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Strategic Review on Developing Salmon Aquaculture with Deep Ocean Water: A Case Study of Nan' ao Deep Ocean Water Park in Yilan County, Taiwan

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Abstract

Currently the utilization of deep ocean water (DOW or deep sea water/DSW) is receiving much attention due to its high added value with large quantity, high productivity and potential for recycling energy. Deep ocean water possesses three main characteristics: low temperature, cleanliness and nutrient richness. In eastern Taiwan, the steep coastal landforms make it a great potential to develop deep ocean water industry. In order to promote DOW related industry, Yilan County government in eastern Taiwan has established DOW Park in Nan'ao Township. Through commercializing the DOW resources and introducing non-governmental investment from the private sectors, the DOW Park aims to promote regional development and upgrade the related industries. In the present study, we investigated the potential market demands, technical conditions and its biological natures of developing salmon aquaculture at Nan'ao DOW Park. It aims to take advantage of the characteristics of DOW to propose industrial strategies on salmon aquaculture with DOW and establish the developmental goals at different times. In general, three stages i.e. short, medium and long-term stages will be analyzed respectively. In the short-term stage, the objective of harvested salmon is to achieve 30,000 mt yr^{-1} for the domestic market demands in the common size of 1 kg-5 kg $fish^{-1}$. In the medium and long-term stages, the objectives are focusing on the markets in Japan, China and Southeast Asian countries, aiming to achieve the salmon harvest with 300,000 mt-500,000 mt $year^{-1}$. The domestic market of the DOW salmon industry is estimated to reach approximately US$ 330 million (NT$ 10 billion) of linking industrial cluster and global value chain. The study may also provide the government an innovative strategy and market orientation towards DOW industry guidance as well an investment consideration for enterprises having an interest in developing DOW related industry.

Keywords: Deep ocean water; DOW; Deep sea water; DSW; Salmon; Aquaculture

Introduction

The deep sea water (DSW) or deep ocean water (DOW), accounting for 95% of all sea water, generally refers to sea water from a depth of more than 200 m below sea level i.e. under normal thermocline. DOW isolated from sun exposure would not be affected by atmospheric or environmental changes. DOW circles the globe over a period of about 2000 years and the upwelling of DOW occurs regularly in the oceans and seas throughout the world. Deep ocean water possesses three main characteristics: low temperature, cleanliness and nutrient richness [1] [2-4]. Its wide range of applications can create an extremely high added value [4-6]. Deep sea water aquaculture has been successfully conducted in Japan and America for several years and has considerable achievements in related industry [7,8].

Nan'ao waters, Yilan County is located adjacent to western of Kuroshio Current in the West Pacific Ocean. Nan'ao waters possess abundant marine resources to nourish all kinds of marine life and have the crucial conditions to develop the DOW related industries [9]. With smooth and rapidly descending seabed topography, it is easy with low-risk to equip extraction pipeline of DOW. Due to the short distance of more than 200 m in depth, the cost of pipeline laying can be reduced relatively. Moreover, the location is adjacent to Taipei-Keelung metropolitan area, which makes the transportation more convenient [9]. Several advantages make Nan'ao waters one of the best candidates in Taiwan to develop DOW industry [10,11]. Together with the DOW can be applied to salmon aquaculture industry with its high economic values not only can it promote the extensive values of Marine Bioscience Park but also create huge benefits [9,10].

Salmon fish farming started on an experimental level in the 1960s but became an industry in Norway in the 1980s and in Chile in the 1990s [12-14]. The farmed salmon industry has grown substantially in the past 40 years and today approximately 60% of the world's salmon production is farmed [15]. In 2015 more than 2,200,000 tons of farmed salmon were produced, while in comparison around 880,000 tons of wild salmon were caught [16]. Yilan County government plans to take advantage of some environmental features of DOW e.g. low temperature, few pathogens and plentiful nutrients to found the Deep Ocean Water Park at Nan'ao (Figure 1), expecting to prosper regional development and industrial upgrade by commercializing resource utilization and bringing in some nongovernmental investments, anticipated to build up an industrial development model that would promote regional growth [9,10]. It is hoped that the study could provide the government with an orientation of industrial guidance, or be a possible reference of investment for enterprises having an interest in this field of work.

