THE APPLICATION OF DEEP SEA WATER IN JAPAN

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ABSTRACT

Deep sea water (from a depth of more than 200 m) has cold temperature, abundant nutrients, and good water quality that is pathogen-free and stable. Basic research on the utilization of this water for fisheries in Japan began in 1976 and at present, deep-seawater pumping systems are established in Toyama and Kochi Prefectures and under construction in Shizuoka and Okinawa Prefectures. The research emphasis of many national organizations, prefectures, universities, and private companies is shifting from basic research to feasibility studies or practical applications of deep sea water. For example, in Kochi Prefecture, located in southern Japan, it was found that deep sea water is advantageous in the aquaculture of cold-water species. Current fisheries-related projects include:

- aquaculture (sea vegetables, fishes, shellfish, etc.)
- basic research on deep sea organisms
- restoration of sea grass habitats

A wide range of projects unrelated to fisheries that are utilizing deep sea water to develop new industries and contribute to local economies include:

- the food industry
- medical treatment facilities
- cooling water for power stations
- agriculture of cold climate vegetables

Future investigations should focus on further explorations of deep sea water attributes, a cascade system for using deep sea water, reduction of costs, and potential environmental impacts.

INTRODUCTION

Currently, the ultilization of deep sea water (DSW) is receiving much attention due to its high productivity, large quantity, and potential for recycling energy. Deep sea water, accounting for 95% of all sea water, generally refers to sea water from a depth of more than 200 m. DSW circles the globe over a period of about 2000 yr, and the up-welling of DSW occurs regularly in the oceans and seas throughout the world. Although it constitutes no more than 0.5% of all water in the seas, up-welled deep sea water is highly productive, supporting nearly 50% of all sea products. With the worldwide population explosion contributing to an ever-increasing consumption of animal protein, the focus on aquaculture will undoubtedly also intensify. The high productivity of DSW as a renewable energy source may increase the role of aquaculture to cultivate food for the expanding human population.

History of Research on the Uses of Deep Sea Water

Research on the applications of DSW is occurring worldwide, particularly in Hawai‘i, USA, at the Natural Energy Laboratory of Hawai‘i Authority (NELHA), and in Norway. The focus in Japan on the research and developmental studies for further applications of deep sea water forms the basis of this paper.

The history of research efforts in Japan on the applications of DSW is depicted in Table 1 (Nakajima 1998). In 1976, basic research efforts were begun by the Agency for Science and Technology. Between 1976 and 1986, we conceptualized deep sea water, developed an understanding of the characteristics of deep sea water, and developed the technology for the pumping of DSW. From 1986, the agency funded a 5-yr research program which resulted in the establishment of deep-seawater pumping systems in Kochi and Toyama Prefectures.

Table 1. History of research.

1976	Basic research
1986	Granted by the science and technology agency
1989	Water pumping systems in Kochi and Toyama Pref.
1997	Exploration of practical applications

Water Pumping Systems in Japan

In 1989, a buoyant catenary system of pumping water was installed in Toyama Bay, Toyama Prefecture, to examine whether on-site productivity could be increased by mixing deep sea water with surface water. That system was replaced by an above-ground system in 1994. In Kochi Prefecture, the first above-ground system of water pumping was installed in 1989 and the second in 1995. Some of the intake water has been shared with private companies, which have designed many products around the use of deep sea water. In Okinawa Prefecture, private companies jointly installed a buoyant catenary system called "Umi-Yakara 1-gou" (Fujii 1998), bringing the number of locations with DSW pumping systems in Japan to three (Fig. 1).

In 1997, egg production of cold-water organisms such as Japanese flounder was accomplished in Kochi Prefecture using DSW (Okamura and Doi 1998). This led to the shift from basic research to feasibility studies and further exploration of practical applications.

The quantity of DSW intake is 920 t/d in Kochi Prefecture and 3000 t/d in Toyama Prefecture (Table 2). The depth of water intake is about 300 m and water temperature is 9.5 C in Kochi and 2 C in Toyama Prefecture. As of yet, there are no large systems in Japan with the capacity or economic efficiency of the system at NELHA in Hawai'i, which pumps water from the deep sea at 88000 t/d (Hachmuth 1991).

