
Ostrea gigas (Thumberg)	Japan
Unio (margaritifera) margaritifera (Linne) *a	Japan (Hokkaido, northern Honshu), Sakhalin, Siberia, Canada, England, Europe
Cristaria plicata (Clessin)	Japan (Hokkaido, Honshu), China
Tridacna gigas (Linne)	Ryukyu Island, Formosa, Bonin Island, South Seas in general, Indian coasts
Haliotis gigantea (Gumelin) *b	Japan, Korea Ryukyu Islands

*a Found in fresh water

*b A gastropod, not a bivalve

SOURCE: Oguchi (1938)

The Japanese pearl oyster *Pinctada martensii* (Figure 4) is by far the most important species in the culture pearl industry. Unless otherwise stated, all data in this report are based upon *P. martensii*. The only other species that will be discussed in this report are the black-lipped pearl oyster. *Pinctada margaritifera* (Figure 5) and its subspecies and the golden-lipped pearl oyster, *Pinctada maxima*. Available data concerning these species have

been incorporated when pertinent to contrast with the discussion of *P. martensii*. The geological distribution of these three pearl-producing species is shown in Figure 1.

2. Diagnostic Characteristics

Pinctada martensii, the smallest of these three important pearl-producing mollusks, produces by far the finest, though not the largest, pearls. *P. margaritifera* and *P. maxima,* giant species of the genus, produce pearls of great size but somewhat inferior quality, because of the relative coarseness of their nacre. Distinguishing characteristics of the three species are summarized in Table B, page .

TABLE B. COMPARISON OF THREE IMPORTANT PEARL BEARING SPECIES OF *Pinctada*

Characteristics	*martensii*	*margaritifera*	*maxima*
Size			
Fully mature	4 inches	7 inches	12 inches
Average	3 inches	6 inches	8 inches
Shell			
Convexity	Convex	Slightly convex	Flattened
Outer shell color	Yellow-gray	Greenish-brown	Pale yellow-brown
Outer shell stripes	About 7 purplish-brown	10-18 radial rows of white spots	Traces only
Nacre	Greenish-silver	Steely	Silver-white
Nacre, shell margin	Yellow orange	Dark metallic green	Golden
Hinge line	Medium length (Shell higher than longer)	Short	Medium
Weight	60-100 shells per kan *a	15 shells per kan	6-10 shells per kan

*a See glossary for conversion factors for units of measurement

SOURCE: Dr. Tokubei Kuroda

BIOLOGY OF THE PEARL OYSTER

1. Anatomy

A knowledge of the anatomy of the pearl oyster is necessary to an understanding of the development of the pearl.

The body of the *Pinctada martensii* is covered by a two-valve shell. Early in the normal life of the individual, the lower valve becomes permanently fixed to some solid object. The movable is hinged to the lower and is controlled by a pair of strong muscles, the anterior and

posterior adductors, which pull the upper valve to the lower and thus close the shell. Although the oyster builds the shell and is attached to it, this shell may be considered the house in which the oyster lives, rather than an anatomical part of the animal.

The anatomy of the animal itself (Figure 6) consists of three general regions: the foot, the mantle and the visceral mass. In the pearl oyster, the muscular foot functions as an organ of locomotion only during the early stage of its life prior to fixation and is not used thereafter. The mantle, a sheath of integument covering the visceral mass, hangs down like a curtain on each side of the body between it and the shell. Not only does this mantle secrete the shell, but its edges are modified locally into inhalant and exhalant siphons, and its derivatives, the gills, perform vital functions of respiration, nutrition, and incubation. The mantle, because of its importance in the development of pearls, will be discussed in detail later.

The mouth is at the anterior end of the alimentary canal in the visceral mass and leads into a short esophagus which, in turn, passes directly into a thin-walled stomach lined with hard cuticle for grinding food. From the posterior end of the stomach a relatively short S-shaped intestine passes to the anus. The rapid vibration of cilia on the gills brings the water and minute particles of food into the mantle cavity through the inhalant siphon. The food is passed to the mouth, and the water is expelled from the cavity through the exhalent siphon. While the water is in the cavity, the colorless blood is aerated in the gills.

The heart is a dorsal organ consisting of a single median ventricle and two lateral auricles. An anterior and a posterior aorta carry the blood away from the heart. The nervous system consists of a pair of central ganglia which constitute a primitive brain, with a nerve cord and simple sense organ.

The sexes are usually separate, as in the edible oyster. Sexual dimorphism is very poorly indicated, making it difficult to distinguish sexes externally. The sex organs are the ovary and the testes, and the sex products are led to the outside by sex ducts. Fertilization is external.

2. Life History of *Pinctada martensii*

To rear any organism successfully the life history of that organism should be known as thoroughly as possible. Japanese scientists know little of the life history of the Japanese

pearl oyster, *Pinctada martensii* at this time, but the oyster technologists are concentrating more and more on this subject.

Study of the early life history of the pearl oyster in nature is difficult owing to the minute size of the organisms. For this reason Dr. S. Kobayashi of Atomiya Pearl Cultured Farm on Ago-wan has attempted to raise the larval stages in the laboratory following artificial fertilization. This also is difficult as the natural environment is hard to duplicate. However, Dr. Kobayashi has succeeded in raising a few larvae of *P. martensii* to the spat stage in his laboratory and has obtained information which he has made available for this report.

In nature the pearl oyster begins to spawn when the water reaches a temperature of 25℃ and a pH (hydrogen ion concentration) of about 7.8. The spawning normally occurs in late June or early July and usually is completes by early August. In the laboratory Dr. Kobayashi found that the optimum conditions for the artificial fertilization of the eggs were a temperature of 28℃ and a pH of 8.6. He was unable to obtain fertilization under lower (less alkaline) pH conditions. After he obtained his tiny living larvae, he fed them on Monas, a microscopic food organism easily raised in the laboratory. He results on larvae culture are summarized in Table C. page .

Studies made by Mr. Yamaguchi, of Japan Institute for scientific Research on Pearls at Kashikojima, carry the developmental history of the oyster through to the fully adult animal. Table D. page , summarizes his studies on the rate of growth of *Pinctada martensii*. The growth rate is shown also in Figure 7.

Dr. Kobayashi found that the growth of the pearl oyster is not uniform throughout the year. Growth is rapid from May to about November, but from November to May the growth either is very slow or ceases entirely. During this winter period the stomach of native oysters are devoid of food. Dr. Kobayashi concludes that *P. martensii* undergoes a period of hibernation when the temperature of the water reaches or falls below 13℃. Table E. page , gives the mean temperature of the surface and the bottom of Ago-wan near Atomiya Pearl Farm during two-year period.

TABLE C. LARVAL DEVELOPMENT OF *Pinctada martensii*

Developmental stage	Time after fertilization	Size (mm) *a
Unfertilized egg		0.048X0.048
2 cell stage	40 minutes	0.041X0.053
4-8 cell stage	1 hour	ND
8-12 cell stage	1 hour , 35 minutes	ND
Blastule	3 hours	ND
Beginning of rotation	ND	0.043X0.046
Gastrula	4 hours, 9 minutes	0.050X0.057
Trodhophore larva	4 hours, 29 minutes	0.048XND
Veliger larva	24 hours	0.050X0.066
Straight-hinge larva	2 days	0.063X0.080
Straight-hinge larva	5 days	0.070X0.160
Umbo stage	10 days	0.189X0.217
Late umbo stage	15 days	0.237X0.243
Fully grown larva	20 days	0.269X0.304
Spat (attachment)	25 days	0.391X0.433

*a See glossary for conversion factors of metric units of measurement

ND: No data available

SOURCE: Dr. Kobayashi, Atomiya Pearl Culture Farm

TABLE D. POST - LARVAL GROWTH OF *Pinctada martensii*

Age	Length (mm)	Age	Length(mm)
1 month	6.0	3 years	70.0
2 months	9.0	4 years	78.0
3 months	17.0	5 years	81.0
6 months	31.0	6 years	82.0
1 year	45.0	7 years	82.5
2 years	59.0	8 years	83.0

SOURCE: M. Yamaguchi, Japan Institute for Scientific Research on Pearls

At the development of the pearl is a result of the physiological activity of the host oyster, the imposition of a period of hibernation into the annual physiological cycle has a definite bearing on the growth and rate of growth of the pearl itself.

3. Early Development of *Pinctada maxima*

At Palau Tropical Biological Station, S. Wada (1942) experimented on *Pinctada maxima*, imported from Australian water for culture research. After considerable experimentation, Wada finally succeeded in producing ripe eggs and spermatozoa under artificial condition.

The mature eggs of this species are 59 microns in diameter. The exuded spermatozoa has a head measuring 5.5×4.3 microns, and a tail 55 microns long. Fifteen minutes after the entrance of the head of the sperm into the egg, the first polar body is protruded. From this point on, Table F, page 2, summarizes Wada's observations on the early individual history of *P. maxima*.

TABLE E. WATER TEMPERATURE IN AGO-WAN

Period	Mean Temperature in Centigrade		Remarks
	Surface	Bottom	
1946			
Aug	29.3	28.6	
Sept	23.5	22.4	
Oct	22.6	23.8	
Nov	15.5	18.8	
Dec	12.0	13.0	Hibernation begins
1947			
Jan	8.4	10.3	
Feb	8.2	9.2	
Mar	10.7	11.2	
Apr	14.4	13.9	Hibernation ends
May	17.5	17.1	
Jun	20.4	20.3	
Jul	25.3	24.5	
Aug	27.9	25.9	
Sept	23.7	23.3	
Oct	18.9	20.1	
Nov	14.3	15.5	
Dec	10.0	10.7	Hibernation begins
1948			
Jan	8.4	8.8	
Feb	10.2	9.7	
Mar	10.4	10.5	
Apr	14.6	15.0	Hibernation ends

SOURCE: Dr. Kobayashi

TABLE F. DEVELOPMENT OF THE GOLD-LIPPED PEARL OYSTER, *Pinctada maxima*

Elapsed Time After Fertilization	Water Temperature in Centigrade	Progress Development
15 minutes	28	Protrusion of 1st polar body
25 minutes	28	Protrusion of 2nd polar body
40 minutes	29	Formation of 1st polar lobe; start of 1st cleavage
43 minutes	30	2-cell stage
1 hour	30	4-cell stage
1½-2 hours	28-30	8-cell stage
2½-3 hours	27-30	Mourula stage
3½-4 hours	27-31	Blastula; rotation begins
5½ hours	26-30	Start of gastrulation
7½ hours	26-30	Apical flagella developing
18½-19 hours	26-30	Shell nearly covers body; larva now a "D-shaped" Veliger size 77 μ L *a, 55 μ Hg, 62 μ H
30-32 hours	25-30	Apical flagella less prominent
7 days	25-32	Umbo projects slightly over hinge line;
9 days	24-32	Umbo projects slightly over hinge line; Size: 95 μ L, 55 μ Hg, 88 μ H
2-3 weeks	ND	Ready for attachment; "Spat", size: 0.5mm

*a L; shell length, Hg; length of hinge line, H; shell height, μ; micron (one micron equals 1/1,000 millimeter)

ND; No data available

SOURCE: S. Wada (1942)

3. Sex Reversal

Sex reversal, wherein a female changes to male or male to female, is known to occur among the oysters as a group. Information on this phenomenon in the pearl oyster has been obtained by R. Wada and S. Wada (1939).

They made their first observation at the Misaki Marine Biological Station in 1936-37, using *P. martensii*. This exploratory investigation yielded results as shown in Table G on the Page 27.

TABLE G. SEX REVERSAL IN *Pinctada martensii*

Date of Observation	Group 1: Males			Group 2: Females		
	Number of Males	Number of Females	Number of Immature	Number of Females	Number of Males	Number of Immature
1936	54	0	0	40	0	0
May 1937	21	22	11	19	5	16

SOURCE: R. Wada and S. Wada (1939)

The Wadas made another exploratory set of observation in August 1937, using a series of *P. maxima*, the Australian white pearl oyster transplanted to Palau. A series of oysters about 17-20 centimeter long were sorted according to sex, returned to the sea, and re-examines in June 1938. The sex of these oysters was found to be unstable, some males having changed to females, some females to males.

With the fact of sex reversal for the species established, observations were repeated in 1938-39, and individual were marked with a leas tag through the shell, making possible the certain identification of each individual. The oysters were all females at the time the observations began. An examination of sex was made periodically thereafter, with results indicated in Table H.

TABLE H. SEX REVERSAL IN *PINCTADA MAXIMA*

Date of Observation	Number of Females	Number of Males	Number of Immature	Total Number *a	Percent of Sex Change
Jun 1938	135	0	0	135	0
Jul 1938	117	4	8	129	3
Sept 1938	114	8	2	124	6
Apr 1939	31	88	2	121	73

*a Total number not constant owing to death from various causes

SOURCE: R. Wada and S. Wada (1939)

Neither the cause nor the full significance of this tendency to reverse sex is clearly understood at this time, but the Japanese assume that the height of sex several coincides

with the spawning season.

HISTORY AND FUNCTION OF THE MANTLE

1. The Mantle

As with all bivalve mollusks, the shell of the pearl oyster is formed by the mantle (Figure 6). The mantle enwraps the visceral mass of the oyster and builds the shell which is the external wall of the cavity. The right and left lobes of the mantle are continuous with each other along the mid-dorsal line, from which point they hang like curtains on either side of the oyster's body.

Histologically, the mantle is a connective tissue membranes protected on the outside by a single layer of epithelium cells. That portion of the epithelium which is in contact with the inner surface of the shell valves is called the outer epithelium and secretes the substances from which the calcareous shell is built. In the area of the mantle cavity, the free inner surface of the mantle is lined with an inner epithelium which is cilated and which performs no shell of nacre secreting functions.

2. Characteristics of the Outer Epithelium

The cells of the outer epithelium secrete, with equal facility, finely crystalline calcium carbonate ($CaCO_3$) in the form of aragonite crystals, better known as nacre of mother-of pearl, and hexagonal calcite crystals which form the prismatic layer of the shell. They also secrete the organic substance conchiolin ($H_{32}H_{48}N_2O_{11}$), with which the calcareous crystals are cemented, and mucous, as the occasion warrants. The factors which cause the biochemical reaction determining the structure and character of the secretion are not fully understood, but it has been established that the deposition of the prismatic layer becomes very marked when the animal is subjected to strong sunlight. Conversely, the outer epithelium activity secretes nacre when the animal is kept in partial or total darkness.

A series of experiments to determine the reaction of pearl-forming mollusks held at varying depth and under various colored lights was begun just before World War II. Although not completed, these experiments indicated that *Pinctada martensii* under varying light conditions, becomes most active in the deposition of nacre when subjected for a relatively

long period to intensely blue light. Examination of the nacre deposited these tests indicated a high luster and an excellent coloration. The purpose of these experiments was to determine, if possible, why some regenerated pear-sac tissues deposited, without apparent cause, alternate layers of aragonite and calcite crystals on an enclosed nucleus, thus reducing the luster and hence the commercial value of the pearls.

Another experiment, designed to reveal the characteristics of the outer epithelium when subjected to various stimuli, was conducted about the same time. In this experiment an opening about 0.5×0.25 centimeters was made in a valve of *P. martensii* by a fine carborundum hone, the layers of the mantle first being removed carefully with forceps to avoid injury to the cell of the outer epithelium. Almost immediately a thick mucous was extruded from the mantle area thus exposed to the light. In one or two days a fine film of conchiolin had been deposited across the opening, thus sealing the puncture against the entrance of water. The oyster then deposited calcite and aragonite crystals in that order, to a thickness equaling that of the shell in the area in which the opening was made. In a repeated experiment in which the oyster was held in darkness, no calcite crystals were deposited across the opening. Thus the results of the experiment support the theory that light is an important factor in determining the physiological activity of the outer epithelial cells of the mantle.

3. Structure of the shell

The shell, secreted by the outer epithelium of the mantle, is composed of "mother of pearl", prismatic (rough, horny) layers, and an organic cementint substance known as conchiolin. A section of a shell shows a thin prismatic layer superimposed upon conchiolin on the outer surface of the shell and a relatively thick layer of mother-of-pearl lining the inner surface.

Mother-of-pearl is pearl white in color and has a finely lamellar structure composed of aragonite crystals embedded in an extremely fine framework of conchiolin. The prismatic layer, which varies from dark brown to dark red, is composed of hexagonal columnar calcite crystals compactly embedded in the framework of conchiolin. The conchiolin is the outermost surface coating of the entire shell, but it is usually eroded in all except immature individuals, including spat. In addition conchiolin is the organic substance from which the framework of both mother-of-pearl and the prismatic layers are built, and it is the cementing substance which binds the calcareous crystals in both the shell and the pearl. If a piece of

shell is immersed in an acid solution, the calcareous crystals are dissolved by the acid, leaving only the organic conchiolin framework. If the dark-colored prismatic layer is treated in an acid bath, the solution becomes reddish-pink from the suspended pigments which originate in the calcite crystals of the prismatic layer. The pigment causes the colors of the prismatic layers. The quantitative deposition of pigmented calcite crystals in alternate layers with aragonite crystals on a pearl nucleus may also be a factor which determine the color of a pearl.

Mother-of–pearl is a fine, extremely dense structured, but the prismatic layer is comparatively brittle. The difference in structural strength is due entirely to the quantities of conchiolin constituting the framework of the respective structures; the mother-of-pearl is more calcareous than the prismatic layer. The quality of the pearl, when naturally grown in the mantle parenchyma or in the connective tissue of the visceral mass, is affected directly by the quantitative ratio of the calcareous matter and conchiolin. A suitable ratio between calcareous matter and conchiolin is needed to produce excellent color and luster.

Iridescence is caused by the interference of rays of light reflected from the microscopic corrugations of the surface.

4. Nacre Secretion and Water Temperature

To determine the relation between water temperature and the nacre-secreting activities of *Pinctada martensii*, H. Oda inserted a nucleus 6.9 millimeters in diameter into each of number of oysters. A regular monthly intervals throughout one year, a number of nacre-coated nuclei were removed and weighed to determine the accretion nacre. Table I shows the calculated nacre deposited in relation to monthly variations in water temperatures, 100 percent being the total nacre secreted during twelve months.

Table I shows that the mean maximum water temperature (28℃) was reached in September and the mean minimum temperature (13.2℃) was reported in January. The maximum nacre secretion was in September-October, and nacre secretion ceased on February and March. Thus the oyster's maximum and minimum nacre secretion activities evidently are one or two months later than the corresponding variations in the temperature of the environment. Nacre secretion apparently ceased when the water temperature fell below 14℃, indicating a definite relationship between secretion and water temperature. From these and other data Oda concludes that a "physiological delay" in nacre secreting

processes follows change in water temperature.

TABLE I. RELATION BETWEEN NACRE SECRETION AND WATER TEMPERATURE

Month	Mean Water Temperature (°C)	Nacre-secreting Activity (%)
Jan	13.2	1.2
Feb	13.5	0.0
Mar	14.0	0.0
Apr	15.5	1.2
May	18.7	4.4
Jun	22.8	8.9
Jul	27.0	13.3
Aug	27.5	17.0
Sept	28.0	20.0
Oct	23.0	20.0
Nov	18.3	10.3
Dec	14.5	3.7
Total		100.0

SOURCE: H. Oda

In places where the water temperature does not fall below the critical minimum for nacre deposition such as Shimoda, Shizuoka Prefecture, nacre is produced every montgh of the year. Whether this luck of a dormant period has any effect on the quality of the resulting pearl is not yet known.

