Oligotrophic Water Caused by Excessive Litter Accumulation in Western Japan

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<Abstract>

Oligotrophic conditions were caused and kept by excessive litter accumulation. In the old days, upper stream terrace rice fields were used and people gathered trees and leaves, and then litter was not accumulated. However, abandoned terrace rice fields, with many weirs, reserved water and litter as the life styles of inhabitants changed and inefficient upper stream terrace rice fields were abandoned. A lot of litter was decomposed using oxygen in water and NO_3^- and Fe hydroxide were consumed into N_2 gas and Fe ion under reductive conditions by decomposition of litter. The consumption of NO_3^- lead to oligotrophic conditions and very rare oligotropjic plants were found. The water plants in the pond with high Fe concentration water contained a high Fe concentration. And Fe concentration in trees and leaves on the ground were very low. The source of Fe derived from weathered granite. Therefore, best way to reserve oligotrophic plants was not to dig out excessive litter and humus, but to keep thick sediment composed of litter and humus in the waterfront.

Key words: oligotrophic condition, weathered granite, terrace rice field, litter, reductive condition

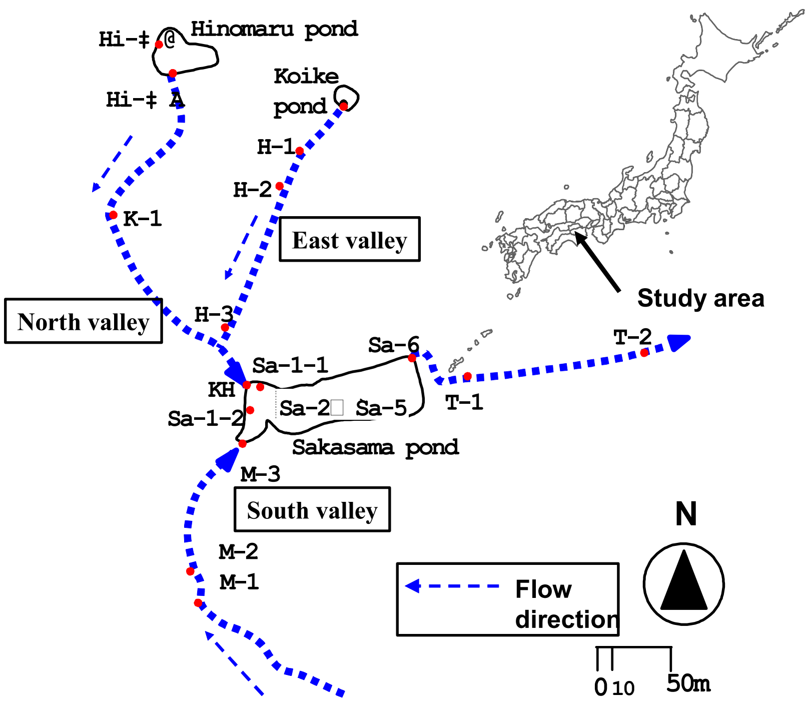


Fig.1 Study area (Shikoku Island)

1. Introduction

Japanese rice fields of yesteryear were cultivated widely and the narrow valleys of upper stream areas were also used for terrace rice fields. Small upper stream terrace rice fields were surrounded by trees and unproductive because of shade. Therefore, rice demand decreased and inefficient upper stream terrace rice fields were abandoned. Furthermore, the life styles of inhabitants changed. Trees and leaves were not gathered for fires and small ponds in the upper streams of rivers with terrace rice fields for agriculture were not conserved because most people who owned rice fields gained their income from town work and only engaged in agriculture only on holidays. Resultantly, large amounts of leaves and humus were deposited in ponds and terrace rice fields and abandoned terrace rice fields.