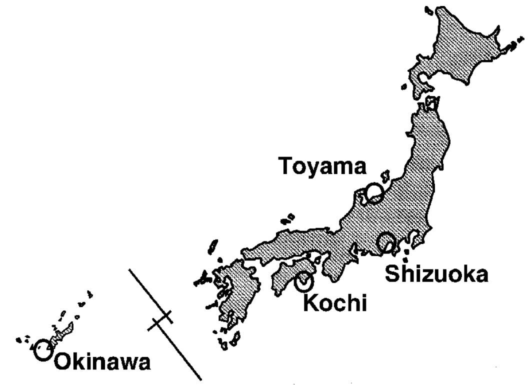

Figure 1. Water pumping places in Japan.

Research in Toyama and Kochi Prefectures indicates many practical possibilities for future applications of DSW and currently many requests for the water are from private companies which have many projects in the planning stages along the coasts of Japan (Table 2). In Kochi Prefecture, a third DSW intake pipe was installed early this year. This system will provide 4000 t/d, 2000 t of which will be utilized for fisheries, with the remainder of sea water provided to companies such as cosmetic firms and chemical companies. In Okinawa Prefecture, a large system is planned which will provide 15 000 t/d of deep sea water (Shimoji and Tominaga 1997). This system will service research facilities as well as a resort. In Shizuoka, plans are being made for the intake of deep sea water from two different sources, one originating from the Kuroshio Current and the other originating from

Table 2. Water pumping systems in Japan.

System	Capacity (m^3/day)	Intake depth (m)	Length from shore (m)	Temp. (degrees C)	Date Installed
Kochi 1	460	320	2,650	9.5	1989
Kochi 2	460	344	2,650	9.5	1994
Toyama	3,000	321	3,060	2	1995
Okinawa 1	-	600,1400	30,000	9,2.6	1997
Okinawa 2	15,000	600	-	-	2000
Kochi 3	4,000	300	2,074	-	2000
Shizuoka	3,000	350,700	-	-	2001

the Oyashio Current.

MATERIALS AND METHODS

Fisheries Related Applications: Feasibility Studies

New ways of using deep sea water for fisheries, agriculture, energy, medical treatment, and environmental purposes are under constant investigation in Japan. Currently, the major use by fisheries is in the aquaculture of fishes, shellfish, sea vegetables, and phytoplankton. The fisheries' sector is also looking into the practical application of handling of captured fish with deep sea water to maintain freshness. Salinity and environmental restoration using the abundant nutrients of deep sea water is another avenue of research.

Aquaculture

A major advantage of using deep sea water for aquaculture is the ability to culture cold-water organisms and deep-ocean organisms in tropical areas. Another is the ease at which water temperature can be controlled by mixing surface water with deep sea water. A third advantage is disease control, as there are few viruses and pathogenic bacteria in deep sea water. A disadvantage of using surface sea water is the maintenance required to keep the water intake pipes free of organisms that cling to the pipes and foul the water. However, when DSW is used for aquaculture purposes, maintenance of the pipes to remove harmful bacteria and other organisms is not necessary. In the Kochi Prefectural Deep Seawater Laboratory, the intake pipes haven't required cleaning for the past 10 yr (Miyamoto 1999).

The species targeted for aquaculture in Japan are mainly those requiring cold, deep, ocean water (Table 3). Most of the aquaculture projects that rely on that type of water are carried out in Kochi and Toyama Prefectures (Fujita 1997; Taniguchi 1997). Almost all the projects are at experimental level, but the egg production of Japanese flounder has been demonstrated to be practical since 1997 (Okamura and Doi 1998).

The abundant nutrients in deep sea water have instigated many projects for the production of sea vegetables and micro algae. In Kochi Prefecture, they have succeeded in producing edible *konbu*, and cold water sea vegetables. The growth of *konbu* in pumped deep sea water is reportedly the same as in its natural habitat in Hokkaido Prefecture, in the northernmost section of Japan, which is known as the production center of *konbu* (Yamaguchi et al. 1994).