5. Origin of Pearls

Pearls are the result of reactions to irritants, and all modern theories of the process by which natural pearls are formed emphasize the importance of the outer epithelial cells in pearl formation. Boutan's hypothesis suggests that a small piece of foreign matter becomes lodged on the outer epithelium and is slowly covered by epithelial cells. Later pressure forces the foreign matter into the parenchyma tissue where a (pearl) sac is built around the foreign matter and where the sac and foreign matter separate from the outer epithelium. Rubbel's theory is similar, except that he postulates partial fracture of the outer epithelium cells. Mr. Oda, the chief research biologist for Mikimoto, maintains that the most likely process is the complete fracture of the outer epithelium and the entry into the parenchyma of the foreign matter, together with a few epithelium cells. These cells, through proliferation,

regenerate and form a sac within the parenchyma and independent of the epithelium. Occasionally a pearl may be formed without a nucleus, but what irritant initiates pearl formation in that instance is not known.

6. Formation of the Pearl Sac

The epithelial layer of the mantle of *P. martensii* is composed of rounded cells which are fitted together loosely as the outermost layer of the mantle. So loose is the assemblage that the cells therein degenerate when subjected to external stimuli. Experiments have shown that this outer layer disintegrates quickly if served from the under-lying tissue of the mantle, wrapped around a nucleus, and then introduced into the connective tissue of another individual. This epithelial layer, therefore, evidently is unable to produce pearl. On the other hand, it has been shown that the numerous knob-shaped unicellular glands beneath this outer epithelial layer, in *Pinctada martensii* at least, produce the substance of which the pearl is composed and a pearl sac is formed as a result of a series of changes will take place in the epithelial layer of the mantle.

Reference to Figure 8 will help clarify the sequence of epithelial changes in pearl sac formation. Under normal conditions the mantle is lined with rounded epithelial cells (A). When exposed to any sustained stimulus, such as a grain of sand, these rounded cells degenerate and slough off (B), and are replaced by elongated epithelial cells (C), until only these elongated cells line the mantle (D). The elongated cells are very elastic and will invaginate in response to contact with a foreign body. When stimulated, these cells invaginate, pinching off a pearl sac around the now-enveloped source of irritation (E). After this, the rounded epithelial cells again appear and begin to replace the degeneration elongated cells (F), the unicellular glands appear, and the original condition (A) is again established.

If a small piece of mantle taken from one individual is inserted into the connective tissues adjacent to the viscera of another oyster, the inner epithelium degenerates and disappears. The outer epithelium, however, can produce new cells and will continue to develop and to secrete calcareous material when transplanted under favorable conditions into the body of another oyster. This characteristic of the outer epithelium is of paramount significance in the formation of either natural or cultured pearls.

When a small piece of living mantle tissue, together with some solid foreign substance, is

inserted into the visceral connective tissue of another pearl oyster, a capsule of connective tissue develop around the solid matter from the introduced mantle tissue within a few days, as described above. As this capsule is forming, the calcium-secreting epithelium of the inserted mantle tissue begins to produce through cells division and within as week or two lines the connective tissue capsule. Finally, the regenerated epithelium completely encloses the foreign matter, thus developing a pearl sac. Under favorable conditions, the pearl sac begins to secrete and to deposit calcareous matter around the foreign material within it as soon as cell division begins. Thus a culture pearl is initiated when a small piece of living mantle tissue is placed adjacent to a foreign body in a selected portion of the body of the host oyster. As the coating of the nacre deposited on this nucleus grows thicker, the pearl sac itself grows larger through cell division.

When the pearl sac is completed, the extremities of the columnar cells of the regenerated out epithelium rest upon the surface of the foreign body. Therefore the relation between the pearl sac epithelium and the introduced nucleus is essentially identical biologically with the relation between the outer epithelia of the mantle and the shell valve. Functionally, the difference is that the pearl sac secretes nacre entirely within the connective tissue of the body, but the formation of the shell and the formation of pearls are the same phenomena. This is the basic principle of pearl culture. The cells of the subepidermal tissue of the mantle , not the nucleus, produce the pearl. Nuclei which enter the body of the oyster without carrying with them particles of the living epithelium will neither be enveloped with nacre nor be made into pearls.

7. Other Methods of Pearl Formation

Although the Nishikawa method of introducing graft tissue and nucleus is the only one thus far used successfully for commercial culture pearl production, Japanese scientists and pearl culturists are exploring other possibilities. The trend of such investigations in indicated by the following Japanese patents:

No. 119,547, issued 12 March 1937 to K. Mikimoto. This patent covers method by which a piece of mantle epithelium instead of inorganic material is introduced as a nucleus.

No. 115,667, issued 8 May 1935 to K. Mikimoto. Colored plates and transparent colored glasses are placed at the top and bottom of baskets containing operated oysters to induce better color in the developing pearls. This procedure is based on the theory that light waves

influence color.

No. 115,643, issued 8 May 1936 to K. Mikimoto. This patent covers a method of producing pearls by ultraviolet rays of electric sparks.

No. 66,977, issued 21 December 1925 to M. Fujita. Operated oysters are lined up in a wire basket in sea water and given an electric shock to stimulate pearl formation by increasing nacre secretion.

DEVELOPMET OF THE PEARL

1. Growth

The growth of the pearl starts immediately after the graft tissue establishes itself and begins to proliferate by cell divisions. The graft not only grows but begins to secrete around the foreign body with which it is in contact. This deposition of nacre may be either relatively fast or slow, depending on environmental conditions. Along the northern limits of the range of the pearl oysters, represented in the Pacific areas by the distribution of *Pinctada martensii* in Japan (Figure 1), the rate of the nacre production is very slow, and in the warmer south Pacific waters around Palau and Butong in the Celebes, the rate of deposition is much faster.

The rate of nacre deposition is in direct relation to the temperature of the water. As water temperature varies with the season, the rate of nacre deposition also varies seasonally. The warmer the water, the more rapidly the nacre is secreted and the faster the pearl grows. The converse is equally true: the cooler the water, the slower is the nacre deposition, until at temperature of about 14℃ the secretion of nacre is inhibited. Below this temperature the pearl ceases to grow, remaining dormant until the temperature of the water rises above the critical minimum required for nacre production. This dormant period is characteristic of the development of the pearl in *Pinctada martensii* throughout Japan except near Shimoda, Shizuoka Prefecture. Here the minimum water temperature is just above the critical limit, and the nacre is secreted throughout the year.

The Japanese believe that a definite relationship exist between the rate of nacre deposition and the quality of the resulting pearl. They believe that slow nacre secretion,

accompanies by a resting period during which no nacre is deposited, produce better quality pearls in *Pinctada martensii* than does the faster year-round growth.

Table 3 shows the rate of growth of the pearl within *Pinctada martensii*, together with the size of the nucleus, the amount of nacre deposited on it, and the ratio of the nacreous layer to the radius of the nucleus. These data show that the pearl's rate of growth is very slow indeed. For example, on a 3.06 millimeter nucleus, the nacre deposition is only 0.318 millimeter in two years. In contrast to this, fragmentary data obtained from Mr. Y. Hori of the Kokusai Pearl Company at Shimoda show that at Palau both *Pinctada margaritifera* and *P. maxima* deposit nacre at the rate of about 3.3 millimeters a year. The diameter of the pearl at the end of one year is 6.6 millimeters greater than that of the introduced nucleus. All information the size of data are available for *P. margaritifera*.

The Japanese believe that *Pinctada martensii* produces pearls of a far higher quality than either the other two species, though not comparable in size. The pearls is from *P. martensii* are to be warmer (more pinkish) in color, harder, and of better luster because of a finer-grained surface. The Japanese attribute these superior qualities to the slow rate of growth and periodic deposition of the nacre.

2. Characteristics

Shape: The ultimate shape of a pearl is determined in general by the nucleus around which it is formed. If the central foreign body is spherical, the resulting pearl will tend to be spherical; if it irregular, the pearl will be baroque, or irregularly shaped.

In nature, the foreign particle which accidentally become the nucleus may be of any shape, so the resulting pearls are exceedingly varies in form. Because the introduced nucleus in the culture pearl is round, the resulting pearls are round. However, many things may happen to the pearl in the three or four years of its submarine development which affect the final product. The pearl still may tend to be round but may have blemishes, protuberances, or other deformities which break the symmetry of its form. Such deformities may be due to faulty technique in operating or to the insertion of the nucleus in the wrong place in the body. About 10 percent of the culture pearls can be classified as being exceptional quality. The percent in natural pearls is much lower.

If two or more nuclei are introduced too close together, the nacre secreted around each

eventually make contact, resulting in Siamese twin pearls, triplets, or various other combined forms. No data are available to indicate whether the position of the pearl in the body of the oyster has any bearing on the ultimate shape. If a semispherical pearl is desired, a nucleus flattened to the extent necessary to give the desired final shape is inserted between the mantle the shell, the flattened surface toward the shell. If the oyster does not succeed in expelling this foreign object, nacre is secreted around it, attaching to the shell. This final product is the blister pearl.

Various shapes of pearls taken from *Pinctada martensii* are shown in Figure 9. The range of variation of form is practically infinite.

Color and luster: The cultured pearl occurs commonly in the following colors: silver, blue, green, pink, rainbow, cream, yellow (or golden), and black. These names would seem to indicate colors, but the color variations, except black and yellow, are so minute and subtle that they can be distinguished only by experienced persons. The slight and intangible differences become apparent in mass assemblages of pearls. The yellow or golden pearls are quite distinct, as are the so-called black pearls which in reality are dark, rich-gray or gunmetal.

Although many theories about the basic causes of the color and luster of the pearl have been formulated, the problem is not understood fully by the Japanese. The color varies according to the reflection and refraction of light rays on the crystalline structure of the pearl, but the causes of the structural variations are not known. Only in the yellow pearl has the presence of a pigment been demonstrated, at least in some cases. This pigment, which is localized in the organic layers, has not yet been isolated or analyzed. The color of the black pearl apparently is due to the presence of organic matter between the pearl layers, but the identity of this material likewise is not yet known. Some evidence indicates that these dark colors may be related to the black secretion of the cells of the mantle edge. These dark pearls can be converted artificially into pink pearls by injecting hydrogen peroxide under pressure into the pigment layer.

Mr. Umekawa of Mikimoto Research Laboratory has compared pearls of various colors, measuring the composing layers and the distances separating them as they appear on the surface of the pearl, as well as the size of the component granules. His results show that the grains are finest in pearls of a greenish color, with yellow and pink ranking next. The coarsest grains are found in the silver pearls. Green pearls have the most surface lines

(1,575 per millimeter), and silver pearls the fewest (1,270 per millimeter). The proportion of calcite and aragonite crystals also are known to vary considerably; less aragonite occurs in pink than yellow pearls, and the latter have more calcite crystals in their structural composition. The component layers of the yellow pearl are vary in outlines, while those of the pink are regular. Originally, the pink pearl is considered the most valuable, but if actual structural quality alone considered, the green pearl would be considered superior, because of the greater smoothness of its surface owing to the closeness of the component layers.

Dr. T. Kosaki of Kyoto University Physics Department believes that color in pearls depend upon some metal porphyrin in their composition. Pink pearls, for example, contain lead porphyrin. Dr. Matsui, chief of the Nippon Institute for Scientific Research on Pearls, concurs in the porphyrin theory, and his organization is now investigating it further. These investigators also think that black and brown pearls may be result of contact of nucleus with the liver or the intestine.

Mr. Otsuki of Atomiya Pearl Co. has observed that the pearl oysters may be arranged in four groups – red, white, yellow and black – according to the color of the conchiolin on the outside of the shell. The coloration of the conchiolin is believed to have a definite relationship to the color of the internal nacre of the shell. As the same mantle cells produce the nacre of both the shell and the pearl, he believes it logical to expect white shell to produce white pearls, yellow shells yellow pearls, and so on. If this were true, then, according to Mr. Otsuki, it would seem equally logical to attempt, by artificial breeding methods, to establish strains of oysters having the colors desired in the pearls. The reddish oysters, which presumably produce the pink pearls, comprise less than one percent of the pearl oyster population. If by artificial fertilization or selective breeding, the number of such oysters could be increased, the production of the greatly desired pink pearl might be augmented. Further work is necessary to substantiate the validity of the theory.

Study of possible relationship between water depth and color of pearls is still in its infancy. Kobayashi and Isawa believe that shallow water tends to produce yellow pearls, and deep water, pink pearls.

The relationship between the position of the pearl in the body and the resulting color also is still being studied. Indications are that pink pearls are most commonly found in the connective tissue close to the gonads. However, minute deviations in the position of the nucleus result in pearls of different colors.

It seems likely that the color of the pearl has a definite physical basis rather than a chemical one, and that color is not accidental.

The luster – the sheen or gloss of the surface – is due to the fact that the surface of the pearl is composed of the ends of crystallized fibers. The refraction of the light on this microscopically uneven surface apparently produces both muster and color. The luster is due to interference of reflected light between a very thin transparent organic layer and the crystalline grains beneath it. Good luster also may depend upon the amount of aragonite present. Pearls which have a dead, dull, lack-luster surface are known as "conchiolin" pearls because of the overabundance of conchiolin and the relative scarcity of aragonite in their composition.

Dr. Keiichi Omori of the Institute of Mineralogy Petrology, and Economic Geology, Tohoku University, has determined the composition of pearls in what appears to be the most accurate analysis thus far made by the Japanese.

Table J. CHEMICAL ANALYSIS OF THE WHITE AND SILVER PEARLS

(percent)

Pearl	$CaCO_3$	$MgCO_3$	$Ca_3(PO_4)_2$	SiO_2	$Al_2O_3+Fe_2O_3$	H_2 *a	Ogr Mat+H_2O *b	Total
White	83.71	7.22	0.35	0.54	0.54	0.89	6.11	99.36
Silver	80.82	2.16	0.15	0.56	Trace	1.26	13.44	98.39

*a Water evaporated from the pearl at a temperature below 110℃

*b Water evaporated from the pearl at a temperature above 110℃

Size: The ultimate size of the pearl depends upon (a) the size of the introduced nucleus, (b) the duration of the growth period, and (c) the vitality and age of the oyster. The best pearl growth occurs in oysters between the ages of three and seven years. For this reason, three-year old oysters are selected for operation, and the pearls are removed from the oyster after an incubation period of from three to four years. After the oyster has attained an age of seven years, its vitality apparently decreases, and the quality of the pearl is lowered as poorer nacre is deposited on its surface. Thus the best pearls are produced within a

three- or four-year period, despite the fact that deposition of nacre over the foreign body continues as long as it remains in the oyster. Therefore the ultimate size of the pearl produced in the culture pearl industry is determined primarily by the size of the nucleus introduced, not by the length of time the pearl is permitted to develop. The diameter of the average pearl increases about 0.3 millimeter each year.

The largest pearl of good quality thus far produced by culture method in *Pinctada martensii* is 10.6 millimeters in diameter, according to information obtained at Mikimoto Farm. This pearl was formed over an introduced nucleus of 6.0 millimeters in diameter, over a period of four years. Other large pearls which have been produced include:

TABLE K. LARGE CULTURE PEARLS

Author	Shell species	Diameter (mm)	Weight (gr.)	Size of nucleus (mm)	Remarks
Isowa	*P. martensii*	10.605	1.875	9.09	3 Years
Isowa	*P. margaritifera*	12.727	ND	6.06	Celebes
Horiguchi	*P. margaritifera*	18.180	3.75	6.06	3 years
Horiguchi	*P. martensii*	15.150	2.55	9.09	4 years

ND: No data available

SOURCE: Mikimoto Pearl Farm

3. Artificial Staining

"Pink pearls", of delicate color not obtainable from oysters with any degree of uniformity, are in demand in the public market. To meet this demand, which cannot be filled in any other way, pearls are sometimes artificially colored.

The first step in the process is bleaching of the pearls in a solution of hydrogen peroxide for several hours. They then are immersed in an eosin solution from 1 to 24 hours, after which they are de-oiled. The longer the pearls remain in the staining solution the deeper is their resulting color. Either of two stains is commonly used: (a) a vegetable oil plus eosin, or (b) ethyl (or Methyl) alcohol plus alcohol-soluble eosin.

A fine luster reportedly results from either of these staining methods. No color other than pink is being produced artificially, and this color in a very limited quantity.

PEARL OYSTER CULTURE

1. Collection and Acclimatization of Native Oysters

The naturally grown pearl oyster, originally almost the sole source of supply for pearl culture, has been replaced to a large extent by oysters raised from cultured spat. However, the naturally grown oysters still are collected.

In the early autumn an intensive effort is made to gather the naturally grown oysters from the many small bays and inlets along the coast of Ago-wan. This operation, which had been discontinued during the later war years, was resumes in September 1946. During August of that year arrangements were completed for a large scale onslaught on the beds of the naturally grown oysters, and on 8-9 September about 945,000 oysters were collected. The success of the project depends on the full cooperation and implementation of the program reflected the community spirit of the many people concerned.

More than 300 small launches and fishing skiffs participated in the oyster collection, each boat carrying four or five persons, two or three of whom were divers. About 1,000 divers and more than 300 tenders were employed in gathering the oysters. At the shore bases, about 100 persons sorted and weighed the oysters, kept records and loaded the tallied shells in barges.

The diving equipment and methods used in these operations are simple. The divers, almost all of them are women (Frontispiece), are clothed in simple long-sleeved, white cotton dresses which cover them from throat to knees. Their heads are covered with white cotton kerchiefs, and their faces are protected by wide diving masks which cover all except the mouth and chin (Figure 10).

When diving in water less than five meters deep, each diver is provided with a small hand net about 25 centimeters in diameters deep. A large wooden bucket, about 60 centimeters in diameter and 50 centimeters deep is attached to the diver's waist by a stout cord. The oysters gathered from the bottom are brought to the surface in the hand net and transferred to the floating bucket which is emptied periodically into tender boats. Each dive, depending on the skill and experience of the diver, lasts about 25 to 40 seconds, and the

catch is from 1 to 10 shells for each dive.

In water of five to eight meters, the divers dispense with the bucket and operate directly from the side of the tender boat. A stout rope supporting a heavy stone, concrete block, or iron weight, passes over a single pulley mounted on a simple davit on the gunwale of the tender boat a little aft of amidships. When submerging, the diver takes a deep breath and grasps the rope close to the weight. The tender releases the rope and clears it from the pulley so that the weight and diver sink quickly to the bottom. A strong cotton life line fastened to the diver's waist is paid out with the weight rope. At a signal from the diver, the tender passes the lifeline over the pulley and hauls the diver to the surface. On reaching to the tender boat, the diver empties her hand net into the boat and rests for about two minutes while the weight is raised to the surface by the tender.

The main vertical distribution of the pearl oyster ranges from 1 to 10 meters. In water exceeding eight meters in depth, the divers last 20 to 25 seconds. All deep diving is done at low tide, and as the tide rises the divers move into shallower water.

Commencing at about 0700 hours each diver works two periods of 2½ hours each every day. At the close of each diving period the collected oysters are taken to the shore base. At sorting tables at the base, the three- to four- year-old individuals, and unsatisfactory shells are discarded. The catch is then weighed, and each diver is credited with the actual weight delivered. The oysters are sold at a predetermined price. In 1946 this price was Yen 60.00 per kan; about 100 oysters weight one kan. The two-year-old oysters are purchased by the fishing association, to be sown in shallow waters. The diver received Yen 30.00 per kan, and the remainder of the money is used by the fishing association to cover the operating costs of the project and to provide benefits for the village as a whole.

Three- and four-year-old oysters which were collected by the divers are taken to the "farm" and are distributed over moderately rough bottom in shallow water. During the summer these areas have been cleaned of all oysters while divers were gathering the previous crop for culture operations. The new oysters remain undisturbed until April or May of the following year, when divers begin collecting the shellfish to be taken to the laboratory for the nucleus insertion operation.

2. Spat Collection and Rearing

Although the native oysters still are collected, the newer method of culture by collecting spat has assumed greater importance. This change occurred about 1924 as the result of experiments by Mikimoto.