Fig.1 shows the study area in Shikoku Island, western Japan. In the study area also upstream rice fields with ponds were abandoned and large amounts of leaves and humus were deposited in ponds and terrace rice fields. The Japanese government has constructed a nature park there to reuse the abandoned land. However, as the dominant species in the Sakasama pond are oligotrophic plants such as Egg bonnet, Potamogeton fryeri, Utricularia tenuicaulis Miki and Nymphaea tetragona Georgi etc and then these plants include a very rare species and small amount of plants are found in the area, to protect these rare plants and conditions was needed and in the process, the best way to keep them was studied. Generally, oligotrophic plants are found at a wetland with peat soil in Japan. A wetland with peat soil is found northern Japan or high altitude area where temperature in both areas is lower than that in the study area. Therefore, in spite of high temperature, oligotrophic plants are found in the Sakasama pond and then these plants are rare. Thereat, the purpose of the study is to clarify why oligotrophic plants are reserved in the area and how to keep the condition or oligotrophic plants.

Before the study, much litter and humus at the bottom of ponds and abandoned terrace rice fields were dug out to keep waterfront from excessive litter and humus deposits because litter and humus change finally into nutrient.

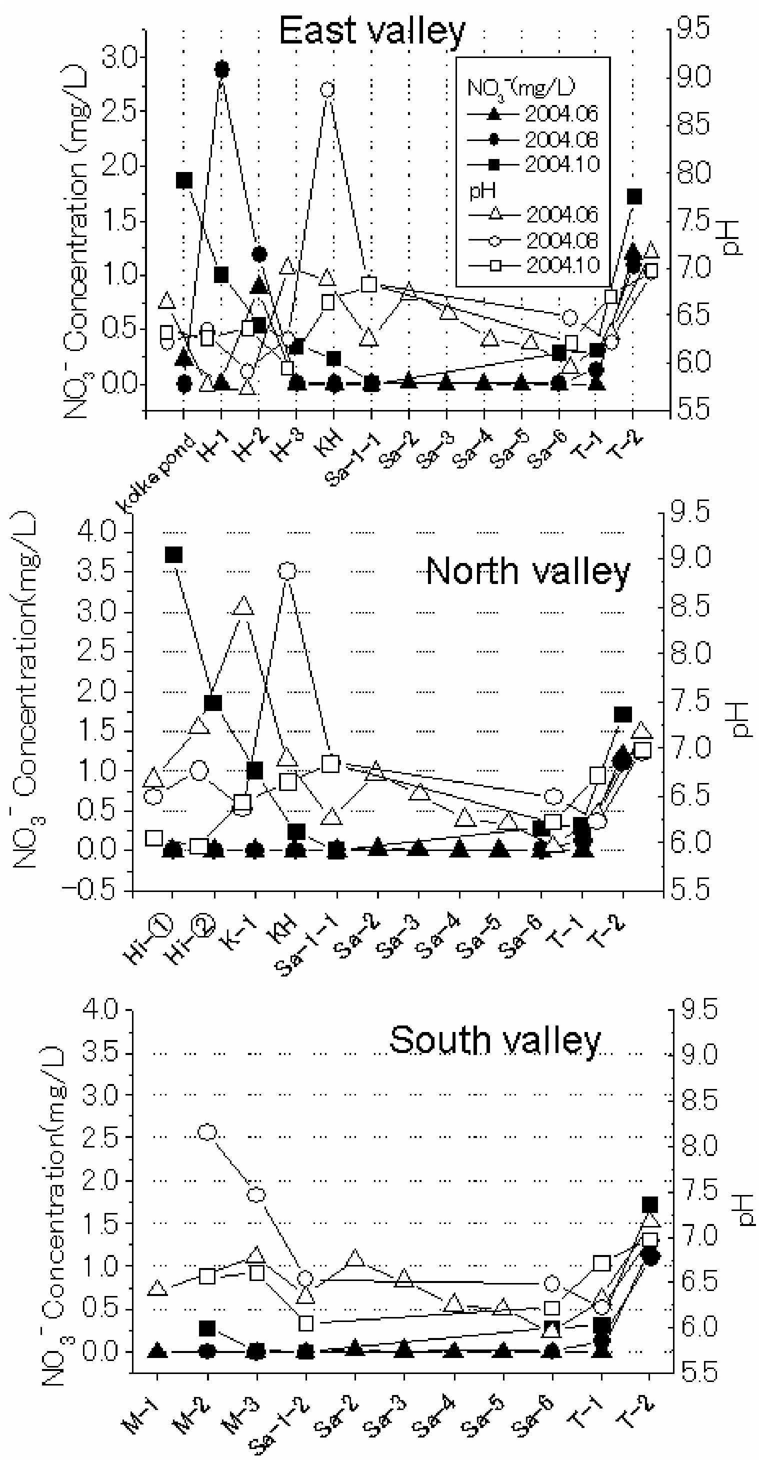


Fig.2 NO_3^- concentration and pH along rivers

2. Study area and method

The study area is the hill at the north slope of the Sanuki mountains including a previously upstream terrace rice field and now abandoned wetland with ponds along small rivers shown in Fig.1. The ponds are also previously used for supplying water into abandoned rice fields. There are three rivers flowing the Sakasama pond. Two rivers start from small ponds, the Hinomaru pond and the koike pond. All ponds were used for rice fields and now abandoned. The Sakasama pond is 100 m in length, 50 m wide, and the maximum depth 2.5 m. River water from the Sakasama pond flows into the Toki River. The structure of terrace rice field was still remained and along the river many weir was remained. These weirs and gentle slope can keep water and a lot of litter and humus. The slope gradient was 0.055 to 0.08. The hill altitude is 100 to 200 m and land is covered with broad-leafed forest. The monthly maximum and minimum temperatures of the study area are 33 and 2 degrees C respectively.

