池干しの謎：ため池のドビ流しと池干し

―ため池の水管理における先人の知恵に関する新しい知見―

松葉成生[*]・木村諭史[**]・辻井悠希[***]・高野良昭[****]・加納義彦[*****]

The Mystery of *Ike-Boshi*: Draining and Drying a Pond

―New insights into ancient wisdom of water management―

Hideki Matuba[*]・Satoshi Kimura[**]・Yuki Tsujii[***]
Yoshiaki Takano[****]・Yoshihiko Kanoh[*****]

ABSTRACT

Our research validates the scientific significance of Japanese ancient practice, "*Ike-Boshi*," draining and drying a pond during the agricultural off-season. With a primary purpose of preserving the Japanese rose bitterling (JRB), we carried out "*Ike-Boshi*." In the emptied pond, through drying in the sun and weather exposure, reduced mud was oxidized, from which surplus nutrients were eliminated, while the silicate was maintained. Later in spring, with new water in the pond, numerous diatoms grew, while growth of green and blue-green algae was suppressed. Larvae (glochidium) of freshwater mussels ate the diatoms, allowing many young mussels to develop. The numbers of JRB and mussels were strongly correlated. Meanwhile, in "*Ike-Boshi*," nutrient-rich sludge was drained into a rice-field where the nutrients were re-absorbed, and toxic substances (e.g., sulfide) were removed. These results points to the value of "*Ike-Boshi*" as a key to suppressing eutrophication, the benefit of reusing the nutrient, and the essence for preserving the ecosystem. We believe that this Japanese ancient wisdom could be used for the water and agricultural management in many other countries.

Key words: *Ike-boshi*, Japanese Rose Bitterling(JRB), eutrophication

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*愛媛大学理学部・**水産大学校海洋機械工学科***清風学園生物部
****清風学園教員・*****清風学園教員、大阪経済法科大学地域総合研究所所員

1. INTRODUCTION

For over two millennia, in Asian countries with a monsoon climate, the primary mode of grain production has been rice farming - specifically, intensive, small-scale farming on terraced paddies. Approximately 40% of the world's population lives in areas affected by this climate and hence this agriculture. This terrace paddy method adapts to the extremes of wet and dry seasons by taking advantage of the steep slopes and fast-flowing rivers of the Pacific Rim. The paddies are filled with water that has been stored in nearby farm ponds, compensating for water shortage in the dry season, and providing an excellent way to manage water for agriculture. Osaka Prefecture in Japan is an example of an area with such water shortages. Fig. 1 shows the location of Osaka within the greater monsoon area. Through the traditional paddy and farm-pond method, rice has been produced in this area - in the same fields continuously on an annual basis - for over 2,000 years.

Fig.1. Area of Asia Monsoon, including study area (Osaka Prefecture).

In the 20th and 21st centuries, changes in agricultural practice have introduced many problems around the world. Water pollution from agricultural chemicals and synthetic fertilizer is a major concern. Runoff of nitrogen and phosphorus from agricultural land has led to eutrophication of lakes and marshes. The proliferation of green and blue-green algae often leads to destruction of natural aquatic ecosystems. Many Blue-green algae, such as *Microcystis*, which poisons the liver of mammals and can be fatal, are toxic.[1] At the same time, the nitrogen and phosphorus so vital as agricultural nutrients are being left un-recouped from the water bodies in state of eutrophication, exacerbating the rapid depletion of our natural resources. This paper reports on research which reveals and investigates the inherent connections among the problems caused by eutrophication: aquatic ecosystem destruction, resulting in reduction of biodiversity; resource depletion, resulting in inefficient crop production and economic loss; and direct losses in seafood production due to deteriorated fishery conditions. This paper presents a compelling solution to these interconnected issues, based on understanding and application of traditional water management techniques.

Photo.1. The Japanese rose bitterling (male)

Dotting the foothills of Mt Takayasu, in Yao city, Osaka Prefecture, are about 400 large and small farm ponds. In addition to their traditional agricultural role in providing much-needed water for rice farming downstream, these ponds were also used as a precious source of protein, such as small fish and shellfish. The ponds also contain a fascinating ecosystem. The most well known feature of the system is a small type of carp, which used to range broadly in the lake and river systems of western Japan, but is now reduced to a few small farm pond areas in Osaka and Shikoku, and one irrigation canal in Kyushu. Known locally by the affectionate nickname “*Kintai*,” the Japanese rose bitterling (JRB) Rodeus ocellatus kurumeus is in danger of extinction (**Photo.1**).

The JRB lays its eggs into the gills of the living freshwater mussel, *Anodonta woodiana*[2), 3)]. Meanwhile, the larvae (glochidium) of the mussel propagate as parasites on the goby *Rhinogobius.sp.OR.*[4)] In order to maintain the natural breeding cycle of the freshwater mussel, which is the egg-laying site for the JRB, the entire pond system must be preserved - precisely the opposite of the current situation.