The practice of gathering oyster spat and culturing the young oysters was wide-spread throughout Japan and the general principles involved were more or less clearly understood by 1885, when Mr. K. Mikimoto began his first experiments. The method had been devised for the edible oysters, and little attention had been given to the possibility of using similar methods in collecting spats of the native pearl oyster. The early experiments in spat collecting consisted simply of submitting stones or pieces of bamboo and waiting for the spat to settle. These substrata then were raised and remove to sheltered areas where they could be observed more easily by the farmer. The expansion of the culture pearl industry led to a marked shortage of naturally grown oysters and intensified efforts to develop an efficient type of spat collector.

Experiments demonstrated that the free-swimming spat of the pearl oyster develops a marked negative phototropism just before settling. This discovery led to the invention of a totally new type of spat collector. This device, patented in 1924 (No. 60312) by Mikimoto, consists of small cage, 84×54×20 centimeters, formed by covering a heavy wire frame with a two-centimeter wire mesh (Figure 11). The cage is suspended vertically and carries seven horizontal shelves of wire mesh. A large door covers the front of the cage,

The cage, which is made of galvanized wire, is dipped into hot coal tar to prevent corrosion, then dipped in a thin sand-cement mixture. When dry, this cement forms a rough coating about two-five millimeters thick over all parts of the cage and provides as excellent base upon which the larvae of the oyster can settle. Black-painted boards are fastened to the sides and bottom of the cage, forming a darkened area highly attractive to the light-avoiding spat. These spat collecting cages are suspended at a depth of six meters from large frame rafts which are anchored in areas where experience has shown that the best "set" of spat may be expected.

The rafts are constructed of an open framework of poles of bamboo of about 10 centimeters butt diameter (Figure 12). Each raft measures about six by five meters, with the longitudinal and transverse poles lashes together at about one-meter intervals. Each frame is supported by five to nine 50-gallon drums or barrels. The rafts are anchored in series of 5 to 10, lashed together end to end. About 50 spat-collecting cages are suspended from each

raft.

The Japanese pearl oyster spawns from July to September, and the spat-collecting cages are set out early in July. They remain in places until late November, by which time the young oysters are about 1.5 centimeters long. The catch per cage varies from 1,000 to 160,000, but the usual range is from 7,000 to 10,000. At the November inspection the young oysters are removed from the spat-collecting cages and transferred to rearing cages.

The rearing cages resemble the collecting cages except that they are divided into four to six compartments and the lack the diagonal subdivisions. They are covered with a one-centimeter wire mesh or with cotton netting if the wire mesh is not available. Within these rearing cages the young oysters are well protected against their natural enemies, and the survival rate is high. These cages are either distributed over the sea bottom in sheltered areas or suspended again from rafts, and they remain undisturbed until the following June or July. The oysters, then about one year old and averaging 2.4 centimeters in diameter, are soon in water three-five meters deep over a fairly rough bottom. Here they remain undisturbed for about two years.

During June, July, and August of the third year, the oysters are collected by women divers and brought to the cleaning barges. These large, pontoon-like structures are fully decked rafts providing a platform about 10×6 meters, with a simple sloping roof. The barges are towed to the collecting areas by motor launch. The collected shells are brought to the barge and sorted and cleaned by a team of workers, mainly girls (Figure 13). Distorted and old shells are discarded, and undersized shells are returned to the growing beds for another year. Adhering seaweeds, anemones, and other encrusting organisms are scraped from the selected shells with a blunt knife. The cleaned shells then are placed in culture cages and distributed in shallow water by raft suspension for an acclimatization period of not less than 10 days. This period allows the oyster to recover from the shock of collecting and cleaning and to become physiologically adjusted to the shallow water conditions.

To alleviate material shortages in years following the start of World War II Mr. Kazo Kakuda of Kakuda, Mie Prefecture, in 1947 perfected a simplified raft method for use in collecting spat of the pearl oyster. This efficient and inexpensive method is a boon to the small-scale farmer who has neither the material nor funds for more elaborate apparatus. Mr. Kakuda's invention consists of a bamboo raft frame 14 meters long and 1.50 meters wide (Figure 14A), from which is suspended a series of 40 straw ropes, one centimeter in diameter and 2.75 meters long. On each rope are strung from 20 to 30 discarded abalone,

oyster, or turbo shells. The length of the rope in comparison with the width of the raft permits the collector shells to hang at a depth of one meter. With the raft anchored in a suitable place, this method has proved highly efficient as a collector of "wild" spat. The spats are collected in June and July, and in November the young shells are removed to baskets for rearing. An average of 20 to 50 spats per collector shell was reported, and a total of 20 rafts pronounced more than 500,000 spats in 1947.

A second spat collecting methods now being tried by Mr. Kakuda uses old fish nets of woven palm rope suspended from a raft (Figure 14B). This spat collector also is proving highly successful. It is cheap and timely, as, unlike the more elaborate collectors, it does not require wire, which is scarce.

3. Preparation for Operation

Before the daily commercial operations on the oysters for nucleus insertion are begun, numerous host oysters must be operated for the technicians who insert the nuclei. The insertion of a bamboo plug between the open valves of the mollusk (Figure 15) is standard practice among all operators, but the method of inducing the oyster partially open its valves varies with the different stations. The methods used may be divided into three systems:

Stagnant water method: The oysters are placed in a shallow metal tray with the dorsal portion (hinge) of the shell downward. They then are covered with sea water, and in a minute or two the valves begin to gape. The opening forceps then are inserted between the valves, which are gently forced apart to permit the insertion of the beveled end of the bamboo wedge or key (Figure 15) which is 6.5×1.5×0.6 centimeters. Because of the speed at which the oysters consume the available oxygen, the water is changed occasionally, but the oysters often are weakened seriously because of a lack of oxygen; consequently the mortality rate of oysters prepared by this method is higher than for other method.

Running water method: In principles, this method is the same as the preceding process, but have the trays and the contained oysters are supplied constantly with running sea water while the oysters are awaiting the insertion of the key.

Dry method: The larger commercial operators bring their host oysters to the station wharf in baskets about 24 hours before the nucleus insertion and hang the basket in the sea

from nearby rafts. One-half hour before the technicians begin their work, laborers dump the oysters on the wharf. Shortly thereafter about 35 percent begin to gape. These are selected for immediate operation, and the bamboo wedge is inserted. Oysters which do not open within a specified time are returned to the water for another four hours, after which they again are removed to the wharf and tested. Those promptly opening their valves are pegged immediately. Experience has indicated that only the healthy, most vigorous individuals will open their valves in the air. The four-hour resting period in the sea enabled weakened oysters to regain sufficient strength to withstand the nucleus insertion operation.

The speculum (Figure 16E) is inserted gently into the anterior-ventral region and sufficient pressure is supplied to open the valve about one centimeter. The wedge-shaped key then is placed between the valves at the posterior-ventral region at an angle of about 45 degrees to the hinge line. The oyster is then ready for the insertion of the nucleus.

Pinctada martensii will remain agape in the air for one or two hours before closing naturally. Under no circumstances should the oyster remain keyed more than two hours before the operation is performed. The animal becomes fatigued from a prolonged forced opening and it then unable to withstand the shock of operation. Experienced operators rarely key their oysters for more than 20 minutes before the nucleus is inserted. This requires close coordination between the keyers and technicians.

Experienced technicians maintain that careless handling while opening the oysters for keying materially contributes to the general weakening of the animal during the nucleus insertion and consequently to a high mortality rate of operated oysters. Fracturing the shell or breaking off the shell's edges during keying definitely is harmful. The oyster habitually withdraws the edges of the mantle lobe to the innermost limits of any such fracture or damage and rebuilds that section before extending the mantle to the shell periphery for normal activities. Damage to the shell therefore results in suspension of normal development while repairs are being made and reduces the normal vitality of the oyster. This affects the quality of the pearl sac and the pearl within the tissue of the animal's body.

4. Laboratory Equipment

While the keyers are pegging the oysters on the wharf in the morning, the technicians are arranging their equipment in the laboratory for the nucleus insertion operation. Each technician works at a small individual desk before a large window, and each has own

complete set of instrument. Almost all the technicians are girls or women.

A complete set of special instruments, varying in minor respects with different organizations and individuals, has been devised for the insertion of the nucleus. All instruments used by the technicians at Mikimoto Farm are made there and represent the accumulated experience of any years and many technicians. Instruments used on the farm are:

a. Equipment for Preparation of Tissue Grafts

1 pair straight surgical scissors for cutting the mantle strip
1 thin scalpel, five inches long, suitable for medical dissection, for trimming and cutting the mantle strip
2 soft-grained wooden discs (crape myrtle, magnolia) about two centimeters thick and eight centimeters in diameter, on which the graft tissue is trimmed and cut.
1 pair fine forceps with finely ground points
1 white porcelain vessel about 20×15×3 centimeters
1 beaker sea water
Supply of good-quality, fine muslin

b. Equipment for Nucleus Insertion

1 bench of suitable height, about 20 ×30 inches, fitted with drawers for instruments, nuclei, etc
1 desk oyster-clamp, designed to hold the wedged oyster in position during the operation, giving the operator free use of both hands
2 porcelain vessels 20×15×2 centimeters
1 beaker seawater
1 wooden pillow for resting operating edge of instrument
1 piece of cotton cloth for wiping instruments
1 shallow wooden tray to receive operated oysters
1 small wooden tray for wedges removed after operation
Sponges
Series of shallow cups holding various-sized nuclei

c. Special Instruments

Scalpels: Hollow ground, curve-tipped surgical scalpels and flat-ground, curved or semicircular scalpel of two millimeters diameter, offset from the line of axis of the shaft to enable making of convex-circular incisions.

Forceps: Fine-pointed, straight forceps with one-millimeter tip.

Spatula: Light spatula (Figure 16D) of stainless steel or non-ferrous metal, about 15 centimeters long with a blade 2.5×0.5 centimeters, used to smooth the mantle folds away from the site of the incision.

Retractor: A slender metal rod fitted with a re-curved hook at each end (Figure 16C), used to hold the foot of the oyster in place during the operation.

Lifters: Fine, probe-like instruments with specially designed tips of various types and diameters at the maximum thickness. The line of axis of the tip is set at an angle to the axis of the shaft, the magnitude governed by the position in the connective tissue in which the nucleus is to be placed. These instruments may be classified as follows:

(1) Flat and torpedo-shaped probe, used to separate the tissue into a channel for the reception of the graft tissue and the nucleus without doing further damage after the incision has been made with the very sharp scalpel;

(2) Flat or round graft lifters (Figure 16A), with spurred tip, used to pick out the tissue from the wooden block and to place the pieces in the channel of insertion in the connective tissue;

(3) Nucleus lifters (Figure 16B), semispherical cups with the same diameter as the nucleus to be lifted, one lifter for each size nucleus. Nuclei are of standard sizes. The nucleus lifters select the nucleus and pass it to the desired position into the probed channel or incised tissue. The cupped tip is moistened and touched to the dry nucleus which immediately adheres to the tip, permitting easy transportation and delicate handling within the oyster.

The specially designed brass clamp (Figure 16G) which holds the oyster firmly in position without crushing the delicate shell during the progress of the operation consists of a

head plate against which a spring clamp plate closes. The front edges of these two plates from short, slightly curved lugs which tend to follow the curve of the oyster shell and prevent lateral movement. The head-plate is mounted on an adjustable tilting head, and the whole apparatus is supported on a telescopic column. This column, 1.5 centimeters in diameter, is inserted in a heavy wooden block base 16.5 ×11× 5 centimeters. When the oyster is placed in this clamp, which is adjusted to exactly the right position, it is ready to be operated on.

5. Preparation of Graft Tissue

As the preparation and insertion of the graft tissue governs the production of the pearl, grafting must be done with the same extreme care and precision that would accompany a delicate surgical operation.

The graft tissue is prepared from the frilled mantle edge of a living oyster. The oyster is opened carefully with a sharp knife, the blade of which is inserted between the valves, and the adductor muscle is cut from its attachment to one shell. Care is taken not to injure the mantle tissue in any way. All extraneous matter is scraped out, using the blunt edge of the scalpel. A strip about seven centimeters long and ¾ centimeters wide is cut from the edge of the mantle. This strip of living tissue is smoothed out carefully on a wet graft trimming block (Figure 16F), and the adhering slime or mucus is wiped off with a viscose sponge.

The thickened outer edge of the mantle, with all dark and discolored areas, is cut away with the sharp scalpel. The remaining tissue is trimmed to form a long, narrow (two-three millimeters) strip, which is then cut transversely into tiny squares. The size of those squares is determined by the size of nucleus to be used, each graft being sufficiently large to cover third of the introduced nucleus. The whole block, with the cut graft tissue adhering to it, is dipped in a beaker of clean sea water. Under moderate temperatures, 17-22℃, the graft tissue will live for about two hours if kept wet with seawater.

Two methods by which the graft tissue may be prepared are:

(a) The graft tissue is cut from the upper mantle layer. A thin cutting block is placed against the body of the oyster and the mantle layer smoothed gently on it. The first scalpel cut separates the mantle strip from the body of the oyster. Slime is removed gently from the strip with the wet sponge as the strip lies on the block. It then is lifted with

fine forceps and reversed to lie with the nacre-producing cells adjacent to the block. The strip is again wiped and trimmed, and the graft pieces cut.

(b) In the method more commonly used, the graft tissue is cut from the lower mantle layer. The mantle strip is cut in place, that is, the scalpel edge cuts through the mantle tissue against the shell of the mollusk, or, a scissors is used. The strip then is drawn by fine forceps onto the wet cutting block, with the nacre-producing cells adjacent to the block. The strip is wiped to remove the mucus, then lifted and reversed so that the nacre-producing cells are uppermost on the block, again wiped clean, and trimmed.

Emphasis must be placed on the fact that, to produce the best pearls, the nacre-producing mantle cells (represented in the cut strip by the little squares thus prepared) must be in contact with the nucleus in the body of the oyster. As these are located only on the outer surface of the mantle, the position of these cells on the cutting block must be definitely known. Grafts prepared by the first method, therefore, are placed after the nucleus has been inserted in the body of the oyster, and are placed on top of the nucleus. Grafts prepared by the second method are inserted before the nucleus is inserted and lie under the nucleus.

To produce the best pearls, both graft tissue and nucleus must be inserted adjacent to tissue on which the graft will "take". Graft inserted into the more highly specialized tissue of organs usually degenerate, and action of the body fluids erodes the nucleus.

6. Preparation of the Nucleus

Although a pearl of sorts may be formed around almost any small object as a nucleus, research and experience have proved that a calcareous nucleus possesses marked advantages over all other kinds. Layer of nacre binds most satisfactorily with a calcareous substance; the nacre is less likely to fracture then the pearls are drilled for stringing the material is easily prepared in the desired spherical form. In addition, suitable limey substances are relatively cheap to produce, and the specific gravity of the material is nearly identical with that of the deposited nacre.

As nuclei range in diameter to a maximum of more than six millimeters, the first requirement for their production is a heavy, solid shell. Most nuclei are prepared from the shells of fresh water mollusks. Unfortunately for the industry, Japan produces no bivalve with a shell thick enough to produce nuclei of the larger diameter in quantities sufficient to

supply the demand. Search for the desired material led to the United States where admirable shell material finally was found in enormous quantities in the *Amblema*, *Quadrula*, *Pleurobema,* and *Megalonais* species from the Mississippi River and its major tributaries. All have massive shells and were found to yield a high proportion of satisfactory nuclei similar in hardness and specific gravity to the superimposed nacre. Mikimto purchased these shells by the dozen carload lots for shipment to his farm in Japan where he manufactured his own nuclei.

In preparing the nuclei, the shells are cut into small cubes of the required general size, then placed between two sheets of iron. The upper sheet is revolved, and the resulting grinding of the cubes, between the plates and against one another, chips off the edges and produces rough spheres. These rough blocks are placed in the cotton bags and subjected to a further grinding treatment which brings the surfaces to fairly high polish. Sometimes a final polish is achieved by the use of fine talc of jeweler's rouge placed in the bag with the nuclei. However, a high polish is not essential.

Although the general size of the finished product is determined by the size of the original cube, some variation occurs, and finished nuclei are graded according to diameters. The nuclei for *P. martensii* are prepared in size from 1.2 to 6.6 millimeters in diameter, each size being 0.3 millimeter larger than the preceding. For special purposes larger nuclei may be prepared. The individual variation within the grades is less than 0.05 millimeter. For use in *P. margaritifera,* nuclei with a diameter of 6.3 to 6.6 millimeters are used; in *P. maxima* nuclei range from 6.6 to 13.2 millimeters.

When World War II started, the culture pearl industry had a sufficient quantity of these nucleus shells to last for sometime. In 1948, however, this supply was almost exhausted, and search for substitute nucleus material is in progress again, this time largely in the field of plastics. Results, however, are definitely disappointing, and the best-known nucleus material remains the thick-shelled bivalves of the Mississippi valley.

7. Insertion of the Nucleus

When the partly open pegged oyster has been placed in the rest clamp with the right valve uppermost, and the tissue grafts have been prepared, the operator smoothes back the mantle folds with the spatula, exposing the foot and the main body mass. The retractor hook is used to hold the foot down and extend it slightly to prevent muscular action. An incision is

made into the epithelium of the foot with the flat probe (Figure 6), and a slender channel is opened into the main mass of the tissue.

A piece of graft tissue is passed down the channel to the site selected for the bed of the nucleus. The nucleus then is picked up in the moistened cup of the nucleus-lifter and is inserted into the layer to lie immediately above the introduced graft tissue. The foot is smoothed gently with the back of the probe to close the channel, the mucous helping to keep it closed. The foot is released from the retractor, and the plug removed from between the valves. The oyster closes immediately and is returned to a holding tray, and another oyster is selected for treatment.

If insertion of a second nucleus is desired (Figure 6), the wooden plug is left in position and the oyster turned over in the clamp with left valve uppermost. The mantle fold again is smoothed back, exposing the visceral mass, and the foot is immobilized by the retractor. The epithelium covering the viscera is pierced by the torpedo-shaped probe, the graft tissue introduced, and the nucleus inserted into the gonad. In this second operation, extreme care must be taken to avoid perforating or injuring the vital organs.

Highly skilled technicians can insert a third nucleus while the oyster is in the second position in the clamp, but the third operation requires such extreme delicacy of technique that most technicians do not attempt it. Well-trained technicians can completed the nucleus insertion operation on 25 to 40 oysters an hour.

New girls require at least one year of apprenticeship to acquire sufficient skill to undertake the nucleus inserting operation. During that period they practice by inserting glass beads into the various operational areas, cutting and preparing graft tissues, and becoming generally expert in the operation involved. Some of the pearl farms now are beginning to train boys and young men in the techniques because so many of the girls get married and give up the work.

8. Convalescence

The operated oysters are placed in freshly tarred culture cages which consist of heavy wire frames 68×60×30 centimeters, covered with 2.5 – centimeter mesh wire netting. One side of the cage is hinged to form a door. Each cage is divided into four compartments and holds 50 to 60 oysters. After the cages receive their quotas of newly operated oysters, they

are suspended horizontally from large groups of rafts anchored in sheltered water near the laboratory. The cages, submerged to a depth of two to three meters, remain undisturbed for four to six weeks after the nucleus operation. During this convalescence period, the oysters recover from the operational shock and repair whatever injuries they have sustained.

At the end of the period the cages are lifted and the oysters inspected. All dead shells are removed, and the cages are transferred to permanent culture rafts by barges or by motor boat tows.

9. Subsequent Culture

The cages are suspended from the permanent culture rafts at a depth of two to three meters. Each raft supports 60 cages containing a total of 3,000 to 3,600 oysters. Except for periodic cleaning they remain undisturbed for three or four years.

At least three times each year, in April, July, and September, the cages are lifted and all encrusting marine growths are scraped from the oysters. Under normal conditions, about 40 days are occupied each year in the cleaning processes. At the same time all dead shells are removed, and a few living oysters are opened to determine the rate of growth of the pearls. The cleaned oysters are placed in freshly tarred cages, and the used cages are returned to the shore base for renovating, and eventual retaring.

In some stations, especially those which do not have enormous quantities of culture oysters under their control, the oysters are cleaned five to eight times a year.