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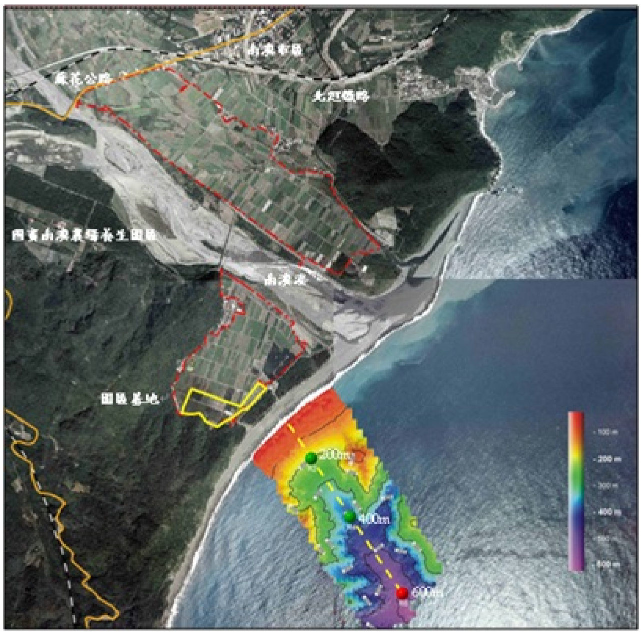

Figure 1: The location of Nan'ao Deep Ocean Water Park, Yilan County, Taiwan.

Materials and Methods

This study has collected the information of domestic and international uses of deep ocean water [8,9], the techniques of salmon culture [13,17] real market demands [16] and its biological natures [14] all taking Nan'ao Deep Ocean Water Park in Yilan as a case study. The study also uses SWOT analysis to compare and contrast the strengths and potentials of salmon culture with DOW, proposing some short, medium and long-term strategies and industrial efficiency after achieving the goals.

Result and Discussion

Preliminary analysis of potential cold-water aquaculture species

DOW aquaculture has been successfully conducted in Japan and America for several years [7,8], particularly the major advantage of using DOW for aquaculture is to culture cold-water fish and deep-ocean fish in tropical areas [18]. The fish species include finned fish, shrimp, shellfish and algae [9,19] However, due to the location of Taiwan, it is essential to consider several factors such as the environmental conditions, market demands, aquaculture technologies and the economic values of the fish species and ultimate to choose the suitable species for cultivation. The preliminary analysis of suitable deep ocean water aquaculture species has been shown as Table 1.

Classification	Suitable cultured aquatic species	Suitable temperature (°C)	Suitable salinity (ppt)	Currently cultured in Yilan(◎)	Recommended cultured aquatic species in the Park
Cold/Warm-Water Fishes	Atlantic salmons	08-18	0-35	-	★
	Flounders/Turbots	5-26 Eurythermic	30-35	-	-
	Pufferfish	16-28	17-33	-	-
	Groupers	22-28	10-35	-	-
	Siberia sturgeons	0-30	0-30 Euryhaline	◎	★
Warm-Water Crustaceans	Kuruma	15-25	25-33	◎	-
	Portunids	16-27	25-34	◎	-
Cold-Water Shellfishes	Abalones	12-20	24-35	◎	★
Warm-Water Shellfishes	Taiwanese abalones	18-28	30-34	◎	★
	Oysters	15-34	20-35	-	★
	Mussels	05-20	29-35	-	-
Cold-Water Macroalgae	Kelps	10-15	30-35	-	★
	Wakame	12-20	27-34	-	★
Warm-Water Macroalgae	Seaweed	10-27	32-35	-	-
	Gracilaria	20-30	15-25	◎	-

Table 1: Preliminary evaluations for suitable cultured aquatic species in Nan'ao DOW Park.

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The strategies of developing DOW aquaculture in Taiwan

Due to the characteristics such as steady low temperature, clean and the least-polluted and rich in nutrients and minerals, DOW is extremely suitable for cultivating and breeding the aquatic organisms. Hawaii is the first place to conduct DOW aquaculture all over the world and abalone, undaria and white shrimp are three main aquaculture species farmed in Hawaii [20,21]. While in Japan, the species of DOW aquaculture are more diversified of which including fish, shrimp, shellfish and algae [8].

Stable low temperature normally below 10 is one of the characteristics of DOW. If farming tropical fish species with 12°C~15°C seawater, then it need to get DOW warming up, which increases instability and also loses the finest use of DOW. Hence the general marine aquaculture of DOW is not suitable for the present species reared in Yilan County. In practical application, it is better firstly to farm cold-water fishes with high economic values such as salmon. Then the receiving water from salmon farm can be used to farm Yilan's local farming species such as sturgeon and abalone, with the warming DOW. Finally by combining the integrated cultivation of algae and oyster with the related species to purify the waters [17,19]. With the practices of segmented farming and water utilization it resembles the concepts of IMTA (Integrated Multi-Trophic Aquaculture/Agriculture), which has been highly promoted somewhere in the world currently [3,22]. It not only farmed the fish species in its most appropriate temperature but also takes the advantage of the DOW adequately, achieving the objective of segmented utilization of DOW and the effluents of sea farming would not affect the nearby environment so badly [17,19].