Before urban development and modern methods caused changes in agriculture, the pond ecosystem was maintained in harmony with the agricultural practice of *Ike-Boshi*, or “Drain and Dry,” which is the annual draining of the ponds out into the paddies, and the subsequent drying of the pond beds. It was accomplished by pulling out the plug (made of wood or stone) in the pond bottom and directing the water, including sediment sludge, into the paddies downstream. At this time, the ponds’ benefit as a food source was evident, as families gathered fish and shellfish. Inevitably, some creatures survived in the small amount of water that remained in the pond. When new water was added a few months later, the entire pond ecosystem, including the JRB, thrived.[5)] Nowadays most of the farm ponds are unused, the plugs left untouched, and the drainage systems clogged and unusable. Noting the extensive damage associated with eutrophication, we were compelled to ask, “What did traditional water management do right?” Specifically, what exactly is it about the seemingly simple practice of *Ike-Boshi* that accounted for abundant fish takes, healthy annual grain crops, and preserved biodiversity? Our research set out to solve this mystery scientifically.

In 1999, a local study group, “Group for the Study of the Japanese Rose Bitterling of Takayasu,” was formed. The group converted one of the farm ponds into an experimental pond, where the ecosystem is being investigated. Early experiments investigated the deterioration of water quality when the pond is left as it is. Eutrophication was more rapid than expected: from the second summer the dominant species of phytoplankton began to succeed from diatom to green algae, and finally to blue-green algae.[5), 6)] At the same time, the reproductive rate of both the JRB and the freshwater mussel began to drop. The cause was attributed to the observed eutrophication.[5)] Examination of the mussels' diet revealed that they ingested primarily diatoms.[7)] In spite of the fact that, from 2002 to 2004, the water had been renewed and part of the sediment sludge removed, the mussels failed to reproduce well. The failure of this previous attempt led us to consider the importance of drying the pond bottom. In 2005 and 2006 we carried out the drying. Our experiments evaluated the effects of drying on pond life, including mussel reproduction. We also investigated changes in the bottom mud as an effect of drying. We found that the entire ecosystem - from soil quality to diatom abundance to mussel reproduction to fish population - benefited greatly from the drying process.

Our research thus points to the value of sludge removal and drying of beds as a key to suppressing eutrophication in rivers, lakes, and marshes around the world. Our experiments also confirmed the presence of nitrogen-rich nutrients in the pond sludge, thereby scientifically validating the wisdom of the ancient practice of draining pond sludge into rice paddies.

2. MATERIALS AND METHODS

2-1. "*Ike-Boshi*," Drain-&-Dry in 2005 and 2006

We performed a drying experiment on the experimental pond (12 by 12 meters, with depth up to one meter) on March 20th, 2005. Pumping out the water, we simultaneously gathered as many fish and mussels as possible and held them temporarily in a purified tank. Using sediment sludge that had previously been removed and left in the open for two years, becoming part of the surrounding soil, we lined the outer edge of the pond one meter wide, leaving a part of the edge uncovered as a control section, as shown in **Fig.2.** We then supplied the pond with new water and released the fish and mussels.

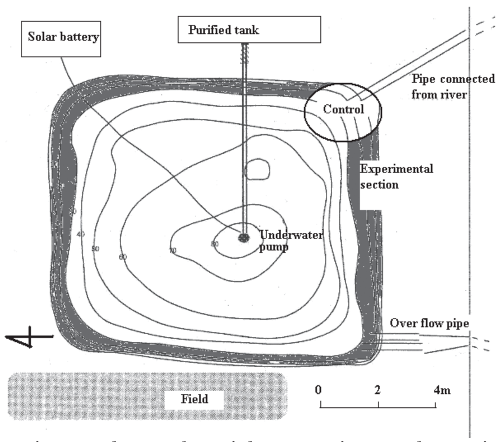

Fig.2. The experimental pond, with experimental section lined with soil dried in the open, and control section without soil addition.

In 2006, we removed the fish and mussels, and dried the pond completely from January 6th to February 5th. We then repaired the pond to set up the bottom plug.? Next, we supplied new water, and released the fish and mussels.

From March 2004 to April 2006 we took regular monthly readings. Pond water temperature and pH were measured. Plankton were collected by drawing a plankton net and fixed with 40% ethanol. In the laboratory, we prepared specimens for counting, determined the genera, counted, and calculated the compositional ratio of diatom, green algae, and blue-green algae. Next, five goby were collected and fixed with formalin in order to count the number of parasitic mussel glochidium on the fin of the goby. (Beginning on July 24th 2006, all the young mussels caught were marked and released.) Mature mussels were collected and the length, height, and width of the shells were measured. After manually opening the mussels, the eggs of the JRB were counted.

