Kingdom of Thailand

FY2021 Ex-Post Evaluation Report of Technical Cooperation Project

"Development of Aquaculture Technology for Food Security and Food Strategy in the Next Generation"

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0. Summary

The project aimed to develop new aquaculture technologies in Thailand by conducting research in five areas that complemented each other: molecular breeding, surrogate broodstock[1], infectious disease control, non-fish alternative meal diet, and detecting and reducing chemical hazards. This is in line with the Thai development policies and needs, as well as Japan's assistance policy, and thus the project relevance is high. In all five areas, research outputs were produced according to the plan. The developed technologies have been applied to the target fish species, and because of the joint research, the researchers' capacity has been improved and the research outputs have been publicly disseminated. Furthermore, efforts have been made to put the research outputs to practical use, and social implementation has been realized, such as the implementation of disease diagnosis services and the production and sale of non-fish alternative meal diets. In addition, several other positive impacts were confirmed, such as the early development and domestic and international approval of diagnostic methods for shrimp diseases that were prevalent, and the improvement of scientific literacy among farmers and private companies. Therefore, the effectiveness/impact of the project is high. The project period and cost are judged as commensurate with the outputs, and the efficiency is considered high. Regarding sustainability, the policy background and the institutional/organizational, technical, and financial aspects are all sufficient for the development of sustainable and high-quality aquaculture technologies and their social implementation. Thus, the project sustainability is high.

In light of the above, this project is evaluated to be highly satisfactory.

[1] Surrogate broodstock is a technique to produce gametes of a fish species for seed production by using a fish species for which a parent fish breeding method has been established as a surrogate parent fish.

1. Project Description

Project Locations

Research with the provided equipment at DOF
(Left: tabletop centrifuge, right: nitrogen evaporator)

1.1 Background

The fisheries industry has been one of Thailand's key industries, and Japan has been an extremely important export partner. At the same time, it was important for Japan that Thailand improved the quality and safety of its fishery products. The native black tiger shrimp, which had been a major fishery product until the early 2000s, was replaced by the nonnative whiteleg shrimp (Litopenaeus vannamei), whose production had declined significantly due to low productivity and the risk of disease outbreaks, among other factors. Diseases also became a major problem for whiteleg shrimp, and it was important to improve breeding techniques for aquatic animals that were resistant to disease and grew quickly. The main species of aquaculture in Southeast Asia were inexpensive tilapia, carp, catfish, and whiteleg shrimp, but to increase fishery production and exportation further, it was not enough to aim for quantitative expansion of these inexpensive cultured species; it was necessary to establish a new aquaculture system targeting high market-value fish. However, the private sector's investment in feed development and seed production for marketable fish had not progressed under the strain, which needed to be led by public institutions. Thus, technologies needed to be developed to improve the motivation of aquaculture companies and farmers for production and to stabilize productivity and the economy through aquaculture.

1.2 Project Outline

Overall Goal		None.
Project Purpose		Advanced technologies for sustainable aquaculture and high quality products are developed in species targeted.
Outputs	Output 1	Molecular markers for selective breeding at the molecular level