Besides, SWOT analyses of salmon aquaculture with DOW at Nan'ao Deep Ocean Water Park are listed in Table 2.

Strengths	Weaknesses
Taiwan's techniques of aquaculture have been famous worldwide and the experiences and industrial base make Taiwan advantageous in the international competition. It is efficient to develop and build up culture techniques for new species.	Salmon culture with deep ocean water is an emerging industry with much uncertainty. With economic recession, it will probably affect the willingness of aquaculture industry to try and invest it.
There are some of aquaculture related institutions for academic research in Taiwan and they have cultivated many skilled people in the field of farming aquatic animals. For the technique of salmon aquaculture with deep ocean water, the institutions could provide assistance and related researches, making this new industry localize the culture process as soon as possible.	The cost of pumping deep ocean water for aquatic animals would be higher than that of using surface ocean water. If the future prices of deep ocean water are higher than the prices the industry expects, it would affect the industry's willingness to cultivate.
Through the advantageous landforms of eastern Taiwan, pumping the low-temperature, clean, full of nutrients and stable deep ocean water to execute cold water culture would make salmon grow faster and better.	The industry's capacity of research and development is weak, which is unfavorable for long-term development, so it needs the government to put in resources to research and develop.
Onshore production ponds are closed systems, avoiding the salmon in the net cage from escaping and interfering with the local species.	The site management of deep water culture is different from the traditional one, so a proper operating procedure needs to be made.
Salmon steaks are popular in the fish markets, and can be accepted by most of the consumers.	The cost of salmon culture with deep ocean water is higher, which may affect the industry's competitiveness.
Countries with deep water resources are quite few, and Taiwan's costs of water pumping are low, so Taiwan has strengths in the industrial competition.	
Opportunities	**Threats**
Taiwan's techniques of aquaculture have its profound industrial base and Taiwan has always been the fry supply center in Asia. The farming techniques of warm-water fish species have been advanced throughout the world. If Taiwan successfully farming the cold-water fish species such as salmon with deep ocean water, it would become an important supply station for the fries of cold-water fish species and adult fish in Asia area, making a big step for Taiwan's aquaculture industry.	The neighboring country, Japan, also has deep ocean water resources, which may threaten Taiwan's deep ocean water aquaculture industry.
Demands of salmon are quite high domestically and internationally, which has lots of business opportunities. Successfully farmed salmon would make Taiwan advantageous to provide live salmon. Additionally, there are different products such as fresh, frozen, smoked and canned products to supply to the domestic markets and restaurants, as well as some neighboring countries such as China, Japan, Hong Kong, Singapore and Korea, making the markets great potentials to expand.	DOW farmed salmon products lack certification mechanism, which would probably lead to the emergence of fakes.
Existing salmon products are fresh and frozen. Offering live fishes would increase consumers' acceptance.	

Table 2: The SWOT analysis of Taiwan's salmon farming with DOW.

High economic potential of salmon aquaculture in Taiwan

Salmon has high economic value with widespread consumption markets domestically and internationally. Salmon is a high value species. According to the most recent Taiwan's Fisheries Statistic Yearbook, approximately 12,000 metric tons farmed salmon (fresh or chilled only) have been imported annually (2012-2016) which equals to NT$ 2.5 billion (US$ 830 million) market value [23]. However, Taiwan's salmon importers estimated the imported salmon has much higher imports than the statistic particularly in frozen salmon. In order to reduce the import duties, many importers offload their salmon containers in Hong Kong, then entering several fishing ports by

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reloading fish on fishing boats. The estimated importing salmon should be 30000 metric tons annually in Taiwan. The direct market value is estimated to be US$200 million (NT$ 6 billion) based on US$ 6.7 kg^{-1} (NT$ 200 kg^{-1} in average). Therefore, the salmon market in Taiwan is stable not only on the market scale but also on the prices. With such localized promoting potential, salmon is a new fish species worth experimenting, developing and localizing into aquaculture with DOW in Taiwan (Figure 2).