Normal harvesting operations begin in October and continue until the middle of January, although operators who specialize in the production of pearls of high luster generally do not begin their harvesting until after 20 December. These operators believe that the oyster deposits only a thin, translucent layer of nacre over the thicker, more colorful layers at the start of cold weather. This translucent layer, deposited during the last month before the harvest, may ass materially to the quality of the pearl. This theory becomes all the more interesting in view of the recent finding of Dr. Kobayashi in regard to hibernation period in the yearly cycle of the pearl oyster as already discussed (Table E).

The materials required for the culture of 1,500,000 oysters are:

TABLE L. EQUIPMENT REQUIRED FOR THE CULTURE OF 1,500,000 OYSTERS

Item	Number
Cages, 50 oysters per cages	30,000 cages
Rafts, 50 cages per raft	500 rafts
Poles, 17 poles per raft	8,500 poles
Barrels, 6 barrels per raft	3,000 barrels
Wire rope, 23 coil per 10 rafts	35 coils *a
No 6 wire rope, 1/2 coil per 10 rafts	25 coils
No 8 wirw, 2 coils per 10 rafts	100 coils
1" steel strapping for repairs to barrels	340 yards
1 1/4" steel strapping for repairs to barrel	120 yards
No 10 wire for hanging cages, floats and repairs	145 coils
No 12 wire for raft construction	50 coils
Heavy fuel oil	580 drums *b
Light fuel oil	200 drums
Kerosene	18 drums
Machine oil	25 drums
Gasoline	20 drums
Mobile oil	15 drums
Coal tar	428 drums
Cement	150 bags

*a One coil equals 200 meters

*b One drums equals 50 gallons

Source: Mikimoto Pearl Farm

ENEMIES AND ADVERSE CONDITIONS

1. Damage by the elements

The elements – temperature, and wind, and rainfall – which can cause damage to the pearl oyster of course cannot be controlled directly, but measures to minimize the damage sometimes are possible. Although normally protected from sudden temperature changes by the fringe of the warm Kuroshio or Black Current, the water of Ago-wan and other pearl culture bays occasionally are influenced by cold eddy currents originating from the deep southern extremity of the cold Kamchatka Current. The sheltered waters of these bays also

are susceptible to air temperature changes, and a prolonged cold period may seriously depress the surface water temperature. As the Japanese pearls oyster is particularly susceptible to cold, any marked divergence from a norm may prove serious. The critical temperature for *Pinctada martensii* is 11℃, and low water temperatures have caused serious losses of culture stock. Such a loss occurred in the winter of 1925 in Ago-wan where hundreds of thousands of culture oysters were killed when the water temperature of the water dropped to 9℃. The only possible defense against such conditions is to tow the raft to warmer bays, and this frequently is done.

Fluctuations in surface and subsurface salinity also may cause serious loss to culture stocks. Although most of the culture areas are outside the influence of large rivers and estuaries, periods of exceptionally heavy rainfall may reduce the salinity below the oyster's limit of tolerance. If a heavy downpour follows a prolonged wet spell, the surface run-off is extreme. When this occurs, the specific gravity of the sea water, normally around 1.027, is reduced to such an extent that the oysters are killed. Ogushi (1938) refers to one such instance when the specific gravity of the sea water at one meter depth was reduced to 1.011, between one and two meters the water was almost fresh and below two meters the specific gravity again was normal. All culture stock in the zone of practically fresh water was killed. The only solution to this problem is to tow the rafts out of the influence of the reduced salinity.

High winds normally play only a minor role in the destruction of oysters because of the protection afforded the rafts by the many indentations of the shoreline. However, the typhoons which strike Japan may tear away rafts and buoys, and the culture cages often are dropped to the bottom. In such instances, divers retrieve cages and contents if possible.

2. Biological Enemies

The pearl oyster now is protected from its biological enemies (other animals or plants) by confining the culture stock in rearing cages which either bar the attack of the enemy or make possible the removal, by periodic cleanings, of the attacking organisms which collect and grow on the cages. The most damaging single factor which causes destruction to the pearl oyster is the red tide, The Akashio of the Japanese. Information on this phenomenon appears later in this chapter

Among the fish, the common eel (*Anguilla japonica*) is known to feed on *P. martensii,* and

many pearl nuclei have recovered their digestive tracts. Eels may attack oysters when they are open, especially when fatigued after the nucleus operation. The black porgy (*Sparus milerocephalus*) and the globefish (*Sphoeroides sp.)* also feed on young oysters, especially those less than three months old. The octopus (*Octopus vulgaris*) is known to consume more than a dozen oysters a night in summer. Very serious octopus depredations were reported for Gokashowan in the summer of 1913 (Ogushi 1938). The culture cage has proved an effective barrier against all these animal predators.

Among the barnacles, four species injure the oysters by attaching at or near the hinges, thus interfering with the opening of the shell, hindering the growth, and causing death. These species are: *Balanus amphitrta nivans*, *B. amphitrita albicostatus*, *B. trigonus,* and *B. tintinnabulus*. Several species of oysters, such as *Osterea Gigas*, together with such sponges as *Rhizomulgule japonica,* cause damage in much the same manner as the barnacles. Seaweeds (*Codium mamillosm*, *C. puguiliformis*, *C. mucronatum*, *C. contractum*, and *C. cylindricum*) do considerable damage by interfering with growth either by direct attachment to the shell or by festooning the cages, thereby obstructing the passage of incoming food. Periodic cleaning of the shells is the only practical defense against enemies which enter the cages.

3. Red Tide

Although red tide has been known since the 16th Century, not until 1858 did an investigation of red tide in the coastal waters around Bombay show the basic cause to be plankton organisms. In 1899 Nishikawa investigated an occurrence of red tide in Toba-wan, Mie Prefecture, and found the organism present to be *Gonyaulax polygram*, which apparently caused no damage to other marine life. *Cocurodium* was found to be the basic organism in a Yokohama red tide in 1909, and *Gymnodium* in Gokasho-wan, Mie Prefecture, in 1922. No special damage was reported in either instance. However, in an occurrence of red tide in Ago-wan in 1917, when *Gymnodium* was found, extensive damage was done to fish and shellfish. In 1929, when *Gymnodium* was present, only slight damage was done in Ago-wan, but in 1934 with that organism again present, both fish and oysters were severely damaged. The Japanese can offer no explanation of this variation as damage. Whether the variation is due to differences in abundance of the organisms, as would seem very possible, cannot be stated definitely, because no counts of organisms per unit volume of water have been reported. Ironically, the organism most damaging to the oyster crop is named *Gymnodium mikimotoii.* This is one of the dinoflagellates which occur in sufficient number to

color the water red, hence the name red tide.

The predominant organisms occurring in the red tides of Japan are as follows;
Dinoflagellata: *Gymnodium*, *Gonyaulax*, *Peridinium*, and *Prorocentrum*
Distomacea: *Chaetoceras*

Certain facts containing the physical conditions which produce red tide were learned by the Mie Prefectural Fisheries Experiment Station (1948) through aquatic and meteorological observations. When the red tide occurred in winter, the water showed specific gravities higher than normal for the season. In early autumn, red tide apparently occurred under higher than normal atmospheric temperatures, and in winter occurrences the atmospheric temperatures were lower and the rainfall less than normal.

Records kept by the Mie Prefectural Fisheries Experiment Station from 1899 to 1938 reveal that akashio has occurred every month in the year except April and July (Table 5). September leads with nine occurrence of red tide, and August is second with six occurrences. The three most virulent red tides occurred in 1911, 1922, and 1934. Whether this almost cycle occurrence has any significance is not clear at this time.

The most recent red tide occurred 18 August – 19 Oct 1948 in many of the smaller bay of Ago-wan. Four out of the five areas in which the tide started in August suffered recurrent epidemic (Table M). The one exception, Fuseda area, experienced the second longest epidemic of the year. In every area, the organism *Chaetceras* dominated the onset of the tide, and *Gymnodoum* dominate the later stages. *Gonyaulax* was not found in this particular occurrence of the red tide

TABLE M. LOCATION AND RECURRENCE OF RED TIDE *a AGO WAN, 1948

Locality	Onset	Conclusion
Katada	18 Aug	26 Aug
	29 Aug *a	15 Oct
Wagu	26 Aug	11 Sept
	20 Sept *b	2 Oct
Tategami	26 Aug	16 Sept
	14 Oct	16 Oct
Shinmei	31 Aug	14 Sept
	14 Oct *b	16 Oct
Fuseda	31 Aug	5 Oct
Mazaki	8 Sept	2 Oct
Koshika	9 sept	11 Sept
Funakoshi	9 Sept	19 Oct
Hamajima	12 Sept	19 Oct
Ugata	24 Sept	5 Oct

*a Dominated by organism *Chaetoceras* and *Gymnodium*

*b Recurrence

SOURCE: Dr. S. Kobayashi

In addition to the direct damage done by the organism of the red tide, indirect damage is caused by the reduction of light penetration into the water as this affects plant and animal metabolism. The number of organism per unit volume affects the color intensity and transparence of the water. The water transparency at different times of the bay was measured at Sekoura-wan on 22 September 1948 by the Secchi disc method (Table N). In this measurement, a 12-inch white porcelain disc is lowered slowly in the water to determine the point at which the disc becomes invisible.

TABLE N WATER TRANSPARENCY DURING RED TIDE, SEKOURA-WAN 1948 *a

Time	0730	0830	0930	1030	1130	1230	1330	1430	1530	1630	1730	1830
Transparency *b	4.3	3.8	3.0	1.8	1.4	2.3	2.0	2.1	3.7	2.5	4.0	3.5

*a Determined 22 1948 by use of 12-inch Secchi disc

*b Depth in meters at which Secchi disc became invisible

SOURCE: S. KOBAYASHI

The number of organisms per cubic centimeter at different depth was measured at two-hour intervals on 1 October 1948 as shown in Table O, page 58.

TABLE O. NUMBER OF GYMNODIUM PER CUBIC CENTIMETER OF WATER, AGO-WAN, 1948 *a

Time	Depth (meters)											Transparency *b
	0.0	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	
0800	40	40	200	80	960	280	160	360	120	40	160	3.0
1000	40	40	120	1,040	10,000	840	1,200	240	320	400	160	2.1
1200	5,750	6,750	5,750	750	2,500	1,750	2,500	300	100	300	750	1.4
1400	80	40	3,680	2,600	1,120	1,040	1,120	680	200	600	320	1.8
1600	240	2,320	2,640	440	680	240	40	120	40	80	160	3.2
1800	40	1,440	4,560	640	760	640	1,120	640	1,000	400	280	3.1

*a Tested 1 October 1948

*b Depth (in meters) at which 12-inch Secchi disc became invisible

SOURCE: S. Kobayashi

The distribution of plankton organisms in the water is far from uniform either horizontally or vertically. Table 6 summarizes measurements of the number of dinoflagellates per cubic centimeter at half-meter intervals from the surface to the bottom at 11 different stations near Sekoura laboratory.

The damage done by this 1948 red tide cannot be evaluated yet, but evidence by sampling indicates that it has been considerable.

The red tide is fatal to fish, mollusks, crustaceans, and any other form of aquatic animal life which breathes by gills or in which respiration is controlled bye pores or small body openings, as in the sponges. Although the actual method by which these micro-organisms cause death is not entirely clear, Ogushi (1938) suggests that death may be due to one or more of the following causes:

(a) Suffocation caused by excessive oxygen consumption by the dinoflagellates. These tiny organisms multiply to enormous numbers, and their oxygen consumption must be considerable.

(b) Suffocation caused by clogging of the gills by great masses of the organisms. Individual organisms stick to the gills and die. More and more accumulate and die, thus clogging the gill filament and preventing the proper separation of the blood therein.

(c) Poisoning by toxic substances secreted by living organisms. This theory is based upon the work of Kominami, who injected red-tide water into the mice and various fish. The mice dies in 12-24 hours, while other mice, injected with red-tide water which had been thoroughly boiled, showed no reaction. Of the six species of fish injected, all dies in from 5 to 47 hours.

(d) Poisoning by toxic substances released by the decomposition of the dead bodies of the myriads of organisms.

Whether death results from a single one of the above situations or from a combination of two or more has yet to be determined. The clogging of the gills theory (b) might explain the variation of damage done by different red tides involving the same organisms, the damage depending upon the abundance and concentration of the plankton in water.

When red tide appeared in Mie Prefecture in 1934, Ogushi (1938) reports that attempts were made to poison the dinoflagellates. When the first sign of the reddish color appeared in the water, a motor launch fitted with a large boom across the stern, was sent out. From this boom cotton bags containing crystalline copper sulfate or bleaching powder were suspended in the water, and as the launch moves along, this material dissolved and dissipated in the water. Mr. Oda of Mikimoto Farm tried this method with good results. Ogushi reports that, according to Dr. C. E. McClung, the same method was used by American oyster culturists. Further study and experimentation are necessary to determine the effectiveness of the method. A far safer method is to tow the rafts with the culture oysters aboard out of the infested are by power launches. This is the usual method practiced.

THE PEARL

1. Recovery and Grading

The operated oysters remain in the cages from three to six years, the time depending on the size and quality of the pearl desired. At the end of the designated period, which average

3 1/2 years, the cages are lifted and the oysters removed and brought to the laboratory.

A skilled laboratory worker opens the shell and removes the mature cultured pearls and any natural pearls which may have developed. Another worker carefully washes the pearls to remove all slime and dirt, then dries them by rubbing with a soft cloth. During drying, the pearls rest on another soft cloth. The operation is rotary and done by hand to avoid scratching the pearls. A third worker receives the cleaned pearls in quantities and hand grades then according to form, removing all pearls in any deformed.

The next step is a careful grading as to size. Several hundred unsorted pearls are placed in circular metal sieve having as its bottom a series of round holes of specific diameter. The first sieve passes only the smaller pearls, the second sieve passes those of a slightly larger size, and so on until only the largest pearls are left. Each size group in a separate container and marked as to diameter.

The pearls are then counted. The counter is a flat, square plastic plate having 10 rows of 10 holes each; it looks much like a pancake turner (Figure 17). The counter is slipped into a mass of pearls and withdrawn, each hole then holding a pearl, 100 pearls to the dip. The number of pearls thus is determined quickly.

The pearls then are sorted roughly into three grades: A, good; B, medium; C, poor. The grade A, or good pearls, include all spherical or very nearly spherical pearls which are not discolored and are of good luster. Grade B, or medium pearls, include baroque pearls of good color and luster and any spherical or nearly spherical pearls of medium color and luster. The Grade C, or poor pearls, include all pearl material not of value as ornaments. Much of this poor material is used for pearl medicine.

A second and more exacting grading follows, again on the basis of good, medium and poor, the final categories being Aa, Ab, Ac; Ba, Bb, Bc; Ca, Cb, Cc. The A grades are the best pearls from every point of view – from form, color, luster, and perfection of surface – and are the pearls used for the better necklaces, eardrops, studs, cufflinks, and single pearls for rings, pins, and brooches. The B grades are used for rings, brooches, clasps, buckles, and other forms of ornamental jewelry. Skilled appraisers do both this second grading and the final evaluation of the necklaces, selected pairs, and single pearls before they are marketed.

2. Making a Necklace

The pearls to be used for necklaces are sent to the drilling room where they are examined carefully for blemishes. Girl workers mark any blemishes with a tiny dot of black ink to indicate to the driller the axis along which the drill should pass and the point at which it should enter.

The drill usually is made of mild steel wire, 0.75 millimeter in diameter, ground to a triangular point. This drill is mounted in a small chuck fixed directly to the spindle of a 1/8–horsepower electric motor. In line with the drill and mounted on a sliding base is a small brass chuck in which the pearl is mounted.

With the pearl in place and oriented so that the drill will enter at the designated spot, the chuck is moved forward, this movement starting the motor. The drill is moistened prior to entering the pearl, and the hole is drilled a trifle more than halfway through the pearl. The pearl then is removed, and a small, sharply pointed bamboo silver is inserted in the drill hole. The pearl is then reversed, centered in the chuck by means of this silver which enters a hole in the back of the chuck, and again drilled until the drill moves freely through the axis of the pearl.

The drilled pearls are then passed to the matching tables where girls sort them in small, black baize-colored, grooved trays (Figure 18). Selected pairs of pearls are placed in two adjacent grooves, in steadily diminishing sizes to the right along the grooves. The pearls are selected and matched for size, color, and luster, and when two similar pearls are matched, they are places in their proper sequence in the growing series. The two grooves eventually hold equal number of pearls, each group forming one-half on the necklace. Finally the larger, central pearl is selected. The pearls then are strung on a fine silk thread with a very fine needle, starting at the small end of one row, passing through each pearl in turn to the larger center pearl, then through the second sequence starting with the largest end ending with the smallest pearl. The thread ends are tied together, and the necklace goes to the appraiser for final inspection and grading. Each necklace is inspected individually as to component pearls and perfection of the grading and matching, and each is weighed and recorded. One hundred necklaces are tied together and again weighed and then are ready for the market.

BY- PRODUCTS

1. Seed Pearls

After the larger, better, and more easily separated pearls have removed from the opened oyster, steps are taken to recover the smaller pearls and pearly fragment (Figure 19). The soft meat, with the exception of the adductor muscle, is recovered from the shell and collected with vats. When a sufficient quantity has been accumulated, the meat is transferred to a wooden or concrete macerating machine fitted with paddles. Sea water is added, and the mixture is churned to the consistency of this soup. The mixture flows from the churn into a series of concrete settling tanks from which the final over-flow passes through a drain into the sea. In this series of settling tanks more than 99 percent of the pearl material not previously removed is recovered.

As the size of the material collected by this method is very small, most of it is used for the manufacture of peal medicines. However, it first is sorted, and the better grade material is separated for use in costume jewelry.

2. Medicines

Many residents of the Orient believe that pearl and mother-of-pearl have high therapeutic value, and the demand for pearl medicine always has been high. With the development of the culture pearl industry, Japan gained control or practically the entire pearl medicine market and built a lucrative export trade on it.

Pearl medicine consists either of pulverized pearls or entire tiny seed pearls and commands a high price. The chemical analysis of the pearl medicine is: calcium carbonate, 94-95 percent; water 2 percent; and foreign matter 3-4 percent.

Medical opinion suggests that although the amount of assimilable calcium in such a powder form would be quite small, the finely ground pearl material probably has a slight beneficial effect, even if only as an antacid specific.

Shell medicine: Shells from the opened oysters are collected into large stock piles and eventually are ground to form a cheap grade of pearl medicine known as shell medicine.

The raw shells are shoveled into a large iron rumbler fitted with five-centimeter baffles.

The cylinder walls of the rumbler are perforated with many 2.5 centimeter holes. Sea water under pressure is pumped into the rumbler which revolves at about 100 revolutions per minute. The scrubbing effect of the shells against the baffles are against one another remove encrusting growth and a large part of the outer horny layer, or periostracum, of the shell.

After drying, the clean abraded shells are ground to a fine gray powder. This powder is bagged and shipped to Toba, where it is treated with phosphoric acid. It is then sold to drug houses where it is prepared for retailing.

3. Fertilizer and Other Products

At some farms, when facilities for cleaning and grinding the shell are not available, the shell is burned and made into quicklime. At other farms it is coarsely ground and bagged at fertilizer and chick feed. A small portion of the better shells are selected for costume jewelry, mother-of-pearl trinkets and inlays, buttons, facing for collar-buttons, and many other minor uses.

4. Canned Pearl Oysters

When the soft parts of the oyster are removed, the adductor muscle remains attached to the shell. This small piece of firm, white meat, about 1.5×0.5×0.5 centimeters, is removed by a sharp knife and transferred to the canning plant where it is prepared and canned by methods similar to those used for the edible oyster. The quantity of the pearl oyster meat canned is small, only a few metric tons a year, and it never was marketed. This method of utilization was introduced by Mikimoto, who used the product as complimentary presents. The meat reportedly has fine flavor and quality.