2-2. Oxidation-reduction potential (ORP) of mud and soil

As a preliminary investigation for evaluating the significance of ORP, ORP of the pond bottom mud and of soil from the surrounding area was measured using an ORP meter in July, 2006.[8] For clarity, “sludge” was defined in this paper as the substance drained out from the pond bottom, normally to be poured into rice paddies. Contrastingly, “mud” was defined as the substance on the bottom of the pond. “Soil” was defined as the bottom mud that has been taken from and left outside of the pond, exposed to the weather over a long period of time, and has become part of the ground. These materials were taken and examined immediately, or dried and tested in the lab. The mud and soil that showed positive ORP value were defined as “oxidized mud” and “oxidized soil” respectively; those with negative ORP as “reduced mud” and “reduced soil.” Mud from the pond bottom was collected from five spots and the ORP was measured. Then soil, which had been left outside the pond for a year, was collected from five spots, and ORP was measured by mixing 80 mL distilled water with 20 g soil. Finally, pond mud that was found to be “reduced mud” (showing a negative ORP) was collected, dried in the sun for 30 days, and re-examined for change in ORP.

2-3. Biological and chemical characteristics of the pond

2-3-1. Phytoplankton, mussels and ORP in pond

After knowing the significance of ORP, we investigated the relationship among the distribution of mussels, distribution of phytoplankton, and ORP of bottom mud on August 27th, 2006. Collecting the mussels, we distinguished them by age (2006 cohort:0+, 2005: 1+, 2004: 2+, 2003 or earlier: 3+years), and recorded the collecting spots and water depth, as shown in **Fig. 3.** From each of sampling spots 1 to 22, we sampled water and bottom mud, and measured ORP. Then mud was taken from the bottom from two spots showing positive ORP (Spots 14 and 19), and two spots showing negative ORP (Spots 15 and 17), and distribution of phytoplankton was measured.

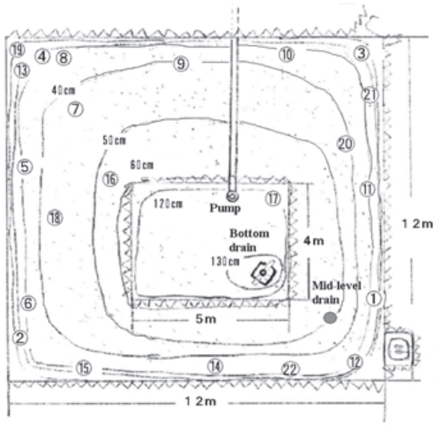

Fig.3. Sampling spots of mussel, phytoplankton and ORP in the pond on August 27th, 2006.

2-3-2. Chemical characteristics of dried mud

It has previously been reported that adding sodium silicate to a fish-breeding pond enhanced diatom propagation, which in turn led to better growth of freshwater mussels.[9] In order to know why diatoms are propagated after *Ike-Boshi*, we examined the concentration of silicon dioxide (SiO_2) and inorganic ions in oxidized and reduced mud. Oxidized mud (50 g wet weight), which had been dried in the sun outside the experimental pond (thus becoming soil), and reduced mud (50 g wet weight) from Spot 17, were placed in glass containers, mixed with 170 mL of distilled water, left at 20℃, and given light of 3,000 Lx. Using PACKTEST® and a spectrophotometer (AQUALYTIC PC Multi Direct), the concentration change of ammonium ions (NH_4^+), nitrate ions (NO_3^-), iron ions, and silicon dioxide dissolved in the supernatant was measured at one-week intervals over a one-month period. Distribution of phytoplankton was also compared between oxidized soil and reduced mud after the month-long experiment.

Afterwards, reduced mud from the pond bottom was collected and examined for change after being dried in the sun for 30 days. This mud (20 g dry weight) was placed in beakers and mixed with 80 mL distilled water. Then, the beakers sat for two hours, and the mixed liquid was filtered. We examined the concentration of silicon dioxide (SiO_2) and inorganic ions of the drying mud weekly for one month after drying.

3. RESULTS AND DISCUSSION

3-1. Effect of "*Ike-Boshi*," Drain-&-Dry on pond life

On March 20, 2005, the number of mussels collected at the *Ike-Boshi* was 72, including 50 added in November 2004, although no young mussels were collected which were born in 2004. The number of JRB totaled 1,350 adult males, 981 adult females, and 1,026 young. Totals of other fishes collected at the same time were 994 goby, 488 *Pseudorasbora parva* (minnow), and 70 *Oryzias latipes* (killifish). After *Ike-Boshi* was done, 1,000 adult male JRB, 700 adult female JRB, 1,000 young JRB, 72 mussels, 600 goby, 400 minnow, and 50 killifish were released into the pond. In the *Ike-Boshi* in January 2006, 533 adult male, 278 adult female, and 5740 young JRB were counted.?Young mussels born in 2005 together with older adults totaled 1,005. Other fishes collected were 563 goby, 124 minnow, and 145 killifish. After *Ike-Boshi*, 258 adult males, 91 adult females, 643 young JRB, 580 mussels (including 30 adults), 318 goby, 105 minnow, and 123 killifish were released into the pond. Other individuals were released into another pond for conservation and study.

3-1-1. Effect of pond drying on phytoplankton

Observations on the composition of phytoplankton in the experimental pond from March to July 2004 (before drying was performed on the pond) are summarized in **Fig.4(a)** and Table.1. The diatom Melosira dominated in April, but green algae and blue-green algae increased from May to July. Measurements of phytoplankton taken after drying was done on March 20, 2005 are shown in **Fig.4(b)** and Table.1. The small diatom Navicula increased abruptly in April, then decreased in May and June, during which time few increases in green algae were observed. In July a few green algae began to appear.