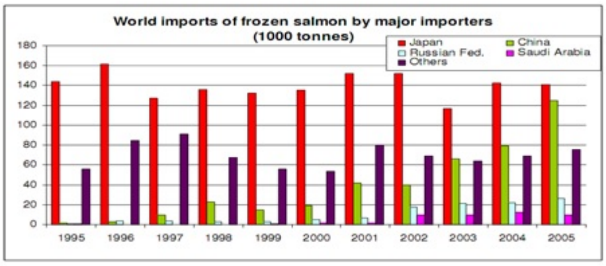

Figure 2: The import frozen salmon production and their major importers.

The salmon market is enormous in Asia, particularly in Japan and China. According to SWOT analysis from Table 2, approximately 140,000 metric tons of frozen salmon have been imported into Japan (not including fresh or other products) and about 120 thousand metric tons imported into China in 2005. Moreover, from 1995 to 2005 the amount of imported frozen salmon has increased rapidly which shows a huge business opportunity in China's salmon market.

Japan is the largest salmon importing country in the world. According to Worldseafoods, about 177,000 metric tons of varied frozen salmon have been imported into Japan in 2009 (not including fresh or other products). With a favorable geography which is close to two major markets (Japan and China), Taiwan has a real advantage to expand the salmon export market in the future. It can be expected that once Nan'ao Deep Ocean Water Park successfully establishes the technique of salmon culture, it will bring huge economic benefit and prosperity for related industries in both domestic and international markets. The land-based farming salmon with DOW can raise salmon faster and better provided effectively controlling the environment. In Norway and other countries salmon have been farmed in the net cage, which is more difficult to control the water temperature and farming environment and heavily influenced by natural climate particularly facing the threats of climate change [24]. Salmon has low feeding motivation especially with its low water temperature in winter which retards its growth. In general it will take salmon two to three years before reaching the market size (3-5 kg).

The land-based salmon farming with the characteristics of DOW cleanness, low temperature and nutrient richness is able to control the environment and water temperature in farming, avoiding bad weather conditions such as rainstorm and typhoons and even preventing salmon from escaping from net cages. It has the same advantages of ocean net cage culture, yet with no disadvantages or risks of it. Although it is not suitable for developing net cage culture in Yilan County, with the effect of farming salmon with DOW, it can grow salmon much quicker and better, shorten the farming time and reduce both the production cost and risk. According to Lorentzen [25] in Figure 3, with proper stocking density salmon can grow faster at the temperature of 10°C-18°C, only take 6 months to one year to grow from 100 g to 3,500 g. If kept in stable 15°C to 16°C, then they only take about half a year. Therefore, low temperatures of DOW could stabilize the temperatures for salmon culture and achieve the goal of fast growing for the whole year, which reduces the costs and improves the competitiveness.

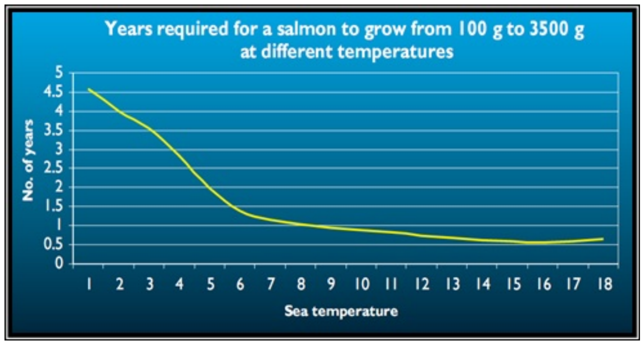

Figure 3: Years required for the salmon body weight from 100 g to 3500 g raised at different water temperatures.

The established global salmon aquaculture industry can save time on research and exploration

The techniques of salmon aquaculture have been successfully developed abroad. Taiwan has abundant experiences and techniques of aquatic species culture and industrial chain of aquaculture has its clear divisions for different aspects and could integrate various resources immediately which means the localization of salmon aquaculture with DOW could put into practice in the near future. Salmon farming with DOW is a brand new task in Taiwan, however in Norway and Chile it has been a well-developed industrialized experience of aquaculture industry. Many studies focused on the issues of salmon culture.

For the past few decades, Taiwan has accumulated plenty of experiences and techniques in aquaculture and cultivated numerous talented people, so it's expected in a short period of time Taiwan could learn from other countries' experiences and localize the task of salmon culture. The most important issue now is to integrate salmon culture with DOW, introduce some successful experiences and mature techniques from foreign countries and through government's organized assistance and guidance build up the correct notion of aquaculture and proper operation procedure and cultivate skilled people in salmon farming, making the task of salmon farming localized. It is hoped Taiwan could soon produce a stable and abundant production of healthy salmon to supply for domestic and international demands.