Table 3. Target organisms of aquaculture using deep seawater in Japan.

Target organisms	Organizations
Fishes	
Japanese flounder	Kochi Pref., Toyama Pref., Kinki Univ.
Flatfish	Kochi Pref.
Globe fish	Kochi Pref., Kinki Univ.
Butterfish	Kochi Pref.
Trout	Toyama Pref.
Sea bream	Kochi Pref.
Anglerfish	Toyama Pref.
Sandfish	Toyama Pref.
Pacific cod	Toyama Pref.
Shellfishes	
Abalone	Kochi Pref., Kochi Univ.
Snow crab	Toyama Pref.
Firefly squid	Toyama Pref.
Shrimp	Japan Sea-Farming Association, Okinawa Pref.
Whelk	Toyama Pref.
Oyster	Japan Marine Sci. & Tech. Center
Vegetables	
Japanese tangle	Kochi Pref., Toyama Pref.
Wakame	Kochi Pref.
Laver	Kochi Univ.
Sea trumpet	Kochi Pref.
Microalgae	Kochi Pref., Toyama Pref., etc.
Precious coral	Kochi Pref.
Plankton	Kochi Pref., Toyama Pref.

Handling of Captured Fishes

In Japan, there are many instances when captured fish are not taken directly to market. One such instance is when fishermen hold them in port until prices increase. Therefore, it is necessary to keep the captured fishes sanitary and fresh until sold. Research for the application of DSW in the handling of captured fishes is focused on the purity of the water. Studies include the use of DSW to wash captured fish in the fishing ports in order to keep them fresh and also to transport the fish. Frozen deep sea water, for example, has already been shown to be effective in the transporting of fish (Kawasaki and Kuyou 1998).

Environmental Restoration

Trials are underway to examine whether the abundant nutrients of deep sea water can be applicable to environmental restoration efforts. The loss of the sea grass habitat is an important topic in Japan. Many efforts have been made to restore sea grass habitats, but most have not been very successful thus far.

In Kochi Prefecture, however, the DSW is discharged into the near-shore ocean waters after it is used. As a result, sea grass was discovered growing along the coastal areas, even where it had not grown before. Accordingly, a new avenue of research developed recently in Kochi Prefecture (Taniguchi et al. 1998) using DSW to initiate restoration of the coastal habitat. In Toyama Prefecture, mixing DSW with surface water to raise on-site productivity was attempted, but it met with limited success as the quantity of DSW was low and the vertical mixing was difficult due to the heavier density of deep sea water (Iseki et al. 1994).

Applications Unrelated to Fisheries

Businesses unrelated to fisheries, such as the food industry, medical treatment facilities, utility companies, and agriculture have found the usage of DSW advantageous. Applications in the food and medical industries are now practical. The use of DSW to cool water for power stations and utilization for agriculture are being explored as future applications.

Food Industry

Various foods and beverages are being produced using desalinized or concentrated deep sea water. Products such as jelly, mineral water, soy sauce, Japanese sake, confectioneries, and salt are made in Kochi Prefecture, contributing to the local economy (Hisatake 1997). These products are very popular due to the "mellow" flavor associated with the water. The exact role of DSW in changing the flavor or taste, however, is not fully understood.

Photo 1. Products using deep seawater in Kochi Prefecture.

Medical Treatment

It is empirically known that sea water is effective for the treatment of atopic dermatitis. However, because of the many bacteria and viruses in surface sea water, it is not recommended for daily application. As an alternative, pure, deep sea water was tested for daily use with promising results (Nomura 1995). Other medical researchers are trying to extract valuable chemicals from micro algae grown in deep sea water (Matsunaga et al. 1997; Komai et al. 1997).

Agriculture

In the subtropical environment of Okinawa Prefecture, it is not possible to grow cold climate vegetables, such as spinach, during the summer months. However, when cold, DSW was pumped through fields of spinach in underground pipes, the spinach grew very well. Such applications of deep sea water for agriculture are performed at NELHA in Hawai‘i, USA, where they have succeeded in producing various cold-season vegetables and crops in the tropics (Daniel 1994).