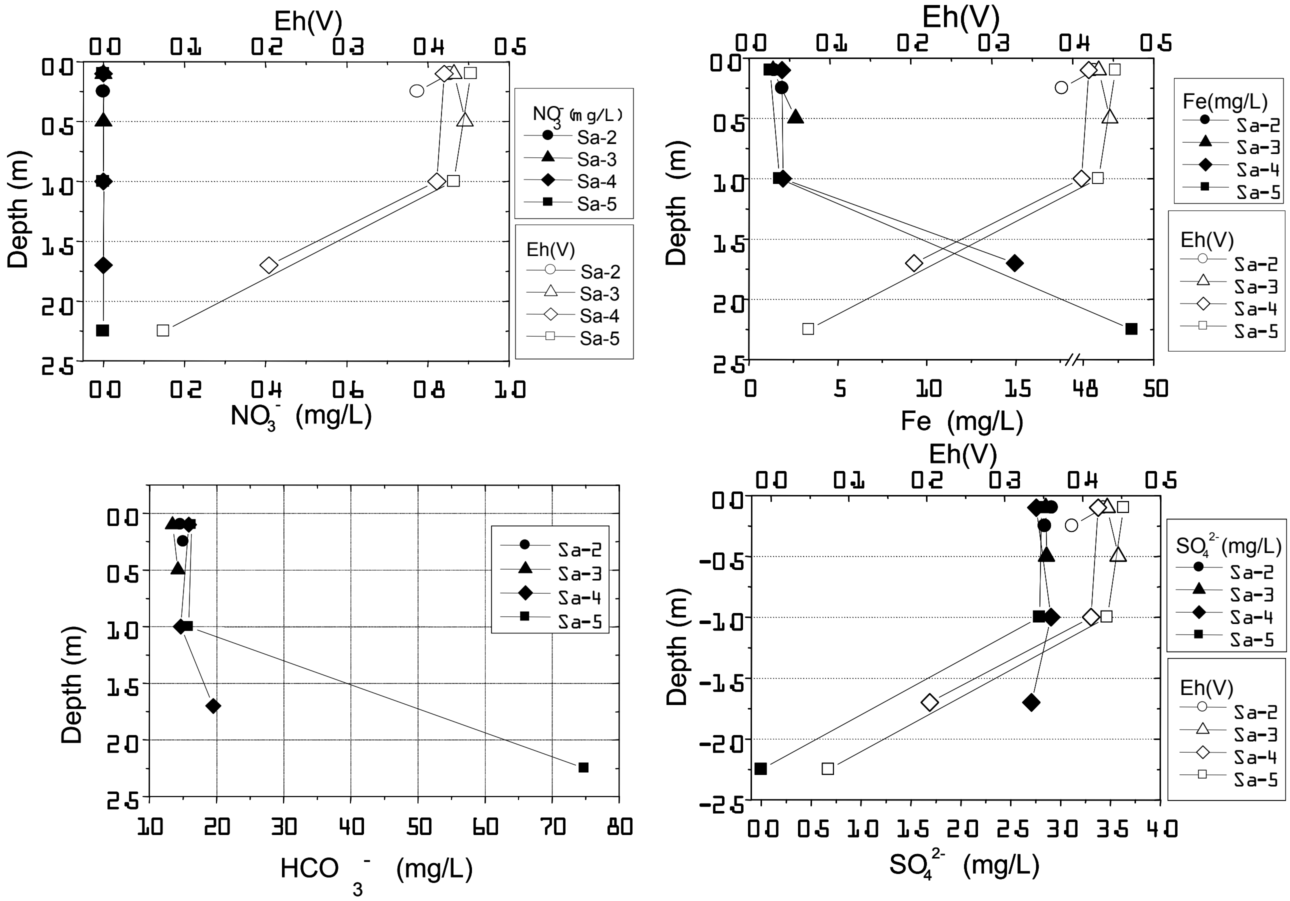


Fig.3 Vertical Changes of Eh and soluble substances in the Sakasama pond in September 2003

Precipitation is 1120 mm per year in the area so the area has a suitable temperature and precipitation conditions for decomposing litter by bacterial respiration.

Water sampling and measurement of pH and ORP in-situ using portable measurement instruments were performed at the points shown in Fig.1 from July 2003 to October 2005. In the Sakasama pond, vertical sampling with 0.5 m interval was performed. Nitrate, ammonium and sulfate ions for sampled water were analyzed by ion exchange chromatography (DX-AQ/ DIONEX) in the laboratory. Fe ion concentrations in water, leaves and plants were analyzed by ICP-AES method (SPS1700HVR /Seiko Instruments). Leaves and plants were dried and Fe ion of them was dissolved by nitrate acid.