ORGANIZATION OF A PEARL FARM

1. Personnel

Pearl culture farms vary greatly in size and organization, from the small family units employing at most to the large Mikimoto establishment which, at the peak of its activity, operated 11 separate farms and employment more than 3,000 persons.

The industry depends largely on female labor, although male employees usually occupy key supervisory positions and operate mechanical equipment. Skilled male personnel supervise the general activities of the farm, grade and appraise the products, conduct research and experimental work, and form the greater part of the administrative staff. Semi-skilled male laborers operate the motor launches, shell grinding machinery, and vehicles. Unskilled males do general maintenance work and conduct the repair rafts, culture, rearing, and spat-collecting cages, barges, and building.

Skilled female personnel do the nucleus insertion operation, spot and drill the pearls, and match and grade the pearl for necklaces. They also are the divers who gather the oysters from the sea bottom. Unskilled female laborers sort and clean the oysters, transfer the young oysters from the spat collectors to the rearing cages, and do general light works.

Training of personnel to perform the nucleus insertion operation, upon which the production of the pearl ultimately depends, requires about three months, but full proficiency is attained only after 12 to 18 months of training and operating.

Isowa Pearl Farm is an example of a good, comparatively small pearl farm. This organization has 10 permanent employers, mostly young women, and employs an additional 10 persons during the busy seasons. Under maximum conditions of operation, this farm produced 330 pounds of pearls annually from 400,000 pearl oysters. However, the present average annual production is only about 80 pounds of pearls.

2. Records of Operations

Documentary records of all operations are kept by culture pearl farmers, but the most complete system so far devised appears to be that used by Mikimoto Pearl Farm. Ordinary bookkeeping methods suffice for the general activities of the farm, but a particularly ingenious and precise system has been developed to record the results of the nucleus insertion operation.

Each technique in the nucleus insertion laboratory is given a number of terracotta blocks, 8×8×2 centimeters. Deeply engraved on each block are a distinguishing Japanese character and three numbers. After the technician operates on the 50 to 60 oysters in a culture cage complement, one of these identifying block is placed in the cage with the

oysters.

The recording clerk enters on a daily record sheet the position of the cage on the "convalescence" raft. After the required period has elapsed, the cage is lifted and the oysters examined. The number of live oysters is noted in the second column on the original data sheet. The cage is then transferred to the permanent culture raft, and its position noted on the "position" sheet. Thereafter, at each cleaning and inspection, the number of live oysters within the cage is noted in the specific column on the original data sheet, and at the end of the culture period, the yield of pearls is noted.

From these sheets, at any given time, a tally of the living oysters can be obtained by vertical summation, and at the same time as accurate check on the skill and production of each technician is maintained.

CONTROL OF THE INDUSTRY

As valuable and easily negotiable of commerce, the Japanese culture pearls were a potential avenue for illegal trading. Measures were taken by the Occupation early 1946 to prevent unauthorized trafficking and to maintain the sale of pearls and pearl products within the normal channels of legitimate commerce.

On 14 January 1946 a memorandum (Appendix B) was sent from the Supreme Commander of the Allied Forces to the Japanese Government, requiring a complete inventory of commercial stock of pearls and prohibiting all transactions except those under current contracts. The directive required that all future transaction must receive written authorization of General Headquarters.

The trade in culture pearls and pearl jewelry was further canalized and brought under stricter supervision by a directive (Appendix C) dated 13 April 1946, which stipulated the quantities of pearl products to be supplied weekly to the Army Exchange Services. A later directive (Appendix D) of 17 May 1946 prohibited all further transactions by retail shops and accurately defined the authorized channels of commerce in culture pearls and pearl jewelry.

Release and sale of pearls was covered by a directive dated 30 December 1946 (Appendix E), which was further clarified by two subsequent directives (Appendixes F. G).

PRODUCTION STATISTICS

The development of the culture industry lacked any over-all control until its wartime consolidation in 1943. Consequently, available statistics are few. Data were collected from time to time for different purposes and on various bases, and the majority therefore are not susceptible of analysis.

The production of pearls reached its peak in 1938 with total of 10,883,512. Mie Prefecture, the center of the industry, also reached its peak in 1938 with a production of 7,068,674 pearls, which represented 64.9 percent of total pearls produced that year.

The production data (Table 7), submitted by the Ministry of Agriculture and Forestry, show the decline of the industry in the years immediately preceding and during World War II. Data on the year prior to 1926 are not available.

Estimates of stock on hand (Table P, page 67) were prepared from the data compiled is compliance with a Supreme Commander for the Allied Power directive (Appendix B) requiring the Japanese to inventory pearl stocks. The complication fails to specify whether the "Stock on Hand" data relate to harvested pearls held by the companies and farmers or whether they include an estimate on the potential wealth currently under cultivation.

Data relating export (Table Q, page 67), submitted by the Nippon Pearl Export Ass., are based on records and estimates collected by the association from its numbers. As the association was not formed until April 1943, the accuracy of the data referring to earlier years cannot be guaranteed.

TABLE P. JAPANESE CULTURE PEARLS: STOCK ON HAND AND 1946 PRODUCTION

Type	Stock on Hand (grams)	1946 Production (grams)	Value (Yen)
Cultured pearls	1,687,000	0	15,750,000
Pearl medicine	157,000	67,500	4,800,000

SOURCE: Ministry of Commerce and Industry

TABLE Q. EXPORT VALUE OF JAPANESE CULYURE PEARLS, 1935-45 (Yen 1,000)

Year	Medical		Ornamental		Total	
	Actual	Corrected *a	Actual	Corrected *a	Actual	Corrected *a
1935	950	950	6,880	6,880	7,830	7,830
1936	1,010	1,263	7,110	8,888	8,120	10,150
1937	1,200	2,000	7,660	12,767	8,860	14,767
1938	1,120	2,800	7,300	18,250	8,420	21,050
1939	960	2,743	5,010	14,314	5,970	17,057
1940	910	3,640	2,850	11,400	3,760	15,040
1941	820	3,280	1,630	6,520	2,450	9,800
1942	400	800	250	500	650	1,300
1943	470	568	480	600	950	1,168
1944	860	573	630	420	1,490	993
1945	820	328	390	156	1,210	484

*a Corrections are based on the following table of currency fluctuation;

Year	Index	Year	Index	Year	Index
1935	100	1939	35	1943	80
1936	80	1940	25	1944	150
1937	60	1941	25	1945	250
1938	40	1942	50		

SOURCE: Nippon Pearl Export Assn

Data shown in these tables, as submitted by the available sources, are seriously at

variance. However, they are included in this report because each table, within itself, demonstrates the trend of this unique industry under the import of the conditions existing while Japan was preparing for war, and through the war years.

FRESH WATER PEARL CULTURE

The history of fresh-water pearl culture in Japan goes back to 1928 and is confined to a single locality, the Hirako reservoir, an arm of Biwa-ko at Shima village in Shiga Prefecture (Figure 20). Dike and a low dam across a narrow-mounted bay hold the water of this 25-acre reservoir at a constant level three feet above the level of the lake. The water level of the lake proper fluctuate several meters annually because of hydroelectric usage.

One of the first to investigate fresh water pearl culture on this site was Masayo Fujita, the early associate and friend of Nishikawa. He was succeeded by several other investigators, including at one time members of Mikimoto staff. The results obtained by these early investigators were considered unsatisfactory.

Since 1945 the work has been conducted by Seiichiro Uda, President and Director of Shinko Pearl Co., Ltd (Shinko Shinju KK), with Keisaburo Sakiyashi as the chief technician. Shinko Pearl Co. has its retaining pens in the Hirako reservoir, and its three buildings are located on the shores of the reservoir. One building is the office and laboratory; the others are warehouses. The nine employees include the chief technician and six operators, and four of whom are women and two men. The retaining pen is a compartmented bamboo-fenced area of about 2 1/2 acres, with water varying from one to two meters in depth over a sand-mud bottom. In one large section of this pen the clams are held from the time they are brought in until they are removed for the graft-insertion. In other compartments the operated clams are held three years until removed for pearl recovery.

Biwa-ko, the largest fresh water lake in Japan, lies wholly within Shiga Prefecture. It is roughly triangular in shape, 38.4 miles long by 13.2 miles at its point of great width, and its apex is directed southwestward. The lake's area is 166,725 acres, and the shoreline totals 141 miles. The southern third is narrow, with a maximum depth of five meters. The deposit of the lake is in the northern third, where 95 meters of water are found. The bottom is rock, sand, or mud, and large areas of a sand-mud mixture are found in shallow waters. This

combination constitutes the ideal habit for the fresh water clam, *Hyriopsis Schlegelii* (Martens), the *ike-chogai* of the Japanese, which is the only species used for fresh water pearl culture (Figure 21). This indigenous clam is limited to Biwa-ko, where it is one of 42 native mollusk species. A hydrographic survey of the lake, not yet completed, shows local abundance of this clam correlated with a bottom type of sand-mud mixture.

The life history of *Hyriopsis schlegelii* is unknown at present, but as artificial propagation of the species is still unnecessary, this subject is of minor importance now. However, knowledge of the clam's life history will increase in importance in the near future, as over-fishing and other causes reduce clam stock and make artificial propagation necessary. The ecology and life history of this fresh water species are now being studied at Shiga Prefecture Fisheries Experimental Station at Hikone.

Ike-chogai is a large, slow growing species which requires from six to seven years to reach an operable size of more than 130 millimeters. A fully grown individual measure about 240×132 millimeters and is 60 millimeters thick.

The slow growth rate of the species is indicated by these data:

TABLE R. GROWTH RATE OF *Hyriopsis schlegelii*

Length of shell (mm)	Age of Clam (years)
77	3
128	6-7
178	13

SOURCE: Shinko Pearl Co

The outside of the shell is dark greenish-black, usually showing signs of chemical erosion near the umbo. The inside is lines with mother-of-pearl which has beautiful color and luster but is often somewhat discolored near the mantle edge.

The clam feeds entirely on phytoplankton, despite the fact that the surrounding water is found to contain 60 percent zooplankton as compared with 40 percent phytoplankton. Young

shells are found abundantly in water from one to two meters deep, and the clams move slowly toward deeper water as they grow. Spat is found only in shallow water in August. The clams occur most abundantly in the southern third and eastern half of the lake at depth of from 2 to 30 meters. The optimum depth is four to five meters.

The mollusks are gathered by local fishermen who use a form of bottom trawl net fitted with a rake across the floor of the net mouth. Divers who have investigated the clam in its native environment report that during the winter, starting October, the mollusks lie one-third embedded in the bottom material, and during August they are entirely buried. The clams are gathered from October to April and are brought to the pearl farm where they are purchased and placed in the retaining pen. Seventy-five percent of the total annual catch is taken during April. Graft insertion operations are suspended during June and July, the spawning period.

No exact data are available for the annual catch of this clam, as it is included among large catches of another edible clam, *Cristaria spatiosa.* That both species are decreasing in abundance is indicated by the fact that in 1947 the catch of the two species totaled only 1,816pounds compared with the 1943 catch of 21,186 pounds. This decline is attributed to overfishing and to the fluctuating water level of the lake for hydroelectric purposes.

Although the principle of the pearl sac is the basis for the production of freshwater culture pearls just as for the marine culture pearls, the practical details of its application are quite different.

In the early fresh-water pearl experimentation, the most serious problem encountered was the high death rate, more one-half of the clams dying within a few days after the graft operation. A second difficulty was that the introduction of a shell nucleus resulted in a pearl of poor quality, wholly unmarketable. As the clam was very large, large nuclei (seven millimeters) were introduced in order to get large pearls, but the pearls produced were dark in color, poor in shape, and lacked luster. Investigation showed that despite the large size of the clam, its internal anatomy is so complicated by a long, twisting intestine that there is not space in the connective tissue to accommodate these large nuclei without infringing on the intestine, with resultant poor color in the pearl. Less than one percent of the pearls proved to be of marketable quality. Thus the introduction of large nuclei had to be abandoned. The following method now is practiced:

The clams are gathered from the retaining pen and brought to the laboratory. The valves are forced open by careful insertion of a speculum similar to that used on the oyster (Figure 16E) and are either held open by the speculum or pegged. The mantle is separated carefully from the shell with a special spatula (Figure 22). Avoiding the deeply pigmented edge, the technician uses a sharp scissors to cut a strip of tissue 40×5millimeters from the surface of the mantle facing the shell, this operation involving about one-half of the thickness of the mantle tissue. The strip is placed on a wet wooden block and cleansed, and cur into four millimeter squares. The mantle from which the strip has been cut is carefully separated from the gills and other body contacts, and from three to four pieces of graft tissue are inserted into the gonad, each square in a different place. Care is taken to avoid connective tissue and its involved intestine. The clam then is reversed, and the graft cutting and insertion are repeated on the opposite side. This each clam accommodates from six to ten grafts. No cut is made in inserting the grafts: the squares are simply introduced into the gonad by means of a special forceps (Figure 22). No nucleus is introduced: the graft tissue is the only foreign matter inserted. A skilled technician can operate on about 100 clams a day.

The clams are returned to the retaining pen where they remain for the next three years. They are then gathered and returned to the laboratory, and pearls are recovered. The clam themselves are used for food but are reported to be tough.

Almost every introduced graft square produces a pearl. As no inorganic nucleus is introduced, these pearls differ fundamentally from the cultured marine pearls. However, both are cultured pearls. The average non-nucleated pearl produced at the end of three years' growth is elongated and irregular and measures about six by three millimeters. Both color and luster are beautiful, but the shape leaves much to be desired.

With improvement in operating techniques, the number of clams which survive - and hence the number of pearls is produced – has improve greatly:

TABLE S. SURVIVAL OF FRESH-WATER CLAMS AFTER OPERATION

Year of Operation	Number of Clams Operated	Number of Clams Surviving	Number of Pearls Expected *a
1946	50,000	2,000	16,000
1947	70,000	3,000	24,000
1948	50,000	40,000*b	320,000*b

*a Estimated on the basis of an average of eight per clam, three years later

*b Estimated on the basis of first six-month survival

SOURCE: Shinko Pearl Co.

Pearls produced on the Shinko farm made into necklaces locally. These are single, double, or intertwining strands.

The fresh-water pearl necklaces also may be allocated for sale to the Occupation Forces and for export to the United States. [*4]

[*4] Negotiations under way in October 1948

GLOSSARY

1. Technical Terms

The following list of technical terms is offered as an aid to the readers. Each term is defined in the sense in which it is used in this report

Adductor muscle	Small but powerful muscle attached to both valves of a bivalve mollusk shell. Contraction of adductor muscle closes the shell.
Alical flagella	Long, slender filament of the veliger larva.
Aragonite	Crystalline form of calcium carbonate, $CaCO_3$. Contains 44 percent CO_2 and 56 percent lime.
Baroque pearl	Pearl of irregular shape.
Bilateral symmetry	Body form in which the right and left sides are mirror images of each other.
Bivalve	Mollusk having a two-valved shell such as oysters and clams.
Blastula	Developmental stage of an individual organism in which a single layer of cells surrounds a simple body cavity. Follows the morula stage.
Blister pearl	Semispherical pearl attached to the shell. Not a free pearl.
Byssus	Thread-like attachments secreted by the young oyster which fix it to some solid object.
Cell division	Method by which living tissue grows; cell reproduction or multiplication. A single cell divides to make two cells.
Collectors	Solid objects such dead shells, bamboo stalks, or wire forms placed in the sea where oysters spawn to afford removal surface for the fixed attachment of the spat.
Conchiolin	Protein (albuminoid) material ($C_{32}H_{48}N_2O_{11}$) constituting the organic basis of mollusk shells, especially of mother-of-pearl.
Connective tissue	Tissue that supports or binds together tissues within the body.
Cultured pearl	Pearl formed around the nucleus artificially introduced into the mollusk.
Dinoflagellates	Group of minute, marine, free-swimming plant organisms characterized by the presence of two flagella near the middle of the body. Usually the dominant organisms in red tide.

Dorsal	Upper (back) surface.
Epithelium	Sheet of cellular tissue forming a covering surface.
Gastrula	Development stage in which two layers of cells surround a body cavity. Follows the blastula stage.
Gland	Single cell or a group of cells which secrete or excrete a substance, usually a liquid.
Gonad	Sexual gland; ovary in female, testes in male.
Graft	Piece of living tissue cut from the mantle of an oyster and inserted into another oyster. If successful, the introduced graft tissue establishes itself and grows, producing the pearl sac which in turn secretes the nacre around the nucleus, thus producing a pearl.
Hinge	Movable joint between the two valves of the shell.
Key	Wood or bamboo wedge used to keep the valves of the oyster apart during the operation of nucleus insertion.
Lamellar	Composed of thin layers or scale-like plates.
Ligament	Chitinous material which covers the hinge and binds the two valves of the shell together. Chemically similar to conchiolin.
Luster	Quality of shining by reflected light. Sheen or gloss on the surface of a pearl or on the inner face of the shell.
Mantle	Outer folds of the body wall of the oyster which line the valves of the shell and which bear the secreting glands.
Mollusk	Soft-bodied salt- or fresh-water animal living within a calcareous shell which is the product of specialized cells in its mantle. In this report, oyster, clams, and snails.
Morula	Solid, more or less globular or mulberry-shaped mass of living cells. Very early, pre-blastula stage in the development of the individual.
Mother-of-pearl	Iridescent inner lining of the shell. Nacre
Nacre	Iridescent inner layer of the shell or the body of the pearl. Consists chiefly of $CaCO_3$ deposited in thin layers with some organic matter such as conchiolin . Mother-of-pearl.
Natural pearl	Pearl usually formed around some minute foreign body such as a grain of sand or parasite introduces into the oyster by natural processes while in the sea.
Nucleus	In natural pearl, may be a parasite, a grain of sand, or other small object around which the pearl is formed. In culture pearl, spherical body cut from a clam shell or other material, inserted into the body

	of the oyster by hand, and around which the pearl is deposited.
Ovum	Female sex cell, the egg.
Parenchyma	Essential tissue of a gland.
Pearl	Product of a bivalve mollusk, producing usually around a nucleus of some sort within the body of the host.
Pearl sac	Tissue surrounding the developing pearl. Secretes the nacre and deposits the material of the pearl.
Periostracum	Horny outer layer of the shell. Usually brown in color.
Phytoplankton	Plankton consisting of microscopic plants.
Plankton	Minute floating animal and plant life found in water.
Polar body	Minute cell which separates from the maturing egg in the early stage of development.
Proliferation	Growth of a tissue by cell division. Cell multiplication.
Sexual dimorphism	External sexual characteristics of the body.
Siphon	Opening through which the oyster sucks in water (inhalant siphon) or expel water (exhalent siphon).
Spat	Veliger larvae which have attached themselves permanently to fixed objects.
Spermatozoa	Active male sex cell.
Tissue	Layer or mass of specialized cells having a common function such as muscle tissue or nervous tissue.
Umbo	Prominence or shoulder of the valve of the shell near the hinge. First part of the shell to be formed.
Veliger	Free-swimming larval stage characterized by long dorsal (apical) filaments and the beginning of shell development. Stage following the trochophore and preceding the spat stage.
Ventral	Bottom or belly surface.
Zooplankton	Plankton consisting of microscopic animals.