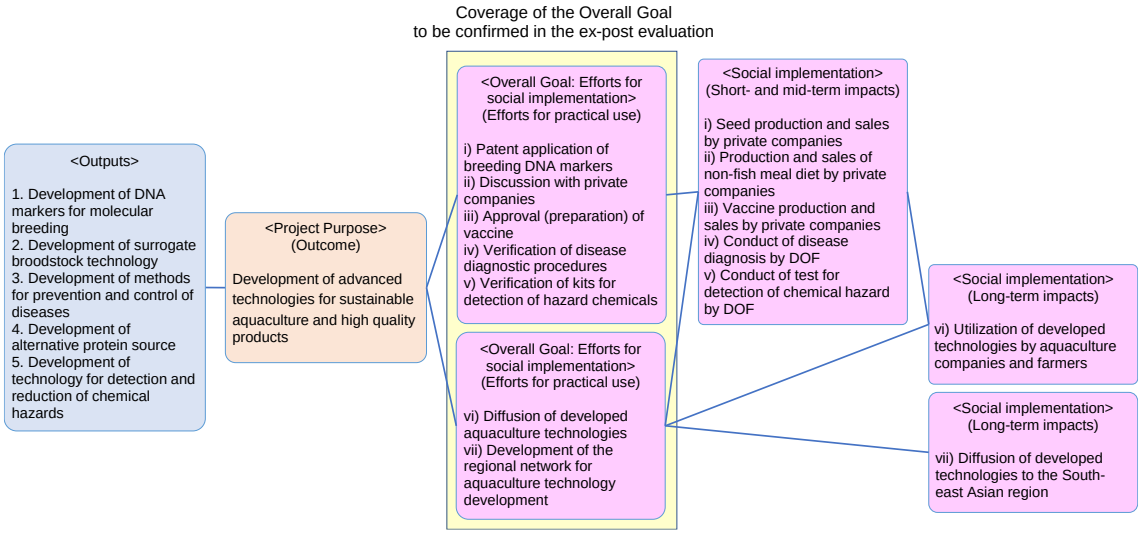
		(growth, disease and/or resistance, stress, etc.) are developed.
	Output 2	Surrogate broodstock technology for aquaculture is developed.
	Output 3	Practical methods for prevention and control of diseases are developed.
	Output 4	Alternative protein source replacing fish meal and broodstock diets are developed.
	Output 5	Technology for detection and reduction of chemical hazards in aquaculture system is developed.
Total cost (Japanese Side)		408 million yen
Period of Cooperation		May 2012 - May 2017
Target Area		Bangkok, Provinces of Krabi, Chonburi, Phetchaburi, Songkhla, Nakhon Si Thammarat, and Nakhon Ratchasima
Implementing Agency		Department of Fisheries (DOF) of the Ministry of Agriculture and Cooperatives, Kasetsart University (Faculty of Fisheries, Faculty of Science), Chulalongkorn University (Faculty of Science), Walailak University (School of Agricultural Technology)
Other Relevant Agencies/ Organizations		Suranaree University of Technology[2]
Organization in Japan		Tokyo University of Marine Science and Technology (TUMSAT), Japan International Research Center for Agricultural Sciences, Japan Fisheries Research and Education Agency
Related Projects		[Technical Cooperation Project (SATREPS)] "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market" (2019-2024)

In the project, five outputs were set for each research area. Output 1 is the development of DNA markers for traits that are important in aquaculture, and the development of molecular breeding technology to select and breed individuals with such traits. As Output 2, surrogate broodstock technology was developed to raise eggs of a different species of large, high-quality fish in a fast-growing and robust fish species, which makes it possible to reduce the size of the parent fish, shorten the maturation period, and enables the selection and breeding of informative traits. It also makes it possible to conserve genetic resources. Output 3 is the development of technology for the control of infectious diseases, including vaccines, as countermeasures against fish diseases in aquaculture in conjunction with the production of highly disease-resistant families (Output 1). Output 4 is the development of protein-

[2] Suranaree University of Technology participated in the project as a cooperation agency. For data collection and analysis in the ex-post evaluation, it was treated as if it were an implementing agency.

enriched meal for aquaculture to reduce the use of fish meal, which is a natural resource, for the conservation of the ecosystem. Output 5 is the development of technology to detect and reduce hazards in feed and hatchery ponds to ensure food safety. Thus, “high-quality” aquaculture production is made possible by spawning and raising safe varieties (Output 5) with high commercial value (Outputs 1 and 3) in a shorter time and while using less space (Output 2). In addition, reducing the reliance on fish meal (Output 4) makes aquaculture production sustainable. Thus, to address interconnected issues, these elements (outputs) work in a complementary manner, leading to the Project Purpose: "Advanced technologies for sustainable aquaculture and high-quality products are developed in species targeted.”

Although the Overall Goal was not set, the Japan Science and Technology Agency (JST) stated in its terminal evaluation report that it was "to establish a new applied technology for industrialization of fish and shellfish (technology to cross the valley of death) that is expected to motivate farmers to increase their production and to create a new food bank for the world in Southeast Asia.”[3] Considering that the SATREPS project required the researchers to "establish a roadmap for social implementation" during the project period, the ex-post evaluation focused on the first half of the stated goal (establishment of applied technology) and set "efforts for social implementation" after the project completion as the expected Overall Goal. Specifically, seven efforts necessary for the social implementation of research outputs were assumed. The following figure shows the path of effects after the achievement of the Project Purpose.



Source: Prepared by the evaluator.

Figure 1: The Project Logic for Achieving Effects (Outputs to the Long-term Impacts)

[3] TUMSAT, *Completion Report of the Development of Aquaculture Technology for Food Security and Food Strategy in the Next Generation* (2017).