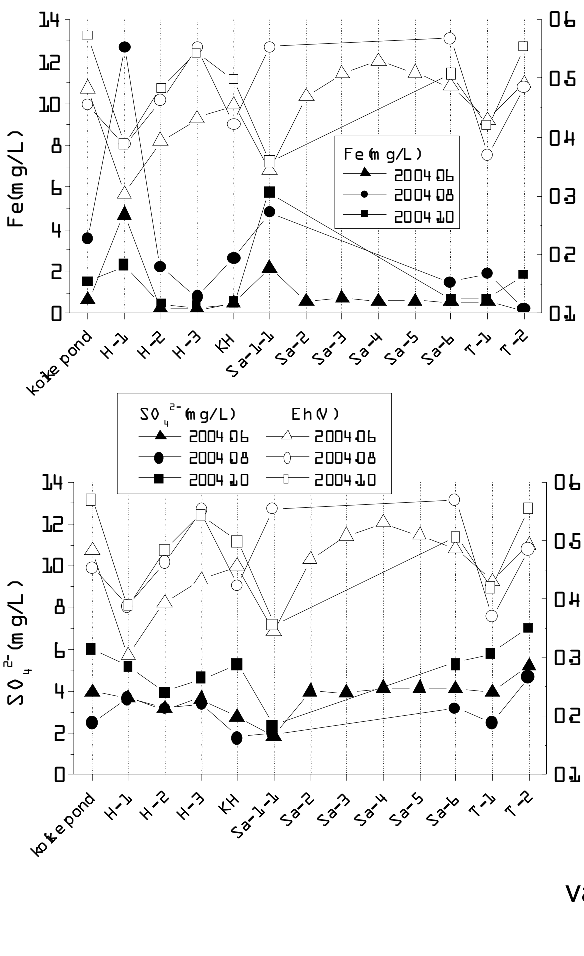


Fig.4 Fe and SO_4^{2-} concentrations and Eh values

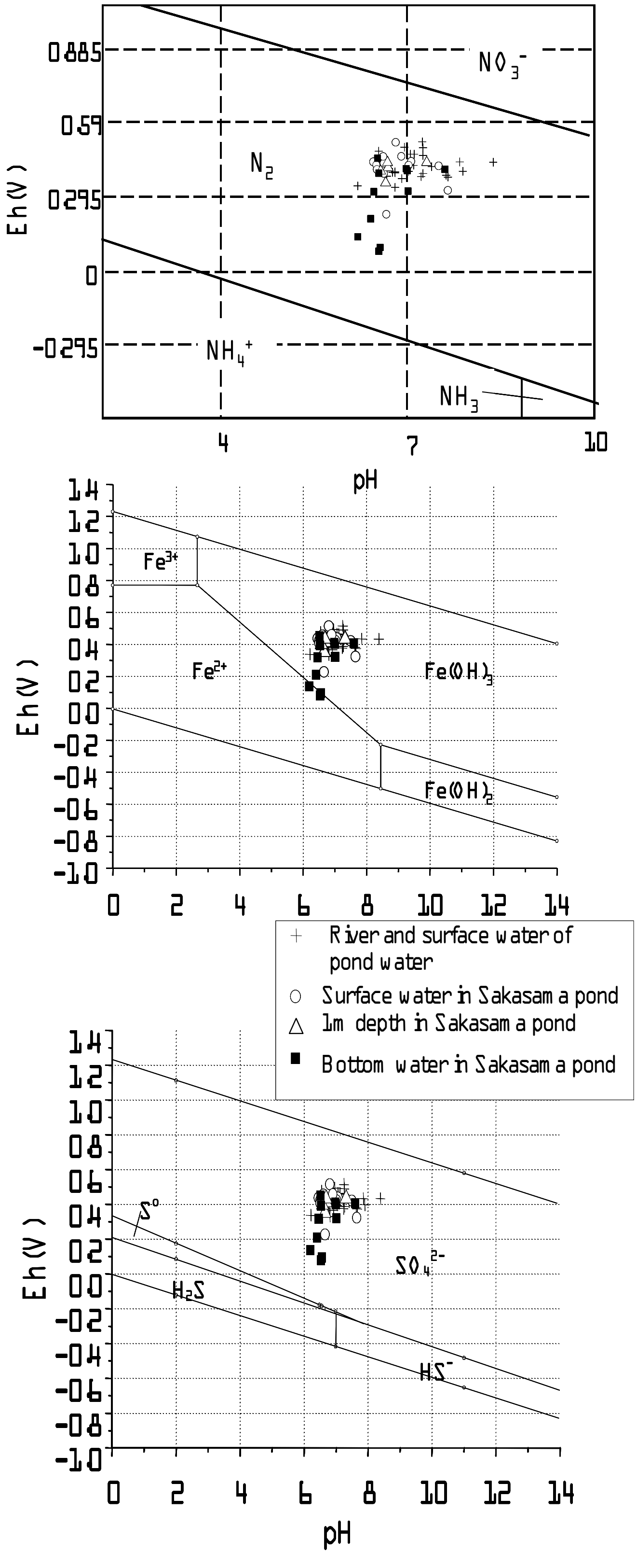


Fig. 5 pH and Eh diagrams of N, Fe and S

3. Results

3.1 Nitrate

Fig.2 shows NO_3^- concentrations and pH values of river and surface pond water along the three rivers. NO_3^- concentrations along all three rivers before flowing into the Sakasama pond were 0 to 3.5 mg/l and then decreased to be 0 mg/l in the Sakasama pond. Down the stream of the Sakasama pond, NO_3^- concentrations increased all season. NO_3^- concentrations in the upstream were high and reached to be over 3.5 mg/l in October. However, in the Sakasama pond, NO_3^- concentrations were very low.