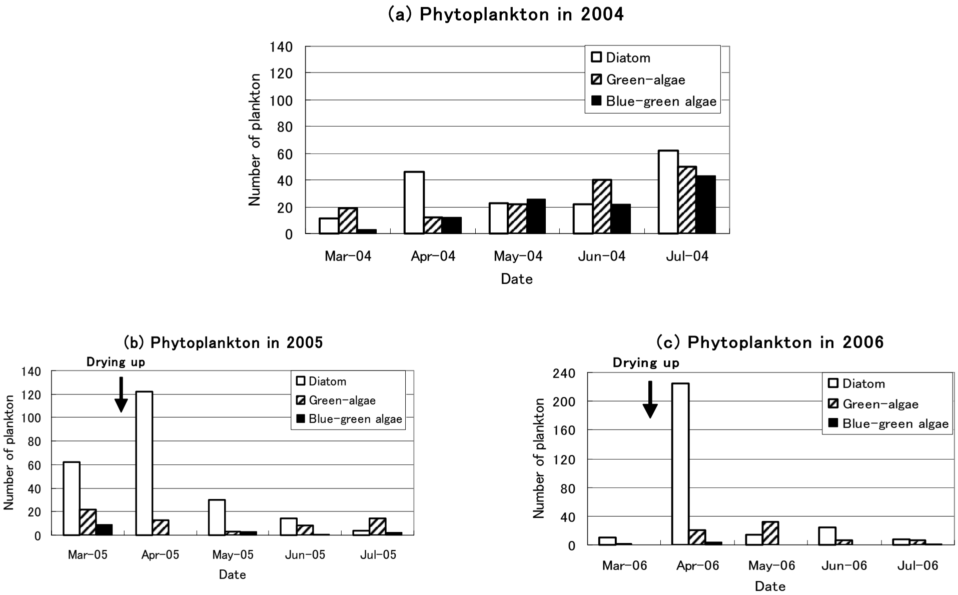

Fig.4. The number of individual phytoplankton in 2004, 2005 and 2006.

Phytoplankton measurements taken after pond drying in February 2006 are shown in **Fig. 4(c) and Table.1.** Little increase of phytoplankton was observed through March, but small-sized Navicula increased abruptly in April, then decreased in May and June, similar to in 2005. Increase in blue-green algae was hardly observed.

It is generally understood that the diet of adult freshwater mussels is mainly diatoms.[6), 7), 10)] It has also been shown that the presence of green and blue-green algae prevent adult mussel growth even when diatoms are present.[11, 12)] Our observations seem to indicate that the process of *Ike-Boshi*, by removing sediment sludge and drying bottom mud, allows for the proliferation of Navicula, which in turn become the main food source for mussel glochidium during their growth in April.

Table. 1. Numbers of phytoplankton (N/10^{-1}mL) observed March through July in 2004, 2005 and 2006

	2004(Date)					2005(Date)					2006(Date)				
(Genetic Name)	3/28	4/29	5/30	6/20	7/25	3/16	4/17	5/15	6/9	7/15	3/19	4/9	5/21	6/18	7/23
Diatom															
Navicula	7	3	2	2	6	13	79	7	1		1	175		1	
Nitzschia	2				3	10	3	5				1	1	2	1
Cymbella	1			2	5	5	5	1				3	1		
Melosira		33	16	12	18	12	8	12	7	2	1	5		5	1
Synedra		5	5	3	17	10	27	5	4		7	36	4	16	6
Cyclotella		4		1	8	7			2	2	1	2	7		
Surirella	1														
Amphora		1		1	2	4						1			
Gyrosigma				1	1							1			
Gomphonema						1							1		
Stauroneis					2										
Total	11	46	23	22	62	62	122	30	14	4	10	224	14	24	8
Green-algae															
Spirogyra	9	1	14	14											
Closterium	1														
Actinastrum	5	1	3		8				4	5				1	
Pediastrum		1	1	6											
Ankistrodesmus	4	1	1			1	2				1				
Scenedesmus		5	1	1	7	7	6	1		2		1	2		
Coelastrum			1	17	32	5	3	1							
Zygnema			1	1											
Staurastrum		1							1	1					
Dictyosphaerium									1						
Golenkinia		1							2	6					
Elakatothrix		1		1	2	4						20	30	3	7
Tetraspora					1	2								1	
Selenastrum						1									
Acanthosphaera						2	1							1	
Cosmarium							1	1							
Total	19	12	22	40	50	22	13	3	8	14	1	21	32	6	7
Blue-green algae															
Phormidium	2	3	14	16	24	8						4			
Nostoc		5	1	2	8				1	2					
Aphanocapsa			1	1		1									
Gloeotrichia	1	4	10	2	1			1							1
Microcystis					6										
Merismopedia					1			2							
Oscillatoria					1										
Chroococcus				1	2										
Total	3	12	26	22	43	9	0	3	1	2	0	4	0	0	1
Total	33	70	71	84	155	93	135	36	23	20	11	249	46	30	16
Distribution Ratio(%)															
Diatom	0.33	0.66	0.32	0.26	0.4	0.67	0.9	0.83	0.61	0.2	0.91	0.9	0.3	0.8	0.5
Green-algae	0.58	0.17	0.31	0.48	0.32	0.24	0.1	0.08	0.35	0.7	0.09	0.08	0.7	0.2	0.44
Blue-green algae	0.09	0.17	0.37	0.26	0.28	0.1	0	0.08	0.04	0.1	0	0.02	0	0	0.06