The scenarios for developing salmon culture with DOW in Taiwan

The present study has proposed the strategies of salmon culture with DOW for short-term, mid-term and long-term scenarios development (Figure 4) as below:

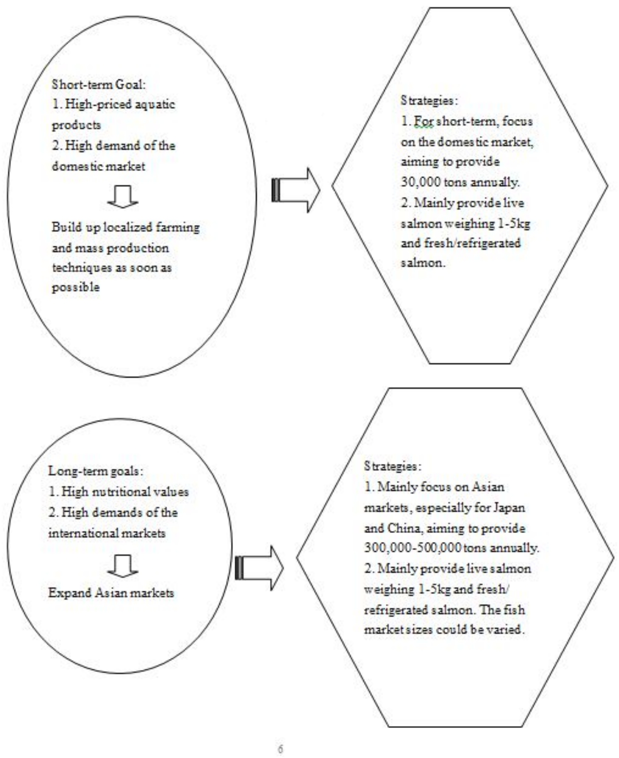

Figure 4: The strategy to develop the salmon aquaculture with DOW in Taiwan.

Short-term scenario: Objectives: Due to high priced salmon and high demands of domestic markets, Taiwan should refer to Norway's successful experiences to develop salmon farming techniques and localizing it to a considerable and stable production and supply for domestic markets.

Developmental strategies: Firstly it should focus on domestic markets and aim to supply the domestic market with half of 30,000 metric tons of imported salmon i.e. 15,000 metric tons. Norway's salmon sold as a whole fish normally weigh over 5 kg which is different from that of Taiwan's market features. The domestic live salmon with 1 kg may have high market values and be easily accepted by local consumers. Besides the traditional 5 kg salmon, Taiwan can take "live salmon" as the main advantages and may supply salmon of which less than 5 kg.

Mid-term and long-term scenarios: Objectives: Salmons is a highly nutritious fish that has a host of benefits for all ages and becomes one of the important aquatic products for human beings. Salmon culture has been operating for over 50 years and the whole industry has developed to its mature phase (FAO, 2017). The culture techniques are well-developed and Norway, Chile, Scotland have already taken their steps into industrial production. The medium and long-term goals are to localize salmon culture techniques and to expand the supply ranges from the domestic markets to the international markets, especially to some Asian countries such as Japan and China. By doing so, the smoothness of the channels could be ensured and the situations of falling prices due to dull sales or mass production could be avoided.

Development strategies: Asian countries have their enormous consumption potentials. Especially for Japan and China, the total annual farmed salmon they imported are over 250,000 metric tons and following by Korea, Vietnam, Indonesia and Saudi Arabia. The consumption potentials are so promising that some neighbouring countries e.g. Taiwan have their competitive advantages. Therefore, the main task in the future is how to stabilize the quantity and quality of the salmon. Asian countries emerge as one of the main consumption market of salmon, so Taiwan could take advantage of its geographical benefit to expand its markets, focusing on the consumption markets of Japan and China. Taiwan to Asian market is much nearer than that Norway, so does Taiwan with its advantages of transportation i.e. the shipping process could be shorter than that of Norway. Therefore, the supply of live salmon is one of the main features and fresh and frozen salmon are also the main markets. For the Asian market, the specification of salmon supply can be diversified according to different market features, offering the customer more choices. As for the production target of mid-term and long-term scenarios could be set at 300,000 metric tons to 500,000 metric tons annually.