pH values were 6 to 6.5 and pH values were sometimes 7 to 9 before flowing into the Sakasama pond. Down the stream of the Sakasama pond, pH values increased from 6 to 7 all season. As oligotrophic plants were found mainly in the Sakasama pond and NO_3^- concentrations in the Sakasama pond were very low, low nutrient was thought to grow oligotrophic plants and then the Sakasama pond was important for analyzing oligotrophic condition. Next, water chemistry in the Sakasama pond was studied in detail.

3.2 Sakasama pond

The Sakasama pond was 2.5 m in depth and vertical sampling and Eh values measurement were performed. Fig.3 shows vertical changes of Eh and soluble substances in the Sakasama pond in September 2003. Eh values from surface of pond to 1m in depth 0.4 V and decreased to be less than 0.1 V with depth indicating reductive condition. NO_3^- concentration was 0 mg/l at all depth and HCO_3^- concentration was about 15 mg/l from the surface to 1 m in depth and then increased with depth and reached to be about 75 mg/l. Similarly Fe ion concentration was a few mg/l from the surface to 1 m in depth and then increased with depth and reached to be about 50 mg/l. Then, Eh value decreased with increase of Fe ion concentration. SO_4^{2-} concentration was uniform till 1 m in depth and then decreased to be 0 mg/l with depth. At the bottom, Fe ion concentration was extremely high and SO_4^{2-} concentration was very low and then reductive condition was kept.

3.3 Fe and SO_4^{2-}

As extreme high Fe concentration and low SO_4^{2-} concentration were found in the Sakasama pond, Fe and SO_4^{2-} concentrations and Eh values in the river system were measured. Fig.4 shows Fe and SO_4^{2-} concentrations and Eh values of river and surface pond water along the river. High Fe concentrations were found before flowing into the Sakasama pond and Eh values also were low when Fe concentrations were high. On the other hand, SO_4^{2-} concentrations were low only at the entrance of the Sakasama pond. At the entrance of the Sakasama pond, many litters were accumulated. Therefore, reductive condition was important for soluble substance concentration and litter was thought to make reductive condition. Next, stable condition was considered.

3.4 Stable condition

Usually organic compounds are decomposed by bacteria using oxygen but with lack of oxygen, NO_3^-, Fe hydroxide and SO_4^{2-} are used. Organic compound is decomposed into NO_3^- using oxygen as the following equation (1).

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138O_2 = 106CO_2 + H_3PO_4 + 122H_2O + 16H^+ + 16NO_3^- \quad (1)$$

Then, litter and humus are decomposed into NO_3^- on the ground under oxidative condition. On the other hand, at the bottom of the pond and on the river, a lot of litter and humus are deposited because in particular, abandoned terrace rice fields have many small weirs. Then lack of oxygen is kept there because a lot of litter and humus consume oxygen and it is not easy to supply oxygen into pond at the bottom from air. Therefore, litter and humus on the river and pond can make reductive condition. Low Eh values at the bottom of the pond were thought to be consumption of oxygen by decomposition of litter and humus.

Fig. 5 shows pH-Eh diagram of N, Fe and S under the condition of 25 degree C and 1 atm pressure with total Fe 10^{-4} mol /l. All sampled river pond waters are plotted in the center of N_2 area in Eh-pH diagram and NO_3^- is stable under more oxidation condition. Under reductive condition, organic compounds such as litter and humus are decomposed using NO_3^- by bacterial denitrification as the following equation (2).

$$\text{Organic compounds} + 2NO_3^- + 2H^+ = 2.5CO_2 + N_2 + H_2O \quad (2)$$

NO_3^- derived from litter and humus under oxidative condition was thought to be consumed under reductive condition by denitrification along the rivers and then NO_3^- concentration was not thought to be very low. In particular, at the bottom of the pond, HCO_3^- concentration was high and then some of HCO_3^- was thought to derive from CO_2 gas produced by denitrification.