3-1-2. Reproduction of the freshwater mussel

The number of mussel glochidium living as parasites on goby tended to show its peak around March each year, as indicated in **Fig.5.** The average number of glochidium on a goby at the peak period of mussel reproduction was about 30 individuals in 2000 and 23 individuals in 2001. In 2002 the average was 7, and in 2003 only one. In 2004 they recovered to 10. In 2005 and 2006 when *Ike-Boshi* was done, the number increased to about 20 each year, although the number was lower than the previous high point.

In 2005, following *Ike-Boshi*, 17 individuals of young mussel were found for the first time on June 19, then 100 individuals on July 24, 118 on August 21 (including 8 individuals which were marked), and 273 on September 18 (including 41 marked individuals). All 100 individuals collected on July 24 were found in the experimental section, and no individuals were found in the control section.

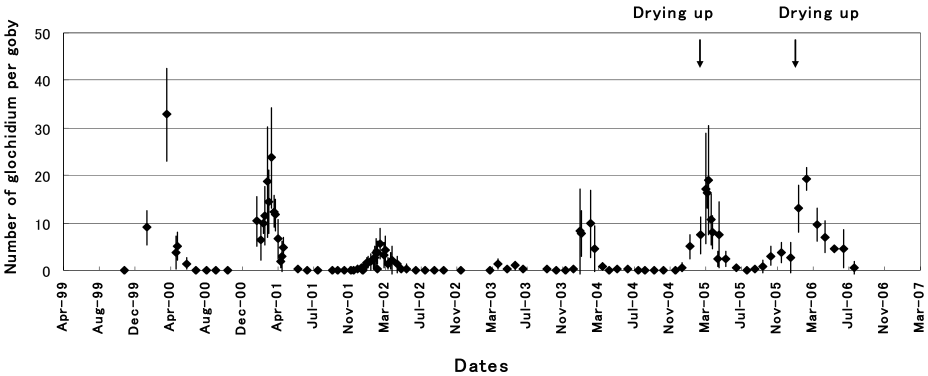

Fig.5. The number of individual glochidium as parasites on the goby in the experimental pond. The vertical bars show the standard deviation (SD).

Regarding the development of young mussels, shown in Figure 6, a total of 270 individuals in 1999 and 130 in 2000 were found. In 2001, however, when the water quality worsened, no individuals were found, and only 5 to 10 individuals were found from 2002 to 2004. After *Ike-Boshi* in 2005, the total number of marked individuals counted was 409 on October 16. Using the mark-and-recapture method, on November 20th, the number of individuals was estimated as $409 \times 142 \div 51 = 1{,}139$. In October 2006 the estimate was 1,300.

In Figure 5 showing the number of parasitic glochidium on the goby, there is only

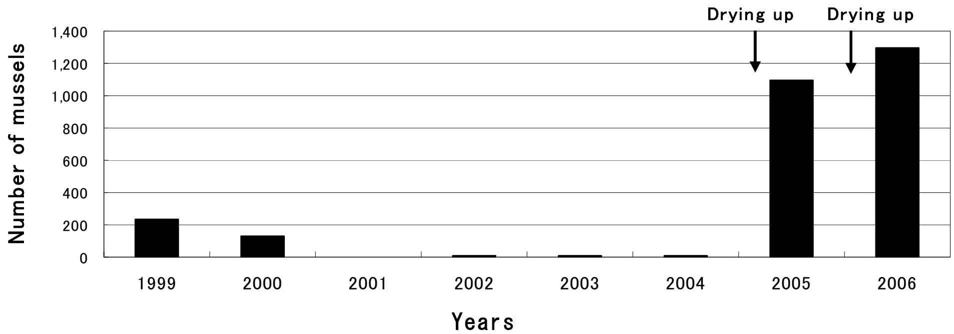

Fig.6. Development of young mussels in the experimental pond .

a small difference between 2001, 2005 and 2006. The development of young mussels, however, shows a great difference, as is evident from **Fig.6.** There were no individuals in 2001, yet more than 1,000 in both 2005 and 2006. These numbers indicate that the key to mussel development is in the period from April, when the glochidium drops from the goby, through June, when young mussels reach 7 mm in length.