2. Conversion Factors

a. Japanese Units of Measurement

Japanese		English
1 kan	-	8.267 pounds
1 bu	-	0.119 inch

1momme	-	0.132	ounce

b. Metric Units of Measurement

1 metric ton	-	1.102	short tons
		2,205	pounds
1 kilogram	-	2.205	pounds
1 gram	-	0.035	ounce
1 meter	-	3.281	feet
1 square meter	-	10.764	square feet
1 centimeter	-	0.394	inch
1 millimeter	-	0.039	inch
1 micron	-	0.000039	inch

3. Japanese Generic Terms

-gai	Oyster	-shima (-jima)	island
-ko	lake	-shinju	pearl
-nada	sea	-shinju-gai	pearl oyster
-retto	island	-wan	bay

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APPENDIX A

MISE – NISHIKAWA PATENT APPLICATIONS

In an effort to get all available facts on who actually discovered the method for producing spherical culture pearls, a search was made for data on Mise – Nishikawa patents. One of these two men must be recognized as the original inventor of the process. Investigation finally unearthed an important document, originally a possession of Mise family and now in the possession of Mr. Masayo Fujita. This document is the decision of the Judge of Patents, dated 20 February 1908, regarding both the Mise and Nishikawa applications, which came to the patent office only five months apart. In it the Mise application is denied. This document is worth preserving and is translated as follows:

Judgment of Patent Infringement

Infringement:	No. 259
Subject:	Formation of Culture Pearls
Application for patent involved:	No. 38318 (13 May 1907)
Applicant:	Tatsuhei Mise, Mie Prefecture
Application for patent involved:	No. 40219 (23 ctober 1907)
Applicant:	Tokichi Nishikawa, Tokyo

Description

The first clause of application No. 38318 (Mise) is understood to be a claim for the patent on a method of pearl nacre deposition by making a hole in the epidemics of a living shell's mantle and inserting a few epithelial cells directly into the connective tissue of the same shell, together with a nucleus. The shell thus operated, on its release in the sea will deposit nacre.

In the second clause of the above application, two pearl oysters are prepared for the operation. Epithelial cells removed from one mantle and fixed with a nucleus are placed in the connective tissue of the second shell through a cut in the mantle. Pearl nacre will be coated around the nucleus of the latter if left in the sea.

On the other hand, Application No. 40219 (Nishikawa), which also requests the patents, deals in its third clause with a technique as follow;

Taking epidemic out of the mantle of a pearl oyster, insert it with an adequate nucleus in a tissue of the same shell or other shell to have nacre deposited on the nucleus. In the fifth clause of the same application a nucleus is rubbed on the epidermis of the mantle to make the cells adhere to the nucleus. Then the nucleus is put in a tissue of the same shell or other shell in order to have nacre deposited.

Upon scrutiny of these applications made by the different parties, it is revealed that: while the former (Mise) will insert mantle epithelium together with a nucleus into the connective tissue of the shell, the latter (Nishikawa) designate the part of the shell where the materials are to be inserted loosely naming it "a tissue" without limiting it as the connective tissue.

In applying the patent law in the present issue, we find it very difficult to discriminate the "connective tissue" from "a tissue" mentioned by the latter (Nishikawa). And this leads us to an opinion that it practically makes little differences whether the matter points of both inventions being concerned with one and the same thing.

With this in mind, we are to give herewith a decision on this issue that reads as follows:

The patent application No. 38319 (Mise) concerning an invention on the method of cultured pearl formation is recognized to make an infringement on the object of the application No. 40219 (Nishikawa).

February 20, 1908 Signed: Ryo Ono
Judge of Patent

Following this adverse decision, Mise filed an appeal which resulted in the second decision reading as follows:

Supplement

On 23 October 1907, Tokichi Nishikawa submitted his invention on culture pearl formation for the issue of the patent by application N0, 40219, in which he claimed the date for the completion of his invention to be 20 February 1899.

Some months prior to this application, Tatsuhei Mise also had applies for the patent by application No. 38318, which was rejected. According to the patent law then existing, the first inventor on any matter would be given the credit for the patent.

23 July 1908

Signed: Hajime Ishikawa
Osamu Oda
Judge of Patent

This decision terms the Mise patent application an "infringement" on a patent not yet by granted nor even applied for when the "infringing" application was filed.

In the original decision the Judge opined that it makes little difference whether the point of insertion of the nucleus is designed at "connective tissue" (Mise) or as "a tissue" (Nishikawa). Unfortunately for Mise, the judge was not a biologist, for that one word "connective" in the Mise application is the key to the success or failure of the entire operation. Mise was explicit, Nishikawa evasive, in the information furnished in the application.

Although Nishikawa's application followed that of Mise by more than five months,the Mise's application was denied because Nishikawa claimed in his application that he had completed his invention on "20 February 1899". The only evidence of this claim is the statement of the patent judge, as the original application apparently no longer exists. At the date Nishikawa allegedly completed his invention, 20 February 1899, he was not yet 25 years old. He was graduated from zoology course of Tokyo University on 10 July 1897, and one week later was appointed technical official (gishu) of the Ministry of Agriculture and Commerce and assigned to Bureau of Fisheries. Therefore he had had only 19 months in which to "complete" his invention as of 20 February 1899. Yet he resigned from Bureau of Fisheries in 1905 (Ogushi 1938) to devote his time to research on pearls. Two years later, on 23 October 1907, he applied for a patent on his method of spherical pearl culture.

Although three decisions may be in full accord with the then existing Japanese patent laws, the judgment of history is not bound by these laws, and the reader can decide for himself who actually discovered the method for the culture of spherical pearl. All he needs to do is to answer this question: is it likely that Nishikawa, knowing he had in his hand the key to the fabulous fortune, would have delayed for nine years, eight months, and three days in

safeguarding his rights to his invention?

Although the Mise application was denied, the Nishikawa application, on the other hand, was not approved. This brings up another point. If Nishikawa had a clear claim to his invention, why did he sign an agreement of joint ownership of the Mise-Nishikawa methods with Mise on 2 September 1908? Nishikawa's application was not granted until 20 June 1916, and then not until 50 days after Mikimoto's application of 16 October 1914 had been granted on May 1916. According to the Report of the Imperial Association for the Encouragement of Inventions (1926), 1913 is the date given for the first Mikimoto spherical pearl production.

The writer believed that Mise was the discoverer of the method of producing spherical culture pearls and that Mise produced the first spherical culture pearl.

Appendix B

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR THE ALLIED POWERS

MEMORUNDUM FOR: THE IMPERIAL JAPANESE GOVERNMENT

THROUGH : GENERAL LIASON OFFICE, TOKYO

SUBJECT : Inventory and Authorized Sale of Polished and Unpolished, both Natural and Cultured Pearls.

1. It is directed that the Imperial Japanese Government take immediate action to prohibit all transactions involving the sale or transfer of polished and unpolished pearls, both natural and cultured, loose or strands, or in miscellaneous jewelry, except:

a. Above described pearls intended for sale in the United States Army Exchange Central Purchasing Office in fulfillment of written contracts in effort prior to the issuance of the directive.

b. Above described pearl stocks now in the hand of retail establishments, provided such

stock do not exceed the quantity of pearls disposed of by the individual retail establishment during the three months preceding the issuance of this directive.

2. Future contracts or transaction will be specially authorized in writing by this Headquarters only upon approval of prior written requests submitted through the Central Liaison Office. Said written request to indicate:

a. Owner of pearls
b. Source of pearls
c. Location of pearls
d. Description of pearls
e. Terms of transaction

3. An inventory of all Japanese-owned pearls, including pearls owned by the Imperial Japanese Government or its agencies, as described in paragraph 1 will be made out in triplicate, and will be taken under your direction not later than 20 January 1946....The inventory will not include:

a. Present inventories of individual retail establishments, provided such inventories do not exceed the quantity of pearls disposed of by such retail establishments during the three-months period proceeding the issuance of this directive.

b. Pearls held and owned by private individuals or firms for their normal or personal use.

4. The master inventory, together with the original and duplicate copy of each individual inventory as referred to in paragraph 3, will be submitted to this Headquarters not later than 5 February 1946, and will contain the following information:

a. Total quantity of loose cultured pearls now hand.

(1) Polished
(2) Unpolished

b. Total quantity of loose natural pearls now on hand.

(1) Polished

(2) Unpolished

Required information under paragraph 4 (a and b) to be listed as follows:

(1) Owner
(2) Location
(3) Quantity
(4) Estimated wholesale Yen value

c. Total quantity of pearl strands and miscellaneous jewelry items, such as necklaces, bracelets, rings, pins, and miscellaneous pieces to be listed as follows:

(1) Owner
(2) Location
(3) Quantity
(4) Description (quantity and size of pearls)
(5) Estimated whole Yen value

5. The Imperial Japanese Government will, upon receipt of this directive, notify this headquarters in writing of action taken to accomplish with the terms of this directive.

FOR THE SUPREME COMMANDER:

/s/ H. W. Allen
/t/ H. W. Allen
Colonel, A. G. D
Asst Adjutant General

APPENDX C

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR THE ASLLIED POWER

AG 091.33 (13 Apr 46) ESS/IE
(SCAPIN 981-A)

APO 500
13 April 1946

MEMORUNDUM FOR: THE IMPERIAL JAPANESE GOVERNMENT

THROUGH : Central Liaison Office , Tokyo

SUBJECT : Release of Pearls

1. It is directed that the Imperial Japanese Government will immediately cause to be made available to the Army Exchange Central Purchasing Office, each week three thousand five hundred (3,500) strands of cultured pearls, three hundred (300) matched sets of three (3) cultured pearls each, and such quantities of pearl rings, pins, earrings, and other pearl articles as may be requested. These pearls will be delivered to the Army Exchange Central Purchasing Office, 4th floor, Hattori Building, Ginza, Tokyo by noon Tuesday of each week unless otherwise directed

2. These pearls will be submitted according to the following schedule which will serve as a guide as to values, quantities, and weights, to the Army Exchange Central Purchasing Office from stocks, as reported in inventories received in compliance with Memorandum AG 091.33 dated 14 January 1946 and presently held by, but not limited to, the following companies:

Japan Cultured Pearl Combine,
N0.4 – 4 chome, Ninomiya-cho, Fukiai-ku, Kobe

Japan Pearl Export Association,
5/18 – 4 chome, Nakayamate –dori, Ikutaku, Kobe.

S. Takashima,
135 – 3 chome, Egoyamacho, Hyogo-ku, Kobe.

Kitamura Shoten,
173 Kamisakabe, Sonoda-mura, Kawabe-gun, Hyogo-ken.

K. Mikimoto,
No. 2 – 4 chome, Ginza, Tokyo.

Mie-ken Shinju Shisetsu Kumiai,
Mie-ken

Koeki Eidan,
Sundry goods Dept, Ebara, Ebara-ku, Tokyo

Schedule:

Value		Quantity		Avg Weight	
¥ 120.00	per strand	175	strands	3.0	momme
200.00	〃	150	〃	3.0	〃
250.00	〃	325	〃	3.0	〃
300.00	〃	500	〃	3.0	〃
500.00	〃	625	〃	3.0	〃
600.00	〃	275	〃	3.4	〃
750.00	〃	350	〃	3.4	〃
800.00	〃	200	〃	3.4	〃
900.00	〃	125	〃	3.8	〃
1,000.00	〃	275	〃	4.0	〃
1,100.00	〃	125	〃	4.0	〃
1,200.00	〃	75	〃	4.1	〃
1,250.00	〃	50	〃	4.1	〃
1,500.00	〃	100	〃	4.9	〃
2,000.00	〃	75	〃	5.0	〃
2,500.00	〃	75	〃	5.0	〃
150.00	per set of pearls in individual boxes	100	sets		
300.00	〃	100	〃		
500.00	〃	100	〃		

3. Terms and condition of sales will be determined by direct negotiations between the suppliers and the Army Exchange Central Purchasing Office.

4. This is not to be construed as a revision of any of the restrictions referred to in Memorandum AG 091.33 dated 14 January 1946, and all transactions involving the sale or

transfer of pearls and pearl articles except those mentioned in paragraph 1 b therein are prohibited.

FOR THE SUPREME COMMANDER:

/s/ J. W. Mann
/t/ for B. M. Fitch
Brigadier General, AGD,
Adjutant General

APPENDIX D

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR THE ALLIED POWERS

AG 410.4 (17 May 46) ESS/IE
(SCAPIN) 963

APO 500
17 May 1946

MEMORANDUM FOR: THE IMPERIAL JAPANESE GOVERNMENT

THROUGH : Central Liaison Office, Tokyo

SUBJECT : Restriction on sale of Pearls and Pearl Articles

1. References:

a. Memorandum for the Japanese Imperial Government, file AG 091.33 (14 Jan 46) ESS/IE, (SCAPIN 593), subject: "Inventory and Authorized Sale of Polished and Unpolished, both Natural and Cultured Pearls", dated 13 January 1946.

Memorandum for the Imperial Japanese Government, file AG 091.33 (13 Apr 46) ESS/IE, (SCAPIN 981-A), subject: "Release of Pearls", dated 13 April 1946.

2. Paragraph 1 b of reference 1 a above is hereby rescinded and no further transactions by retail establishments are permitted.

3. Sales and transactions will be limited to those authorized by references 1 b above or

as approved under the provisions of paragraph 2 reference 1 a.

4. The Imperial Japanese Government is directed to establish immediately adequate regulations and penalties to insure strict compliance with the provisions of this directive. Three copies each of the original and the transaction of said regulations and penalties will be submitted to General Headquarters, Supreme Commander for the Allied Powers upon promulgation.

FOR THE SUPREME COMMANDER

/s/ B. M. Fitch
/t/ B. M. Fitch
Brigadier General, AGD
Adjutant General

APPENDIX E

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR YHE ALLIED FORCES

AG 386.7 (30 Dec 46) ESS/FT
(SCAPIN 1428)

APO 500
30 December 1946

MEMORANDUM FOR: IMPERIAL JAPANESE GOVERNMENT

THROUGH : Central Liaison Office, Tokyo

SUBJECT : Release and Sale of Pearls, Natural and Cultured, and Articles Containing Pearls.

1. The following memoranda to the Imperial Japanese Government from General Headquarters, Supreme Commander for the Allies Forces are rescinded:

a. File AG 091.33 (14 Jan 46) ESS/IE, (SCAPIN 593), dated 14 January 1946, subject: Inventory and Authorized Sale of Polished and Unpolished, both Natural and Cultured Pearls.

b. File AG 091.33 (13 Apr 46) ESS/IE. (SCAPIN 981-A), dated 13 April 1946, subject: Release of Pearls.

c. File AG 410.4 (17 May 46) ESS/IE, (SCAPIN 963), dated 17 May 1946, subject: Restriction on Sale of Pearls and Pearl Articles.

2. It is directed that the Imperial Japanese Government take immediate action to prohibit all transactions involving the sale or transfer of Natural or Cultured Pearls and Pearl Articles except:

a. Transactions involving the sale to or for the Central Purchasing Office, General Headquarters, Army Forces, Pacific.

b. Transactions specially authorized in writing by this headquarters. Requests for authorization will be submitted in writing through the Central Liaison Office. These requests are to indicate;

(1) Owner of pearls
(2) Source of pearls
(3) Location of pearls
(4) Description of pearls
(5) Intended purchaser of pearls
(6) Terms of transaction

3. It is directed that the Imperial Japanese Government will make available each week to the Central Purchasing Office, General Headquarters, Army Forces, Pacific, Shibusawa Building, 3-1 chome, Kayaba-cho, Nihonbashi-ku, Tokyo, the following:

a. Three thousand (3,000) strands of cultured pearls of which a minimum of fifteen hundred (1,500) strands will be as follows:

Value	Quantity	Average Weight
¥ 300	200	3.0 mme
400	150	3.0 〃
600	225	3.5 〃

	700	200	3.5 〃
	1,000	250	4.0 〃
	1,200	150	4.1 〃
	1,500	150	4.9 〃
	2,000	150	5.0 〃
Over ¥2,000			
but under	3,000	25	5.0 〃

b. Matched sets, three (3) pearls per box as follows:

150	100	3.0 mme
300	100	3.0
500	100	3.5

c. Such individual pearls as the Central Purchasing Office may order for rings, jewelry, etc.

4. Terms and condition of sales will be determined by direct negotiation between the suppliers and the Central Purchasing Office.

5. After inspection, any pearls not desired by Central Purchasing Office for sale through Authorized Exchange systems will be designated for export through the Board of Trade (Boeki Cho), Ministry of Commerce and Industry.

6. The Imperial Japanese Government is directed to establish adequate procedures and regulations and penalties to insure strict compliance with the provisions of this directive. Three copies of each of the original and the translation of said regulations, and procedures and penalties will be submitted to General Headquarters, Supreme Commander for the Allied Powers upon promulgation.

FOR THE SUPREME COMMANDER

/s/ R. Y. Hersey
/t/ For John B. Cooley
Colonel AGD,
Adjutant General

APPENDIX F

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR THE ALLIED POWERS
APO 500

AG 386.7 (21 Sep 48) ESS/FTC 21 September 1948

MEMORANDUM FOR: JAPANESE GOVERNMENT

SUBJECT : Release and Sale of Pearls, Natural and Cultured and Articles Containing Pearls.

1. Memorandum for the Japanese Government from General Headquarters, Supreme Commander for the Allied Powers, file AG 386.7 (30 Dec 46) ESS/FT, SCAPIN 1428, 30 December 1946, subject: Release and Sale of Pearls, Natural and Cultured, and Articles Containing Pearls, is herewith rescinded.

2. It is difficult that the Japanese Government take immediate action to prohibit all transactions involving the sale or transfer of natural or cultured pearls and pearl articles except:

a. Transactions for export in acceptable foreign exchange. For purpose of this SCAPIN, sales to Central Purchasing Office are classified as exports.

b. Domestic transactions specifically authorized in writing by this headquarters. Requests for authorization will be submitted in writing to General Headquarters, Supreme Commander for the Allied Powers. These requests are to indicate:

(1) Owner of pearls
(2) Source of pearls
(3) Location of pearls
(4) Description of pearls
(5) Intended purchaser of pearls
(6) Purpose of transaction

(7) Terms of transaction

3. All export transactions will be made in accordance with established export procedure in force at the time of the transaction.

4. The Japanese Government is directed to establish adequate procedures, regulations and penalties to insure strict compliance with the provisions of this directive. Three copies of the original and the transaction of said regulations, procedure and penalties will be submitted to General Headquarters Supreme Commander for the Allies Powers, upon promulgation.

FOR THE SUPREME COMMANDER:

/s/ A. J. Rehe
/t/ for R. M. Revy
Colonel AGD
Adjutant General

APPENDIX G

GENERAL HEADQUARTERS
SUPREME COMMANDER FOR THE ALLIED POWER
APO 500

AG 386.7 (21 Sep 48) ESS/FTC 29 October 1948
SCAPIN 1935/1

MEMORANDUM FOR: Japanese Government

SUBJECT : Release and sale of pearls, Natural and Cultured and Articles Containing Pearls.

1. Reference is made to Memorandum for the Japanese Government from General Headquarters, Supreme Commander for the Allied Powers, AG 386.7 (21 Sep 48) ESS/FTC, SCAPIN 1935, dated 21 September 1948, subject: Release and Sale of Pearls, Natural and Cultured and Articles Containing Pearls.

2. Reference memorandum is hereby amended, by deleting subparagraph a of paragraph 2, thereof, and by substituting therefore the following:

a. Transactions for export are acceptable foreign exchange. For the purpose of this SCAPIN, the following shall be deemed to be transactions for export in acceptable foreign exchange under sub-paragraph:

(1) The sale by a holder of natural or cultured pearls or articles containing such pearls (all of which pearls and articles are hereinafter called "pearls") directly for export or to the Central Purchasing Office.

(2) The acquisition of pearls for export, or for sale to the Central Purchasing Office, by an exporter who

(a) Before any acquisition registers as an exporter of pearls with the Board of Trade, and who

(b) Certifies to the Board of Trade within ten (10) days after any acquisition of pearls the number and description of the pearls so acquired.

Sales to registered exporters under the forgoing need not to report under subparagraph 2b. All other transactions must comply with subparagraph 2b.

FOR THE SUPREME COMMANDER:

/s/ A.J. Rebe
/t/ for R. M. Revy
Colonel, AGD
Adjutant General

Appendix H

SUMMARY OF PATENTS RELATING TO PEARL AND PEARL OYSTER CULTURE

In order that those interested in the history and trends of pearl culture may know something or what the Japanese pearl culturists and scientists have attempted, the following summary of all patents granted in the field of pearl culture is submitted. The data were gathered from the records of the Japanese Patent Office in Tokyo. After each patent number appears (a) date of application, (b) date on which the patent was granted, (c) name of the person receiving the patent, (d) general subject of the patent, and (e) a brief outline of the scope of the patent.