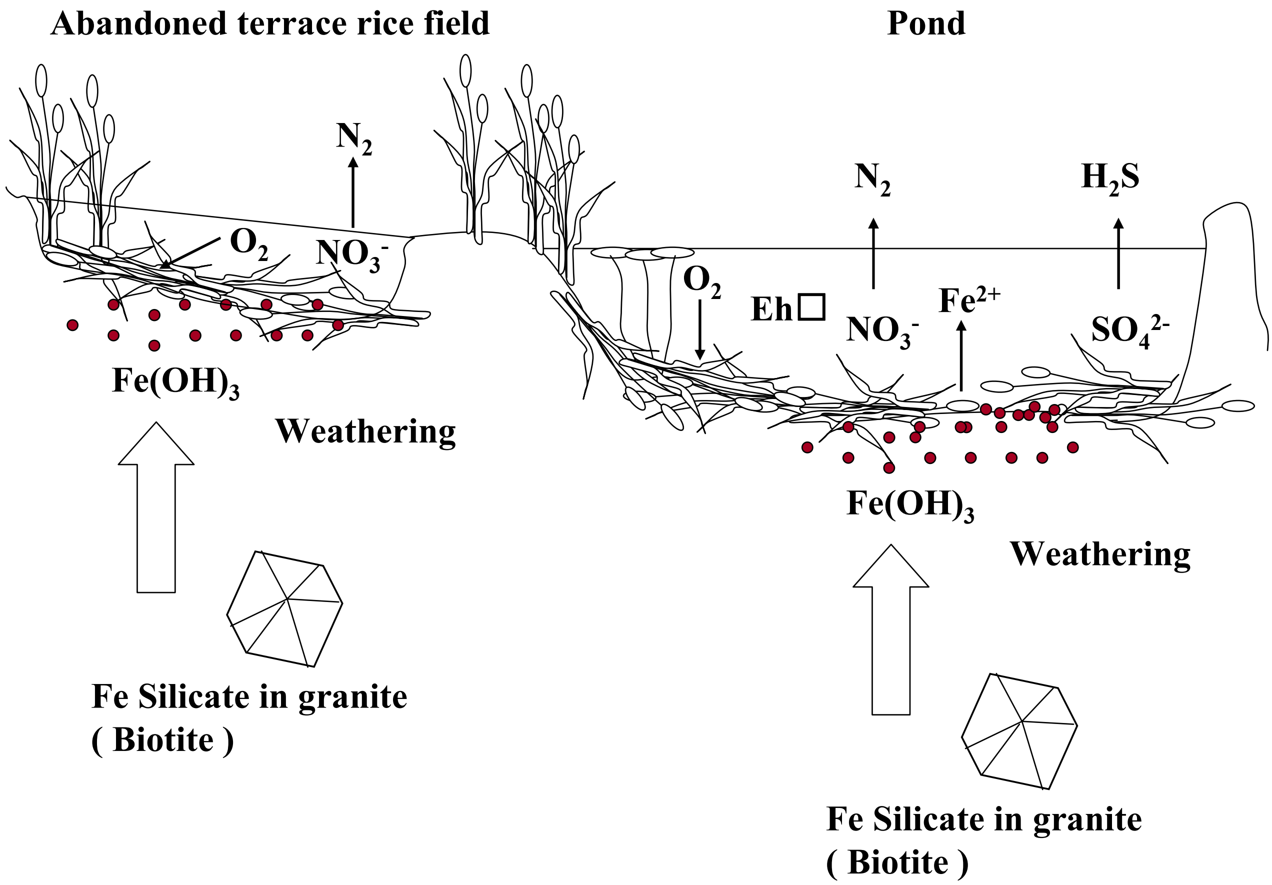
$Fe(OH)_3$ is stable for most of water but at the bottom of the pond, Fe^{2+} is stable. In particular, inside of litter and humus sediment at the pond, Eh values were thought to be lower and then Fe^{2+} was more stable and actual Fe concentration at the bottom of the pond was very high. As well as NO_3^-, organic compounds are decomposed using Fe hydroxide by bacteria as the following equation (3).