3-1-3. Number of eggs laid by JRB

The average number of the eggs of JRB laid into the mussels at the peak period of spawning was 62±31 (average ±SD, n=9) on July 6 in 2003, 50±37 (n=10) on June 20 in 2004, and 71±50 (n=15) on May 15 in 2005. As JRB eggs remain in the mussels for about a month,10) the total number of JRB eggs was estimated by the total number of mussels (46 individuals in 2003, 46 in 2004, 72 in 2005, and 580 in 2006) multiplied by the average number of eggs each month. As shown in **Fig.7,** the total number of eggs laid was estimated at about 4,300 in 2003, about 6,500 in 2004, and about 13,700 after *Ike-Boshi* in 2005. After *Ike-Boshi* in 2006, the total number of eggs laid was estimated at 22,200, far surpassing that of 2005. There were 200 mature JRB females in March 2003, 700 in March 2004, 700 in March 2005, and only 91 in March 2006. As a result it became clear that the most significant factor affecting the number of JRB eggs was density of mussels rather than number of mature JRB females.

3-2. Relationship between drying and ORP

Collecting mud from five spots in the experimental pond in July 2006, average ORP was-143±20 mV (average±SD, n=5), which showed that it was reduced mud. Contrastingly, the mud that had been taken from the pond bottom and left in the

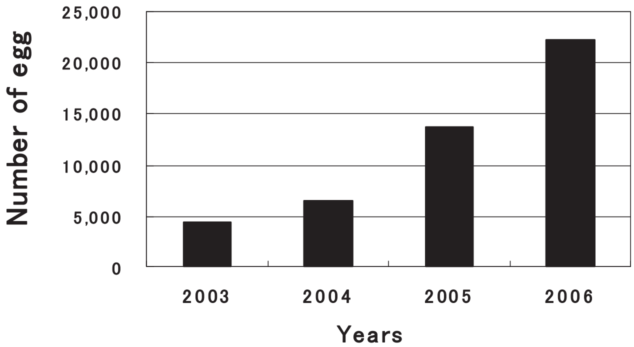

Fig.7. Estimated number of eggs of JRB in the experimental pond.

open for a year (that is, had become soil) averaged +281±14 mV (n=5), which showed that it was oxidized soil. Reduced mud with ORP of -200 mV changed to oxidized mud with ORP +150 mV after drying in the sun for a week, as shown in Section 3.3.2.

It was considered that *Ike-Boshi* in March removed the upper layers of bottom sludge and changed the remaining reduced mud into oxidized mud, which helped nurture the small-sized diatom Navicula on a large scale in April, when the glochidium of the freshwater mussels, feeding off the diatoms, grow.

3-3. Relationship between chemical characteristics of pond bottom and pond life

3-3-1. Relationship among phytoplankton, mussels and ORP

The distribution of mussels in the pond is shown in **Fig.8.** Young mussels (0+) born in 2006 are distributed widely at a depth of 20-40 cm, especially in the shallows of the northeast and southwest corners. The mussels born in 2005 (1+) are found a little deeper, and those born in 2004 (2+) and 2003 (3+) still deeper. In the northeast corner (Fig.3), spots 4 (+86 mV), 13 (+20 mV), and 19 (+10 mV) showed positive ORP values. The lowest value was found at the deepest spot, 17 (-145 mV), while the second lowest was spot 15 (-130 mV) at the northwest of the pond. Diatoms were plentiful at spots 4 and 19 where ORP was positive, whereas the blue-green algae Oscillatoria bred strongly at spots 17 and 15, where ORP was negative.

The above results are interpreted to mean that oxidized mud enhanced diatom breeding and suppressed growth of green and blue-green algae. The results also indicate that young freshwater mussels grow actively on spots where diatoms breed well.

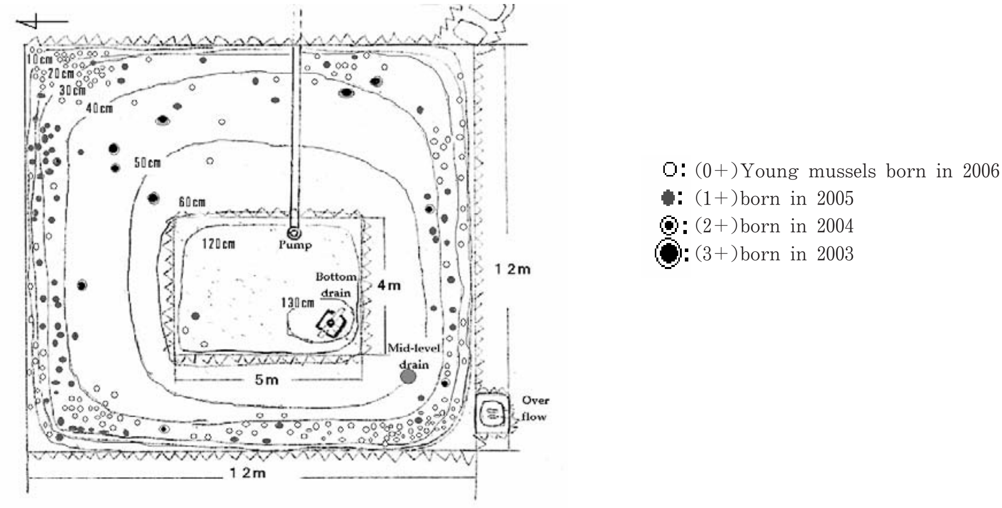

Fig.8. Distribution of the mussels collected August 27th, 2006.