2670: 13 Sept 94: 27 Jan 96: K. Mikimoto: method of pearl formation. A spherical or semispherical nucleus is made of glass or shell before it is ground with salt. The nucleus then is inserted into a pearl oyster to be coated with nacre.

5542: 12 Mar 02: 26 Jun 02: K.Mikimoto: method of coating nacre on nucleus. After being coated with nacre the nucleus is removed from the rear of the semispherical pearl, and another nucleus is inserted to fill the empty pearl. The inside of the pearl and the new nucleus can be painted with various colors to produce as many pearls of the same color as may be required

12590: 1 Mar 07: 27 Apr 07: T. Mise: needle to insert nucleus. The point of a thin metallic tube is cut aslant and sharpened, and a nucleus is received at the end of the tube together with pieces of epithelium from mantle. A spring needle inserted inside the tube pushes the nucleus through the connective tissue and leave it inside the oyster.

13673: 17 Aug 07: 12 Feb 08: K.Mikimoto: method of pearl formation. The mantle is pressed and then release so as to form a constricted sac inside. A nucleus smeared with glycerin is inserted in the sac.

15002: 26 Mar 08: 26 Sept 08: K. Mikimoto: mounting pearls on screwed nucleus. Developed from Patent No.5542. A female screw is cut inside the edge of a semispherical pearl, and a male screw is fitted to the filler. For modification of the filler, two semispherical nuclei with a nut and bolt at each center are cut for mounting as an ornament.

15612: 15 Dec 08: 2 Feb 08: K. Mikimoto: method of pearls formation. Developed from Patent No.13673. A straight or diagonal cut is made on the sac constricted in the mantle, and a glycerinated nucleus is inserted.

16064: 14 Mar 09: 10 Apr 09: K. Mikimoto: nucleus with celluloid bed. A plate of celluloid or shell is used for a bed on which one to semispherical nuclei are fixed and then inserted between the mantle and the shell. This is to secure them in the body and thus produce more pearls per shell.

17568: 13 Sept 09: 27 Jan 10: S. Momose: plating a sliced nacre. A spherical coated pearl is sliced and then polished to give a concentric coronal luster to the secretion. Various colors are arranged on the back of ornamentation. The effect is that of a flat pearl with the luster of spherical pearl.

17984: 6 Oct 09: 28 Apr 10: Y. Kinoshita: fixing nucleus with cement. A nucleus is glued to the shell with cement or resin to prevent its extrusion.

23645: 5 Feb 12 : 20 Mar 13: K.Mikimoto: paint protecting pearl oyster. Parasites on the shell are killed with formation, and the surface is covered with gelatin solution to make it smooth. The shell is coated with paint based on drying oil, resin, lampblack, zinc oxide, red lead, rouge, manganese, boric acid, and volatile oil.

23687: 4 Jul 10: 31 Mar 13: K. Mikimoto: injection of lime for nucleus. Developed from Patent No.17984. Pulverized hydrolyzed lime is injected into the mantle tissue to act as a nucleus; powder is used to prevent escape when the injector is removed.

24694: 3 Mar 10: 6 Oct 13: G. Tada: contraction of nucleus sac by silver wire. Nucleus sac is tied off with silver wire.

24917: 5 Feb 12: 11 Nov 13: K.Mikimoto: protection of shell by coating with chemicals. To protect the shell from parasitic growth, weak formalin is first applied, then gelatin solution. Later a drying agent made of resin, zinc oxide, rouge, lampblack, volatile oil, and drying oil is applied to the shell.

25757: 25 Dec 13: 8 Apr 14: K. Mikimoto: basket to protect oysters from parasites. Pieces of pumice or charcoal are placed on the shelves of the wire rearing baskets. They

serve to keep adequate spaces between the oysters, and in May and June when the parasite "zenbo" abounds in the water, these pillows induce the parasites to adhere to them instead of to the oysters.

26356: 4 Jan 14: 24 Jul 14: K. Mikimoto: basket with screw propeller. An upright cylindrical wire basket which has a smaller basket inside and several shelves between the basket on which the oysters are placed. At the center of the inner basket a shaft with a screw propeller stirs up the water, which promotes the oysters' growth.

27074: 2 Feb 13: 28 Dec 14: K. Mikimoto: insertion of nucleus by hinge operation. Separating the hinge of the shell, a nucleus is inserted through a cut in the mantle immediately below the hinge. The hinge is again joined so as to function normally.

27186: 1 Oct 08: 27 Jan 15: Y. Kinoshita: setting nucleus in hole in shell. A hole is made in the shell and a nucleus inserted with either cement or resin

29049: 16 Oct 14: 1 May 16: K, Mikimoto: grafting of nucleus into mantle. A nucleus coated with epithelium is grafted into a cut of the mantle. A cut is made in the mantle, and an end of the cut tissue covers the nucleus and heals the cut.

29628: 24 Oct 07: 20 Jun 16: S. Nishikawa: insertion of epithelium in the shell tissue. Epithelium removed from the mantle is inserted in a tissue of the body of that oyster or of another.

29629: 24 Oct 07: 20 Jun 16: S. Nishikawa: insertion of pearl sac in shell tissue. A natural pearl sac is prepared and inserted into a tissue of the shell's body under one of these conditions: (1) a pearl sac with a nucleus, (2) a pearl sac without a nucleus, (3) a pearl in a sac, and (4) a pearl in a sac with the adjacent tissue.

29630: 13 May 07: 20 Jun 16: S. Nishikawa: insertion of epithelium with nucleus into the tissue. Inserted into the tissue of the body is of these materials (1) mantle epithelium with a nucleus, (2) a nucleus rubbed on mantle epidermis to which epithelium has adhered.

30011: 3 May 16: 11 Sept 16: T. Mise: air pump to insert nucleus. A sucker-like shallow bowl is attached at one end of a tube to receive a nucleus. A rubber bell at the other end serves as an air pump to leave the nucleus in the body of the oyster.

30771: 24Oct 17: 15 Feb 17: S. Nishikawa: insertion of pearl sac cell into tissue of the oyster. A tissue of the shell is inserted into the epithelium of the mantle epidermis with the adjacent tissue, with or without a nucleus.

31151: No data available: 1 Jun 20: Nihon Pearl Co., Ltd.: lining of cut base of pearl. A hole is made in the cut base of a pearl removed from the surface of a shell and filled with a gluey substance. A stopper with a T-shaped head is set in the hole.

31270: 2 May 14: 5 Jul 17: T. Mise, M. Ueda, K Suzuki: vacuum tube to insert nucleus. A vacuum tube with a sucker pushes a nucleus through a cut in the body tissue. When the nucleus is in the proper position, air is let into the tube to leave the nucleus in place. The diameter of the sucker is less than that of the nucleus.

33640: 13 May 18: 15 Jan 19: K. Mikimoto: grafting of coated nucleus under epidermis. The opening of the epithelial sac containing a nucleus is tied with a thread and then grafted under the epidermis of the outer shell. A contracting agent is applied to the muscle so as to remove the thread. The wound should be disinfected.

34138: 20 Jan 19: 14 Apr 19: K. Mikimoto: grafting of coated nucleus under epidermis. Developed from Patent No.33640. The process is similar to the above except that the thread is removed before the nucleus is placed under the epidermis. This operation is simpler than the preceding operation.

36172: 10 mar 20: 15 Apr 20: K.Mikimoto: spat collecting box. A rectangular box with wire ends, made of wood or anticorrosive metal, containing two compartments and having lateral wings at one end. The front compartment is furnished with shelves; the second room has partitions projecting from the floor and ceiling and inkling inward. The partitions are patient with cement mortar. In the spawning season larvae are carried by the current from the oysters on the shelves in the front room, and they settle on the coated partitions, where they grow in safety. A hinge door expedites handling of shells and spat; the wings give ability to the box against the current when hung in the sea.

36700: 28 May 20: 1 Jul 20: K. Mikimoto: basket for rearing pearl oysters. A flat wire basket in which pearl oysters are confined. It has two supports at one end to enable adjustment to the gradient when the basket is installed on the bottom of the sea.

37746: 14 Jun 17: 24 Dec 20: T. Mise, M. Ueda: capillary vessels to stimulate nacre secretion. A capillary vessel is inserted through the hinge secretion of the mantle toward the mantle epidermis. A nucleus is inserted on the joint close to the vessel and stimulates secretion of nacre on the nucleus.

38635: 9 Feb 20: 14 May 21: S. Nishikawa: insertion of epithelium after nucleus is enclosed. A nucleus is placed in a cavity of the connective or flesh tissue. After healing, the epithelium is inserted through another hole in order to reach the nucleus and form the pearl sac.

38801: 1 Apr 21: 1 Jun 21: K. Mikimoto: double rearing baskets, hinged. Developed from Patent No.36700. Two flat wire baskets are hinged together at the top. A large at each corner permits adjustment to bottom gradient.

40584: 12 Sep 21: 9 Nov 21: K. Mikimoto: nucleus coated with fish scales. Nuclear material is coated with liquid celluloid mixed with scales of the hairtail fish and smeared with resin dissolved in borax. The product can now be used as a nucleus.

42010: 1 Jun 20: 17 Mar 22: K. Mikimoto: injection of chloride of lime for nacre secretion. After inserting nucleus, an injection is made to promote nacre secretion using (1) chloride of lime or (2) chloride of lime mixed with magnesium chloride.

42326: 9 Sept 21: Apr 22: K. Ikeda: painting or fish silver in empty pearl. An empty spherical pearl is bleached, and the inside is painted with nitrocellulose mixed with silver. The inside of the pearl is then lined with another nucleus.

42908: 8 Sept 21: 22 Jun 22: K. Ikeda: empty pearl painted with cellulose ester. The nucleus is removed from a semispherical pearl, and the inside of the pearl is painted with a solution of nitrocellulose or other ester before being refilled.

43352: 27 Nov 21: 28 Aug 22: K. Otsuki: silver wire to stimulate pearl sac formation. A nucleus is placed in the fresh tissue near the foot, and a wire is inserted to reach to the nucleus. This wire is of silver or other metal or is nonmetallic material containing calcium; it is removed when the pearl sac is formed.

44875: No data available : 23 May 23: H. Ogawa, Mitsubishi Co., Ltd: grafting of cut after insertion. The flesh of the oyster is caused to shrink by a shock. A piece of the flesh is removed and grafted into the cut through which a nucleus has been inserted to hold the nucleus in place.

45421: 4 Jan 21: 23 May 23: K. Mikimoto: scarlet solution for dripping. Epithelium from the mantle is dipped in aminoazotoluene-azo-naphtol solutionbefore grafting and is washed in Ringer solution as it is grafted.

60059: 28 Apr 22: 22 Jan 24: K. Otsuki: pearl used for secretive agent. A nucleus is inserted near a pearl, the pearl is removed, and the sac is used for the new nucleus. This process can be operated.

60312: 19 Jan 23: 1 Apr 24: K. Mikimoto: oyster spat collector. A shelter formed by plates surrounding a with basket. Larvae sinking to the bottom through the top of the basket stick to the bed.

60602: 5 Oct 22: 14 May 24: M. Fujita: protection against parasites. The surface of the shell is cleaned and coated with a thin sea water-proof metal held in place by water proof glue such as rubber cement.

61570: No data available: 27 Oct 24: M. Fujita: protection of oyster by rubber sheet. This process is similar to that described for Patent No.60602 except that a thin sheet of rubber is used instead of metal.

65074: 13 Jan 23: 28 Nov 25: R. Konishi: grafting nucleus between two mantles. Two pearl oysters of the same species are prepared for operation and their mantles exposed by removing a piece of the shell. The mantles and shells are then grafted together with a nucleus between.

65916: 5 Oct 22: 25 Sept 25: M. Fujita: electric stimulation for pearl formation. Electric current is discharged on pearl oysters to stimulate the mantle to increase nacre production.

66977: 11 Oct 22: 21 Dec 25: M. Fujita: electric stimulation for pearl formation operated oysters are lines up in a wire basket, the anterior mantle is touched or penetrated with a positive electrode, and the posterior mantle with a negative electrode. While the basket is

hung in water, numerous oysters are given an electric shock to stimulate growth.

71266: 20 Aug 23: 3 Mar 27: H. Ogawa and Mitsubishi Co.: insertion of sliced epithelium. Developed from Patent No.29628. A cut is made in the body of the oyster; the epithelium adjacent to it is sliced and one end remains attached. The free end is folded into the cut, with or without a nucleus.

77325: 9 Apr 27: 6 Jul 28: K. Otsuki: insertion of nucleus between foot and liver. A cut is made in the epidermis between the foot and liver, and a nucleus is placed in the cut close to the retractor muscle. A part of the retractor muscle is separated from the shell to restrict contraction.

84804: 29 Aug 28: 9 Jan 30: K. Otsuki: removal of byssus for putting in larger nuclei. The byssus is removed, and the tunic covering a hollow between the posterior retractor and intestine is cut to receive the nucleus. A larger nucleus can be inserted because of the removal of the byssus.

86667: 19 Nov 28: 14 May 30: K. Otsuki: weakening function of anterior reactor. A part of the anterior muscle and adjacent tissue is scraped to make a hole through which a nucleus is inserted. The nucleus is fixed to a layer connecting the anterior and posterior muscles as so to weaken the elastic function of the retractors.

89132: 27 Apr 29: 14 Nov 30: S. Nishikawa: insertion of nucleus in ventral area. A cut is made in the tunic of the posterior retractor muscle, and a nucleus is inserted through the cut into the ventral portion. The wound heals quickly because of the elastic properties of the retractor.

92400: 4 Jan 30: 11 Aug 31: K. Mikimoto: basket for pearl oyster breeding. A pearl oyster basket designed to admit water. No light is admitted, however, because the basket is hung in deep water. The purpose is to obtain a transparent mantle with which to coat a nucleus.

92401: 4 Jan 30: 11 Aug 31: K. Mikimoto: smooth coating of nucleus with mantle tissue. Developed from Patent No. 34318. After the spawning season, a nucleus is enclosed within the mantle epidermis obtained by rge method described in Patent No. 34138. The remaining part of the coat and the knotted thread is removed to make a mouth smooth. The enclosed nucleus is pressed to the layer of the tunic through a cut made in the tunic.

99134: 14 May 31: 21 Jan 33: H. Ota and another: artificial ovulation for nucleus insertion. Developed from Patent N. 29630. The ovary is forced to discharge so as to permit the gonad to reduce in size; this promotes the health of the oyster. Then a nucleus is inserted

100330: Oct 32: 20 Dec 33: K. Mikimoto: insertion of nucleus into visceral area. Developed from Patent No. 29630 and 30771. After inserting nucleus into the visceral area the wound is sutured; this permits the use of larger nucleus.

106825: 6 Oct 33: 6 Jul 34: S. Ida: insertion of nucleus in gonad. The foot of the shell is removed to make an opening through which a nucleus is grafted to the tunic of the gonad.

112516: 12 Nov 34: 20 Sept 35: K. Mikimoto: etching treatment of nucleus. Developed from Patent No. 29630. Surface of nucleus is etched with a weak acid or smeared with nitrocellulose solution mixed cochineal pigment (lake). The epithelium of the mantle is rubbed in sea water to obtain liquid containing epithelial cells. The nucleus is covered with the liquid and inserted in the oyster.

115642: 23 Oct 34: 8 May 36: K. Mikimoto: non-nucleated pearl formation. One of the following is pulverized; shell, carbonate of lime, fuller's earth, or anhydrous silicic acid. With this is mixed epithelium from the mantle of a pearl oyster to form a thin mud in sea water. This mixture is placed in the body of the mother oyster, and pearls without nuclei are formed.

115643: 13 Oct 34: 8 May 36: K. Mikimoto: ultraviolet rays for pearl formation. After a nucleus has been inserted, the oyster is exposed to ultraviolet rays to heal wound quickly.

115677: 24Oct 34: 8 May 35: K. Mikimoto: reflectors for iridescent pearl formation. Colored plates, colored wire netting, transparent colored plates are placed at the top and bottom of a basket containing operated oysters. The object is to produce a rich iridescence in the pearls.

119 547: 22 Feb 36: 12 Mar 37: K. Mikimoto: injection of calcium chloride and Vitamin D. Developed from Patent No. 42010. Pieces of epithelium taken from an oyster are inserted as a nucleus in place of inorganic material. The oyster is then injected with calcium chloride and Vitamin D solution.

146609: 7 Mar 40: 13 Nov 41: U. Shiozaki and one other: breeding of pearl oyster for medical use. Powdered nacre is spread in the body of a mother oyster. Many particles of pearl suitable for medicine are produced.

173102: 23 Dec 34: 9 Jul 46: B. Hamaguchi, K. Isowa: formation of lustrous pearls. The lustrous pearl tunic is separated from the shell or broken, together with the shell, by drilling. The shell is returned to the water to grow many new lustrous pearls.

Patent Applications Not Yet Granted

App No. 5412: Filed 13 Aug 37: published 20 Dec 38: S. Mizumoto: marble nucleus. Marble from Gifu Prefecture and Shikoku is processed mechanically into spherical nuclei.

App No. 1631: Filed 20 Jan 47: Published 23 Oct 47: M. Atomiya: breeding pearl oyster seed. Fertilized ova and sperm are produced artificially in a bowl containing dilute ammonia and sea water. After a few minutes they are returned to normal sea water to grow into veligers. They are then released in a pond which is sheltered with a screen to adjust light and prevent growth of mosquito larvae. Carbohydrate is added to the sea water in the pond to supply food for the larvae.

TABLE 1. DISTRIBUTION OF PEARL CULTURE FARMS, 1948

Prefecture	Location	Farms	Rafts	Leased Area (acres)
Shizuoka	Shimizu	1	8	
	Shimoda	1	2	
	(Subtotal)			239.7
Mie	Kagamiura-wan	2	57	
	Matoya-wan	13	344	
	Ago-wan	90	2,378	
	Gokasho-wan	11	86	
	Nie-wan	5	137	
	Yoshizu-wan	4	*a 0	
	Hozaura-wan	2	20	
	Shimazu-wan	1	*a 0	
	Nishikiura-wan	2	10	
	Hikimoto-wan	3	40	
	(Subtotal)			5,979.90
Wakayama	Tanabe	4	66	231.5
Kochi	Tosa-wan	4	117	
	Shimizu	1	50	
	Sukumo	1	0	
	(Subtotal)			1,925.90
Ehime	Hirajo-wan	1	15	179.7
Miyazaki	Urajiri-wan	1	10	114.4
Nagasaki	Omura-wan	9	322	
	Tsushima	2	80	
	(Subtotal)			1,823.10
Kumamoto	Amakusa	1	6	4.1
Shiga	Biwa-ko	1	*b 0	41.3
Total		**160**	**3,748**	**10,539.60**

*a Winter farms only; rafts not used.
*b Fresh-water pearl farm; rafts not used
SOURCE: Bureau of Fisheries, from reports made by individual culturists as of 1 September 1948.