The abundant nutrients of deep sea water are also favorable for agriculture. When watered with diluted deep sea water, spinach actually grew faster than when tap or surface water was used (http://www.lizard.co.jp/deep-sea/hourensou.html).

DISCUSSION

Future Applications

A variety of possible applications of deep sea water are topics of future research. One possible use is to cool the water emitted by power stations. Preliminary studies demonstrate that the cold temperature of DSW increases the efficiency of heat exchange. The small variation in temperature between discharged deep sea water and coastal waters reduces any potential damage to the near-shore environment. However, if deep sea water is to be used for cooling water at power stations, quantities as large as million t/d would be needed. The intake of such a large quantity of DSW could affect the global environment, for example, by changing the balance of carbon dioxide or altering ocean currents. Therefore, environmental impact studies have been initiated.

Thalassotherapy, or medical treatment using sea water, is being examined. Currently, some resort facilities in Toyama Prefecture perform thalassotherapy using DSW (http://www.micnet.ne.jp/hotaru-n/museum/english/index.html).

Future uses of DSW in agriculture might be for hydroponic plant culture or maintenance of seed at cool temperatures.

Future Problems

Problems that might result from increased use of DSW are also under consideration. Although it is recognized that deep sea water is effective in various applications, the exact functions and ramifications are not clearly understood. Methods must be developed to reduce the high costs of constructing DSW water pumping systems. Further studies should be done to understand and assess the environmental impacts of intake and discharge of deep sea water on the coastal environment.

To alleviate some of the anticipated problems, a cascade system of using deep sea water has been proposed (Fig. 2, Ikeda 1997). In this system, intake water is used for air-conditioning and then used for aquaculture. After it is used for aquaculture, the DSW is discharged into the ocean for environmental restoration. This system can decrease the negative environmental impact of discharging cold water while maintaining the positive attributes of deep sea water. In Kochi Prefecture, DSW that has been used to culture sea vegetables then used in the aquaculture of abalone, is one method of using a cascade system whereby the deep sea water pumped from deep depths is utilized to the fullest and the environmental impacts are minimized.

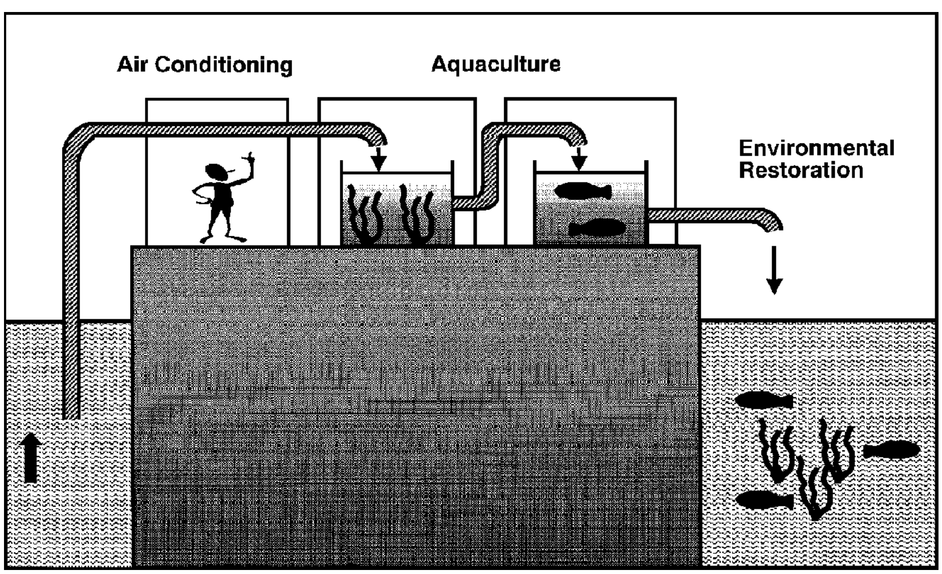

Figure 2. Cascade system of using deep seawater.

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