3-3-2. Chemical characteristics of dried mud

Analysis of the mud and soil left at 20℃ in light of 3,000 Lx is detailed in **Fig.9.** It was found that the reduced mud contained a high concentration of ammonium ion (NH_4^+) on the first day, and increased nitric ion (NO_3^-) after 8 days. However, the value approached almost 0 on the 15th day. The concentration of Fe ions and silicon dioxide (SiO_2) decreased and approached almost 0 on the 15th day. On the other hand, the oxidized soil contained less than one mg/L of ammonium ion (NH_4^+) and nitric ion (NO_3^-), which did not increase, although Fe ions increased gradually. In oxidized soil the concentration of SiO_2 held steady for much longer than in reduced mud. One month later, in the oxidized soil many diatoms grew (**Photo.2**), whereas in the reduced mud not only diatoms but also numerous blue-green algae grew (**Photo.3**).

We consider that the reduced mud on the pond bottom caused eutrophication because it contained high concentrations of ammonia and organic matter, and led to growth of blue-green algae as well as diatoms. Also, mud removed after draining the pond, then dried, contained minimal sulfide and nitrogen, and changed into oxidized soil with a high concentration of silicon dioxide, and led to large-scale growth of small diatoms.

Analysis of the supernatant of the dried mud is summarized in **Fig.10.** After two weeks an increase of iron ions and silicon dioxide was observed; ammonium ions were

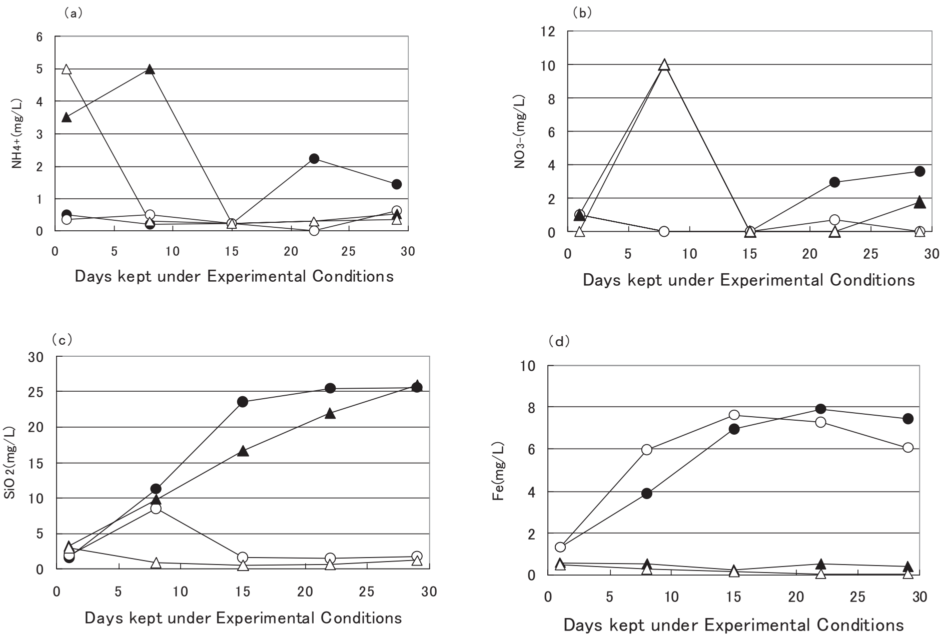

Fig.9. Concentration profiles of inorganic ions in the supernatant of dried (oxidized) soil and reduced mud left in dark and light conditions. (a) Ammonium ion, (b) Nitric ions, (c) Silicon dioxide (SiO_2) and (d) Fe ions.
—●— Oxidized soil (in dark)
—○— Oxidized soil (in light)
—▲— Reduced mud (in dark)
—△— Reduced mud (in light)

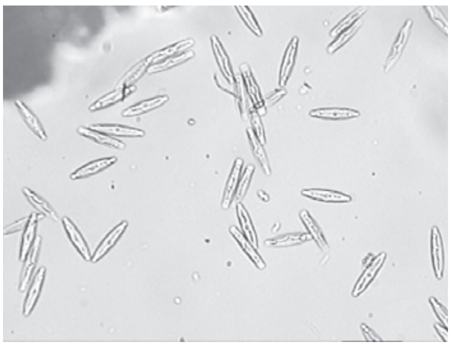

Photo.2. Diatom growing in oxidized soil.