Industrial chain benefit analysis

Referring to the experience of salmon cage culture industry in Norway, its vertical industrial chain has meticulous division of operations and close cooperation, indicates mature development in each section and creates considerable job opportunities and output value. It is worth learning by Taiwanese aquaculture industry. For example, Norway's salmon industry of vertical industrial chain in 2005 includes hatchery, smolt cultivation, salmon culture, harvesting/processing, selling/launching, transporting each process of cultivation and breeding and the whole salmon industry can bring a significant income estimated to be 17.1 billion Krone (USD$ 307 million/NT$ 92.3 billion), including:

Hatchery output value: about 100 million Krone (USD$ 12.8 million) (0.6% of GDP).

Smolt cultivation output value: about 1.2 billion Krone (USD$ 153.2 million) (7% of GDP).

Salmon culture output value: about 11.8 billion Krone (USD$ 1.51 billion) (69% of GDP).

Working crafts: about 300 million Krone (USD$ 38.3 million) (1.7% of GDP).

Harvesting/processing output value: about 2.3 billion Krone (USD$ 293.8 million) (13.5% of GDP).

Selling/listing output value: about 700 million Krone (USD$ 89.4 million) (4.1% of GDP).

Transportation output value: about 700 million Krone (USD$ 89.4 million) (4.1% of GDP).

Nonetheless, the scale and value of the salmon market in Taiwan are always steady. If we generally estimate the benefit of industrial chain by the production goals mentioned above, the total output value may reach USD$ 295 million (NT$ 8.65 billion):

Hatchery output value: USD$ 1.7 million (NT$ 50 million).

Smolt cultivation output value: USD$ 20.4 million (NT$ 600 million).

Salmon culture output value: USD$ 204.6 million (NT$ 6 billion).

Harvesting/Processing output value: USD$ 40.9 million (NT$ 1.2 billion).

Selling/launching output value: USD$ 13.6 million (NT$ 400 million).

Transportation output value: USD$ 13.6 million (NT$ 400 million).

Total output value: USD$ 294.9 million (NT$ 8.65 billion).

If the related (surrounding) industries e.g. feed industry and biotechnology and vaccines industry being included, the production values would be more considerable. Particularly the successful vaccination techniques developed in the past two decades highly reduce diseases and the use of antibiotics and chemicals contribute to sustainable, profitable growth in salmon farming [26-28]. Assuming the feed conversion rate (FCR) is 1:1 and the feed cost is USD$ 1.53 (NT$ 45) per kilogram, the feed cost for preliminary production goal would be approximately USD$ 46 million (NT$1.35 billion) which means the same value for the demand of salmon feed industry in Taiwan. It is estimated that the total economic value of the domestic salmon market would reach USD$ 341 million (NT$ 10 billion).

According to this concept, when reaching the mid-term, long-term production goal (300 to 500 thousand tons/per year), the total industrial chain benefit would reach USD$ 3.41 billion (NT$ 100 billion) every year which definitely worth government's support and promotion.

Conclusion

Deep sea/ocean water honored as "Blue Gold Industry" is an extraordinary natural resource with developmental potential in Taiwan and a great access to develop localized industries for eastern Taiwan (Yilan, Hualien and Taitung) particularly in Yilan as the transportations such as railways and highways that can rapidly connect with Taipei-Keelung metropolitan areas. For also the ocean shipment, Suao International Port provides international transportation making Yilan advantageous to produce fisheries products. However, a rather practical concern is how to reduce the DOW pumping cost. The authors suggest two aspects for solution: the better solution may be firstly to execute Ocean Thermal Energy Conversion (OTEC) by pumping the deep ocean water 1,000 meters deep (about 2°C to 5°C) and missing with the surface ocean water (about 25°C to 30°C). After the ocean water cooling down through heat exchange it would be suitable for the use of aquaculture. The other solution is only focusing on salmon aquaculture by pumping the deep ocean water (250-300) meters deep (about 12°C to 15°C). Whether executing OTEC or focusing on salmon aquaculture, the main principle is to maximize the quantity of pumping water and to organize diversified and multiple segmentation to exploit deep ocean water, creating added values for DOW industry. For example, the effluent produced by salmon aquaculture can be used in the first phase of the cultivation of crustacean or algae and then recycled use in the second phase of fish culture (e.g. sturgeon). The effluent produced by the second phase of fish culture could be used in the second phase of the cultivation of crustacean or algae and finally discharged to the ocean. Therefore, in order to develop and prosper the industry of deep ocean water, it is necessary to integrate the strengths of the government, industries, academia and the public cooperating with each other and creating a win-win situation.

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