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4+424FeOOH+848H^+ = 424Fe^{2+}+106CO_2+16NH_3+H_3PO_4+742H_2O \quad (3)$$

Therefore, according to equation (3), Fe ion was thought to be produced with reductive condition although the source of Fe hydroxide must be clarified.

SO_4^{2-} is stable for all water along the rivers and low SO_4^{2-} concentration water was not found. However, partially inside of sediment such as litter and humus of pond, some SO_4^{2-} was thought to be consumed because smell of H_2S was detected from the sediment by destroying sediment.

Fig. 6 Schematic diagram of N, Fe and S changes under reductive condition



As well as Fe and NO_3^-, organic compounds are decomposed using SO_4^{2-} by bacteria as the following equation (4).

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4+53SO_4^{2-} + 106H^+ = 53H_2S + 106CO_2 + 16NH_3 + H_3PO_4 + 106H_2O \quad (4)$$

Therefore, a lot of litter and humus were thought to consume oxygen in river and pond waters and then to make a reductive condition. Under reductive condition, consumption of litter and humus was thought to produce Fe ion and to consume NO_3^- in water. Partially, SO_4^{2-} was also thought to be consumed.

3.5 Fe source

Fe concentration of litter or humus was studied. Fe concentrations in most of dried leaves and plants such as Japanese cedar, fern, Prunus, bamboo grass, camellia, rhododendron, viburnum, and abelia on the ground were less than 0.1 mg/g. Some water plants in the Sakasama pond showed high Fe concentration but these plants grew under high Fe ion concentration. Fe concentration of water shield in the Sakasama pond was 2.5 mg/g. Fe source was thought not to derive litter and humus but to derive from soil or rock. This area is covered with weathered granite. Usually Fe concentration in granite is over several %. Fe mineral is originally silicate and Fe is not easy to resolve. However, Fe mineral in granite was thought to change into Fe hydroxide by weathering and then Fe hydroxide in weathered granite was thought to be Fe source because Fe hydroxide mineral is easier to resolve than Fe silicate mineral. We have two types of granite, ilmenite series granite and magnetite series granite in Japan. Original Fe minerals in Ilmenite series granite and Magnetite series granite are biotite and magnetite respectively. Magnetite is strong mineral for weathering but biotite is easy to change into Fe hydroxide. The study area is covered with ilmenite series granite and then Fe hydroxide derived from weathered ilmenite series granite was thought to be Fe source.

4. Conclusion

Japanese rice fields of yesteryear were cultivated widely and the narrow valleys of upper stream areas were also used for terrace rice fields. However, inefficient upper stream terrace rice fields were abandoned and trees and leaves were not gathered for fires because of life style of inhabitants change. Then the remained weir with terrace rice field and pond reserved water and large amount of leaves and humus.

Consumption of oxygen by decomposition of excessive litter and humus in pond and river made reductive condition in water and under reductive condition excessive litter and humus in pond and river were decomposed by consuming NO_3^- and then water remained low nutrient. Under low nutrient condition, rare oligotrophic plants such as Egg bonnet, Potamogeton fryeri, Utricularia tenuicaulis Miki and Nymphaea tetragona Georgi etc. were thought to grow. Therefore, best way to reserve oligotrophic plants was not to dig out excessive litter and humus but to keep thick sediment composed of litter and humus in waterfront.

Under reductive condition decomposition of excessive litter and humus in pond and river changed Fe hydroxide into Fe^{2+} and then high Fe ion concentration both water and water plants were found in the pond and river. Fe source was thought to derive from Fe mineral in weathered granite.

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