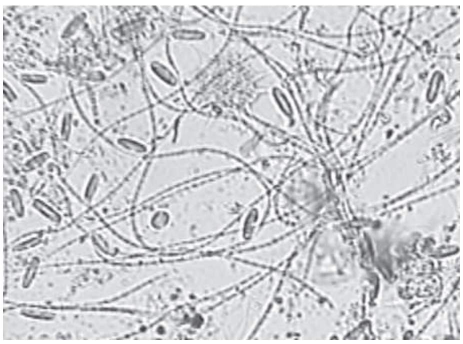

Photo.3. Diatom and blue-green algae growing in reduced mud.

still present after a month. The increase in iron ions was attributed to iron(+2) sulfide being removed from iron sulfide in the mud and changed into iron (+3) oxide, which

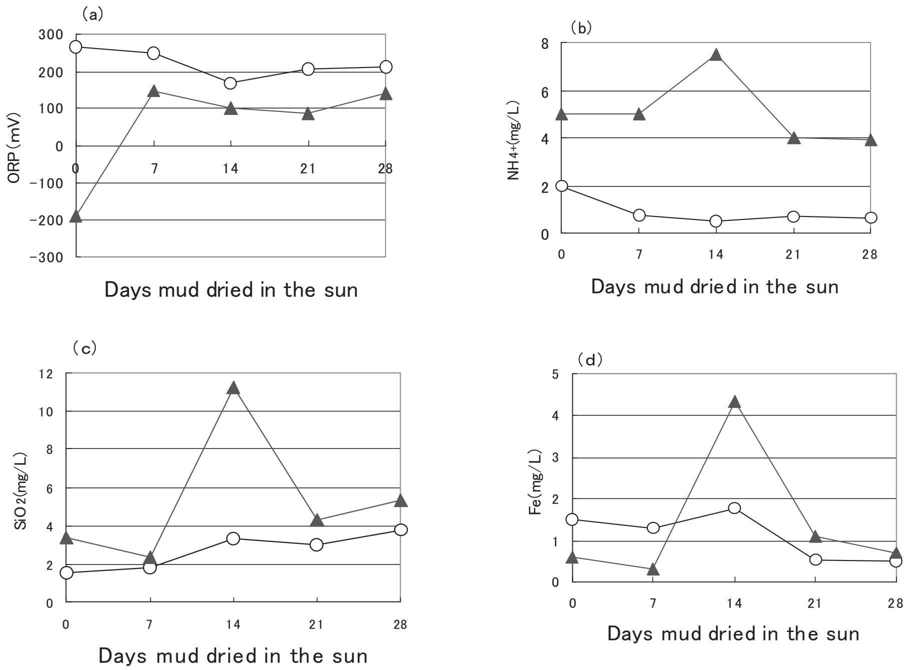

Fig.10. Change in ORP and in concentrations of inorganic ions in the supernatant of oxidized soil and dried mud. (a) ORP, (b) ammonium ions, (c) silicon dioxide (SiO_2), and (d) Fe ions.
—▲— Dried mud (from pond bottom)
—○— Oxidized soil

has a higher solubility.

4. CONCLUSION AND FURTHER RESEARCH

In November, during the agricultural off-season, by means of *Ike-Boshi* - draining and drying of farm ponds - nutrient-rich sludge is removed from ponds and reduced mud changed chemically into oxidized mud. Through drying in the sun and exposure to weather, surplus nutrition is eliminated from this oxidized mud, and the concentration of silicate is maintained in it. The following April, with new water in the ponds, a large number of small-sized diatoms grow, while growth of green and blue-green algae is suppressed. Larvae (glochidium) of freshwater mussels, which reach their peak breeding in March, begin to live on the pond bottom and eat the small-sized diatoms, allowing a great number of young mussels to develop in the pond. It is considered that the number of JRB is strongly correlated with the number of mussels. The entire pond ecosystem is thus maintained, permitting not just the survival, but the abundance, of life there.

According to the manager of a local fishery, when *Ike-Boshi* is not done, eutrophication advances, and the minnow catch (normally 1,000 kg) decreases by about 20% annually, becoming half (500 kg) of the original catch in just 3 years. Yet when it is practiced, the catch is likely to return to its previous state. In addition to preserving aquatic biodiversity, the great numbers of goby, bitterling, mussels, and other forms that appeared when *Ike-Boshi* was performed in our experimental pond, point directly to *Ike-Boshi* as one solution to the world's food problem.

Through our research, it became clear that another major food concern, grain agriculture, also stands to gain from the practice of *Ike-Boshi*, which since ancient times has supplied vital nutrients (such as NH_4^+) to rice paddies. We found that in the agricultural fields using the drained sludge, toxic substances such as hydrogen sulfide were removed, and sources of nitrogen such as ammonia were being reused.

Our research thus scientifically proves the value of what our predecessors have accomplished by naturally taking advantage of the mountainous topography and monsoon climate: simultaneous suppression of eutrophication and reuse of resources, resulting in abundant aquatic life and preservation of biodiversity, as well as in successful repeat cropping without synthetic fertilizers.

With the mystery of *Ike-Boshi* largely solved, and the benefits of draining and drying farm ponds becoming clearer, we are planning to implement the practice in several more farm ponds in our local area in Japan. By demonstrating the benefits of reversing eutrophication and its many adverse effects, we want to lead the way in recovering and strengthening the world's fisheries and its aquatic biodiversity, in providing clean water and combating eutrophication in rivers, lakes, and marshes, and in increasing the efficient use of nature's scarce agricultural nutrients.

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