TABLE 2. JAPANESE PEARL CULTURE FARMS, 1926-48

Year	Number of farms	Leased area (acres)
1926	114	16,784.40
1927	126	17,841.10
1928	121	21,635.20
1929	130	16,898.50
1930	133	16,480.20
1931	141	16,567.60
1932	135	16,380.90
1933	177	16,159.50
1934	222	13,571.70
1935	257	13,508.40
1936	285	12,921.00
1937	302	12,474.00
1938	306	13,351.00
1939	365	13,913.70
1940	356	13,022.60
1941	ND	9,040.40
1942	ND	5,730.00
1943	ND	3,620.30
1944	ND	2,746.10
1945	ND	2,124.30
1946	ND	2,593.20
1947	ND	ND
1948	160	*a 10539.6

*a From Bureau of Fisheries records
ND No data abailable
Source: Statistical Report of the Ministry of Agriculture and Forestry

TABLE 3. NUCLEUS SIZE, DEPOSITION OF NACRE, AND GROWTH PERIOD RATIO IN *Pinctada martensii*

Nucleus				Pearl			Increase	Thickness	Ratio of nacre layer	Operated Dec–Jul	Operated Aug–Dec
Diameter		Weight		Diameter	Weight	Weight	in Diameter	of Diameter	to radials of nucleus	(age in years)	(age in years)
bu	mm	gram	grain	mm	gram	grain	mm	mm			
0.55	1.65	0.005	0.086	2.2	0.013	0.20	0.515	0.257	0.330	1/2	ND
0.60	1.80	0.007	0.115	2.3	0.019	0.29	0.515	0.257	0.285	1/2	ND
0.65	1.95	0.011	0.174	2.5	0.023	0.36	0.515	0.257	0.264	1/2	ND
0.70	2.10	0.015	0.231	2.7	0.026	0.40	0.545	0.272	0.259	1	1 1/2
0.75	2.25	0.019	0.289	2.9	0.034	0.53	0.575	0.287	0.255	1	1 1/2
0.80	2.40	0.023	0.347	3.0	0.041	0.63	0.575	0.287	0.239	1	1 1/2
0.85	2.55	0.026	0.405	3.2	0.049	0.76	0.606	0.303	0.238	1	1 1/2
0.90	2.70	0.033	0.521	3.3	0.056	0.87	0.606	0.303	0.224	1	1 1/2
0.95	2.90	0.037	0.579	3.5	0.064	0.99	0.606	0.303	0.209	1	1 1/2
1.00	3.05	0.041	0.637	3.7	0.071	1.10	0.636	0.3218	0.209	2	2
1.05	3.20	0.049	0.752	3.8	0.083	1.30	0.636	0.318	0.199	2	2
1.10	3.35	0.059	0.868	4.0	0.094	1.50	0.667	0.333	0.199	2	2
1.15	3.50	0.063	0.984	4.2	0.110	1.60	0.667	0.333	0.19	2	2
1.20	3.65	0.071	1.100	4.3	0.120	1.80	0.697	0.348	0.191	2	2
1.25	3.80	0.079	1.215	4.5	0.140	2.10	0.697	0.348	0.183	2	2
											2 1/2
1.30	3.95	0.090	1.389	4.7	0.150	2.30	0.727	0.363	0.183	ND	2 1/2
1.35	4.10	0.101	1.562	4.8	0.170	2.60	0.727	0.363	0.177	ND	2 1/2
1.40	4.25	0.116	1.794	5.0	0.190	2.90	0.727	0.363	0.170	ND	2 1/2
1.50	4.55	0.143	2.199	5.3	0.230	3.50	0.758	0.379	0.167	ND	2 1/2
1.60	4.90	0.169	2.604	5.6	0.270	4.20	0.788	0.394	0.161	ND	2 1/2
1.70	5.20	0.206	3.183	6.0	0.320	5.00	0.818	0.409	0.163	ND	2 1/2
1.80	5.50	0.248	3.819	6.3	0.380	5.90	0.818	0.409	0.162	ND	2 1/2
1.90	5.80	0.289	4.456	6.6	0.450	7.00	0.848	0.424	0.146	ND	3
2.00	6.10	0.341	5.266	6.9	0.540	8.40	0.879	0.439	0.144	ND	3
2.10	6.40	0.405	6.250	7.3	0.630	9.70	0.909	0.454	0.142	ND	3
2.20	6.70	0.454	7.002	7.6	0.740	11.30	0.909	0.454	0.136	ND	3
2.30	7.00	0.506	7.812	7.9	0.870	13.60	0.937	0.469	0.134	ND	3
2.40	7.30	0.589	9.086	8.3	1.020	15.80	0.970	0.485	0.133	ND	3
2.50	7.60	0.666	10.185	8.5	1.150	17.40	0.970	0.485	0.128	ND	3 1/2
2.60	7.90	0.743	11.458	8.9	1.330	20.50	1.000	0.500	0.127	ND	3 1/2
2.70	8.20	0.821	12.674	9.2	1.500	23.10	1.030	0.515	0.126	ND	3 1/2
2.80	8.50	0.919	14.178	9.5	1.680	25.90	1.061	0.530	0.125	ND	3 1/2
2.90	8.80	1.102	15.625	9.8	1.860	28.70	1.061	0.530	0.120	ND	3 1/2
3.00	9.10	1.114	17.187	10.2	2.090	32.20	1.091	0.545	0.120	ND	3 1/2
3.10	9.40	1.241	19.155	10.5	2.330	35.90	1.091	0.545	0.116	ND	3 1/2
3.20	9.70	1.346	20.775	10.8	2.570	39.60	1.121	0.560	0.115	ND	3 1/2

ND: No data available

SOURCE: Mikimoto Pearl Farm

ABLE 4. DIAMETER AND WEIGHT OF SPHERICAL PEAR CULTERED IN *Pinctada maxima* AT PALAU

Diameter	Weight	
mm	Grams	Grains
3.7	0.075	1.5
3.9	0.994	1.9
4.2	0.113	2.3
4.5	0.124	2.5
4.8	0.161	3.2
5.2	0.200	4
5.5	0.263	5.3
5.8	0.300	6
6.1	0.338	6.8
6.4	0.413	8.3
6.7	0.468	9.4
7	0.488	9.8
7.3	0.544	10.9
7.6	0.600	12
7.9	0.675	13.5
8.2	0.750	15.0
8.5	0.844	16.9
8.8	0.994	19.9
9.1	1.142	22.9
9.4	1.256	25.1
9.7	1.350	27.0
10.0	1.483	29.3
10.3	1.575	31.5
10.6	1.763	35.3
10.9	1.969	39.4
11.2	2.156	43.1
11.5	2.381	47.6
11.8	2.625	52.5
12.1	2.925	58.5

SOURCE : Kokusai Pearl Farm, Shizuoka Prefecture

TABLE 5. RED TIDE OCCURENCES IN MIE PREFECTURE
1899 - 1948 *a

Year	Month	Location	Organism
1899	Aug	Toba-ko	*Goniaulax*
1900	Sept	Ago—wan	*Goniaulax*
	Nov	Ise-wan	*Goniaulax, Ceratium*
1904	Dec	Gokasho-wan	*Ceratium, Gymnodium, Prococentrum*
1905	Mar	Gokasho-wan	*Gonyaulax*
1911	*a Jan-Mar	Gokasho-wan	*Gymnodium*
	Jun	Asoura-wan	ND
1912	Aug	Ise-wan	ND
	Sept	Hamajima Port	*Ceratium, Chaetoceras*
1015	Dec	Gokasho-wan	*Gonyaulax, Ceratium*
1916	Feb	Gokasho-wan	*Gonyaulax, Ceratium*
1917	Aug-Sept	Ago-wan	*Gymnodium*
	Sept	Asoura-wan	*Gymnodium*
1921	Sept	Ago-wan	*Gonyaulax*
1922	*a Jan	Gokasho-wan	*Gymnodium*
	Mar	Gokasho-wan	*Gymnodium*
	Sept-Oct	Ago-wan	*Gymnodium, Peridinium*
1927	Aug-Sept	Ago-wan	*Gymnodium, Chaetoceras*
1929	Aug-Sept	Ago-wan	*Gymnodium*
1930	Oct	Ise-wan	ND
1934	Jan	Gokasho-wan	*Gymnodium*
	Feb	Gokasho-wan	*Gymnodium*
	May	Ise-wan	*Gymnodium*
1948	Aug-Oct	Ago-wan	*Chaetoceras, Gymnodium*

*a : Most severe and deadly red tide occurrences
ND : No data availably
SOURCE: Mie Prefecturl Fisheries Experiment Station, 1948

TABLE 6. NUMBER OF PLANKTON ORGANISMS PER CUBIC CENTIMETER OF WATER AT AGO-WAN, 1948 *a

Station	Half meter intrvals from the surface																		Time of	Transparency
*a	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	Sampling	meters *b
1	4,120	5,600	1,360	2,200	1,240	1,600	640	440	400											912	1.00
2	160	200	760	960	880	1,280	960	560	800	680	400	600	640	1,040	1,280					925	2.40
3	200	120	600	600	800	400	560	280	320	440	400									940	2.75
4	280	160	320	360	440	480	200	320	600	320	40	40	40							1,011	3.15
5	1,720	1,280	1,760	1,840	2,480	1,920	1,160	760	640	600	440	720	400	360	720	280	320	440	240	1,030	1.95
6	240	240	1,520	1,360	1,160	920	840	880	1,280	440	400	240	320	200						1,056	2.00
7	440	640	520	720	400	960	720	440	640	680	280	440	80	720						1,118	1.80
8	80	80	1,120	920	840	1,520	1,400	720	760											1,132	2.00
9	560	440	920	1,280	920	360	640	840	720	480	360	400	320	400						1,150	2.20
10	240	720	2,400	2,560	1,520	320	720	640	600	1,280	360									1,215	1.50
11	120	240	9,000	7,400	1,200	2,760	1,160	1,480	1,040	880	2,120	1,080	1,000	1,040	1,040					1,230	1.20

*a Eleven stations near Sekoura laboratory, tested 28 September 1948

*b Depth at which 12-inch Secchi disk became invisible

SOURCE: Dr. S. Kobayashi, Atomiya Pearl Culture Farm, Ago-wan

TABLE 7-1. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
MIE PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	6,255.0	1,118,600	70,760
1927	6,426.4	2,219,300	48,385
1928	10,688.0	1,505,150	71,930
1929	8,549.4	2,700,032	218,220
1930	8,727.6	4,341,010	317,188
1931	8,609.9	9,356,275	565,175
1932	8,467.9	23,060,201	2,513,949
1933	8,510.9	13,023,532	1,255,384
1934	8,902.9	49,477,704	3,322,433
1935	7,909.6	35,920,350	5,540,055
1936	8,050.2	35,174,009	4,731,113
1937	7,763.0	28,428,140	6,908,064
1938	8,010.8	23,574,980	7,068,674
1939	8,110.5	54,829,120	6,900,880
1940	7,963.5	20,602,100 (Pounds *a)	6,383,500
1941	2,867.1	12,385,723	3,929,416
1942	1,004.6	981,426	4,627,400
1943	1,167.7	1,260,513	2,582,620
1944	608.4	996,452	1,615,864
1945	155.6	18,070	682,600
1946	463.3	123,546	3,702,000
Total			59,733,610

TABLE 7-2. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
SHIGA PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	ND	ND	ND
1927	ND	ND	ND
1928	ND	ND	ND
1929	ND	ND	ND
1930	ND	ND	ND
1931	ND	ND	ND
1932	ND	ND	ND
1933	ND	ND	ND
1934	ND	ND	ND
1935	ND	ND	ND
1936	21.2	40,000	2,720
1937	16.3	39,749	2,750
1938	16.3	36,528	3,550
1939	30.4	49,845	3,200
1940	30.4	34,540 (Pounds *a)	3,000
1941	20.8	41,474	ND
1942	20.8	5,789	ND
1943	20.8	5,954	ND
1944	49.0	2,630	ND
1945	14.7	91,797	400
1946		66,160	ND
Total			15,620

TABLE 7-3. PRODUCTION OF CULTURED PEARL AND PEARL OYSTERS, BY PREFECTURE, 1926-4

WAKAYAMA PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	986.1	1,000	475,400
1927	1,317.9	16,500	370,865
1928	863.5	ND	161,800
1929	1,018.8	115,000	117,100
1930	1,018.8		143,200
1931	1,011.3	10,000	147,000
1932	1,011.3	34,400	137,000
1933	880.6	150,000	50,000
1934	971.0	273,000	105,000
1935	1,288.8	314,200	65,000
1936	692.5	252,000	33,000
1937	581.3	487,580	19,000
1938	688.7	240,580	15,100
1939	964.2	387,000	125,750
1940			
1941			
1942			
1943			
1944			
1945			
1946			
Total			

TABLE 7-4. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
EHIME PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	667.2	12,800	ND
1927	667.2	161,050	9000
1928	667.5	11,550	15000
1929	667.5	13,000	30000
1930	667.5	13,550	50000
1931	669.8	32,900	68000
1932	669.8	32,400	42000
1933	662.6	5,500	102000
1934	660.3	400	56000
1935	660.3	400	300000
1936	655.9	400	290000
1937	652.5	6,000	221666
1938	652.5	5,000	360000
1939	656.6	5,000	258000
1940			
1941			
1942			
1943			
1944			
1945			
1946			
Total			

TABLE 7-5. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
KOCHI PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	2,317.2	200,450	9,593
1927	2,690.3	75,000	620
1928	2,690.3	196,535	66,744
1929	2,481.1	638,700	93,181
1930	1,896.3	237,754	68,711
1931	1,896.3	437,318	57,608
1932	1,896.3	159,200	57,786
1933	1,896.3	92,246	69,353
1934	1,896.3	473,665	90,525
1935	2,139.9	523,999	185,625
1936	1,946.2	289,332	213,333
1937	1,946.2	280,600	234,166
1938	1,965.0	238,333	324,750
1939	1,966.3	181,600	282,303
1940	1,958.3	155,000	307,220
		(Pounds *a)	
1941	1,766.0	44,906	339,670
1942	1,909.1	2,067	322,000
1943	ND	ND	ND
1944	13.6	314	ND
1945	1,727.2	331	ND
1946	1,361.1	41	ND
Total			2,723,188

TABLE 7-6. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
SAGA PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	ND	ND	ND
1927	ND	ND	ND
1928	ND	ND	ND
1929	ND	ND	ND
1930	ND	ND	ND
1931	ND	ND	ND
1932	ND	ND	ND
1933	ND	ND	ND
1934	760.0	ND	ND
1935	0.2	ND	ND
1936	ND	ND	ND
1937	ND	ND	ND
1938	55.5	300,000	300,000
1939	69.4	390,000	340,000
1940	59.5	950,000 (Pounds *a)	ND
1941	54.8	454,850	ND
1942	ND	ND	ND
1943	ND	ND	ND
1944	ND	ND	ND
1945	ND	ND	ND
1946	ND	ND	ND
Total			640,000

TABLE 7-7. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE< 1926-46 NAGASAKI PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	2,019.9	1,355,900	102,000
1927	2,112.4	804,600	151,589
1928	2,135.9	294,200	64,000
1929	2,133.4	1,108,500	152,118
1930	2,136.3	1,402,700	223,422
1931	2,370.8	402,000	228,180
1932	2,381.8	556,200	891,200
1933	2,391.5	603,800	1,003,500
1934	ND	222,224	917,800
1935	882.6	227,440	1,592,963
1936	667.5	319,429	1,733,922
1937	742.5	472,857	3,389,631
1938	1,118.1	424,737	2,735,118
1939	1,506.0	429,356	2,490,231
1940	1,376.3	368,927 (Pounds *a)	2,244,818
1941	1,662.8	38,894	1,994,738
1942	1,031.9	1,558,010	1,013,256
1943	1,131.0	2,068	1,566,740
1944	819.3	2,068	125,000
1945	ND	ND	ND
1946	1.6	17,367	2,000
Total			22,622,226

TABLE 7-8. PRODUCTION OF CULYUTRD PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
KUMAMOTO PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	ND	ND	ND
1927	ND	ND	ND
1928	ND	ND	ND
1929	ND	ND	ND
1930	ND	ND	ND
1931	ND	ND	ND
1932	12.7	12,000	1,500
1933	12.7	12,000	1,500
1934	12.3	12,000	1,200
1935	12.4	84,100	12,300
1936	12.4	83,000	12,000
1937	19.4	25,276	22,176
1938	19.6	33,332	25,620
1939	19.8	44,600	36,630
1940	21.5	47,300	22,000
		(Pounds *a)	
1941	9.3	27,291	ND
1942	16.3	16,540	ND
1943	22.2	38538	4,000
1944	ND	ND	ND
1945	ND	ND	ND
1946	ND	ND	ND
Total			138,926

TABLE 7-9. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
MIYAZAKI PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	16.3	ND	8,000
1927	16.3	ND	5,800
1928	ND	ND	ND
1929	ND	ND	ND
1930	ND	ND	ND
1931	59.3	ND	ND
1932	0.8	ND	ND
1933	0.8	ND	ND
1934	0.8	ND	4,000
1935	0.8	ND	47,000
1936	0.8	ND	50,000
1937	0.8	ND	55,000
1938	0.8	ND	45,000
1939	1.0	ND	33,800
1940	1.0	12,000 (Pounds *a)	12,500
1941	1.0	ND	200,000
1942	1.2	331	3,000
1943	1.0	6,633	500
1944	10.0	50	210
1945	10.0	744	500
1946	9.8	662	2,400
Total			467,710

TABLE 7-10. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
OKINAWA PREFECTURE

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	4161.0	2,150	2,332
1927	4185.0	2,400	2,400
1928	4185.0	2,200	2,200
1929	1763.0	22,950	13,365
1930	1763.0	23,534	12,600
1931	1738.0	24,800	13,200
1932	1738.0	27,403	11,700
1933	1738.0	25,300	10,990
1934	302.6	11,978	3,200
1935	302.6	12,168	6,679
1936	302.6	10,090	5,600
1937	304.4	8,700	5,500
1938	304.4	8,500	5,700
1939	304.4	9,180	5,230
1940	302.7	5,250	3,850
		(Pounds *a)	
1941	ND	ND	ND
1942	ND	ND	ND
1943	ND	ND	ND
1944	ND	ND	ND
1945	ND	ND	ND
1946	ND	ND	ND
Total			104,546

TABLE 7-11. PRODUCTION OD CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46
OTHER PREFECTURES

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	361.8	10,000	ND
1927	425.3	50,170	ND
1928	440.5	ND	1,400,161
1929	285.7	841,706	17,500
1930	270.9	26,974	4,375
1931	211.8	25,921	ND
1932	202.0	20,789	ND
1933	65.5	20,512	ND
1934	65.4	44,285	ND
1935	311.1	184,200	ND
1936	591.7	47,857	ND
1937	446.8	41,160	ND
1938	519.2	74,330	ND
1939	285.0	48,500	6,000
1940	48.8	53,800 (Pounds *a)	ND
1941	49.7	330	ND
1942	0.1	ND	ND
1943	ND	ND	ND
1944	13.1	90,143	ND
1945	ND	ND	ND
1946	15.3	ND	13,196

TABLE 7-12. PRODUCTION OF CULTURED PEARLS AND PEARL OYSTERS, BY PREFECTURE, 1926-46 TOTAL

Year	Area (Acres)	Number of Mother Shells	Number of Pearls
1926	16,784.4	2,790,900	668,085
1927	17,841.1	3,329,020	588,659
1928	21,653.2	2,009,635	1,781,834
1929	16,898.5	5,439,888	641,481
1930	16,480.2	6,160,522	819,496
1931	16,567.6	10,289,214	1,079,163
1932	16,380.9	23,902,593	3,655,135
1933	16,159.5	13,932,890	2,492,727
1934	13,571.7	50,515,256	4,510,158
1935	13,508.4	37,266,857	7,749,622
1936	12,921.0	36,216,177	7,071,688
1937	12,474.0	29,790,061	10,857,953
1938	13,351.0	24,936,320	10,833,512
1939	13,913.7	56,374,201	10,482,024
1940	13,022.6	22,596,137 (Pounds *a)	9,253,838
1941	9,040.4	14,109,017	7,890,967
1942	5,730.0	2,896,824	6,030,656
1943	3,620.3	1,314,202	4,214,860
1944	2,746.1	1,116,880	1,751,074
1945	2,124.3	110,942	733,500
1946	2,593.2	236,720	387,596

*a 1941-46 statistics in pounds, not individual shells
ND No data available
SOURCE: Statistical year books of Agriculture and Forestry, published by Ministry of Agriculture and Forestory