1.3 Outline of the Terminal Evaluation

1.3.1 Achievement Status of Project Purpose at the Terminal Evaluation

The Project Purpose was judged to have been achieved. Research activities progressed almost as planned, and notable research outputs were reported. Thai researchers acquired advanced knowledge and skills necessary for research, and joint papers were written. However, it was noted that only one of the nine target fish species had all the technologies developed and that further integration and completion of the technologies would be needed.

1.3.2 Achievement Status of Overall Goal at the Terminal Evaluation

The Overall Goal was not set in JICA's terminal evaluation. It was reported that some efforts were implemented for the social implementation.

1.3.3 Recommendations from the Terminal Evaluation

The following recommendations were made.

(1) Clarification and sharing of the vision of "the aquaculture technology for food security and food safety in the next generation"
(2) Confirmation of the activity progress by research area and the prospect of their practical utilization
(3) Discussion on the acquisition of the intellectual property rights
(4) Utilization of the research network developed through the project implementation
(5) Promotion and dissemination of research outcomes
(6) Technical assistance to the neighboring countries

2. Outline of the Evaluation Study

2.1 External Evaluator

Junko Noguchi, Foundation for Advanced Studies on International Development

2.2 Duration of Evaluation Study

This ex-post evaluation study was conducted with the following schedule.

Duration of the Study: July 2021 – January 2023

2.3 Constraints during the Evaluation Study

Due to the prevalence of COVID-19, the planned field survey was canceled and replaced by a remote survey through field survey assistants. At some of the implementing agencies, entering the facility and collecting information through face-to-face interviews and observations were not possible. For this reason, the survey method was switched to allow online interviews in addition to questionnaire surveys.

3. Results of the Evaluation (Overall Rating: A[4])

3.1 Relevance (Rating: ③[5])

3.1.1 Consistency with the Development Plan of Thailand

The project was relevant to Thailand's development policies at the time of ex-ante evaluation as well as the time of project completion.

The "10th National Economic and Social Development Plan" (NESDP) (2007-2011) identified value creation based on knowledge and innovation as one of the development strategies. The 11th NESDP (2012-2016) mentioned the importance of developing a profitable aquaculture industry and developing technologies to reduce aquaculture production costs. The 12th NESDP (2017-2021) also mentioned that in order to strengthen the competitiveness of the production and service sectors, farmer support that meets market demand, sustainable fishery production systems, and research and development using new technologies and equipment in the production process should be implemented. In addition, the Government of Thailand has stated in its "Kitchen of the World" plan that it would aim to increase food production and make it an export industry.

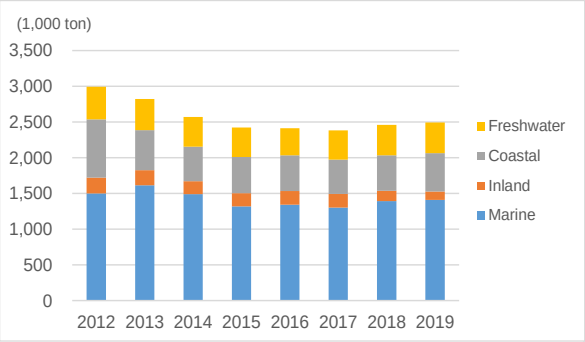
The "Strategic Plan" (2009-2012) of the Department of Fisheries (DOF), which serves as the basic policy for the fishery sector, identified (1) increasing production through aquaculture, (2) improving the quality of fishery products using farmed fish, (3) increasing fishery resources through aquaculture, and (4) strengthening research and development related to aquaculture, as major issues in the aquaculture sector. The same was true for the "Strategic Plans" (2013-2016) (2017-2021), which added the perspective of maintaining sustainability and diversity of fishery resources through fishery resource management.

3.1.2 Consistency with the Development Needs of Thailand

The project was consistent with Thailand's development needs at the time of both ex-ante evaluation and project completion. Annual per capita fish and shellfish consumption in Thailand was 33.7 kg in 2016, increasing on average by 11% from 2012 to 2016 compared to the previous year[6]. However, fishery and aquaculture production was on a decreasing trend from 2.99 million tons in 2012 to 2.38 million tons in 2017 (Figure 2). During the same period, aquaculture production was 1.27 million tons and 880,000 tons, respectively, and it was declining as well. The share of aquaculture production in the total production also decreased significantly from 43% to 37% over the same period. In terms of the fishery and aquaculture production value, it went from 174.3 billion baht in 2012 to 159.7 billion baht in 2017 (Figure 3). During the same period, the value of aquaculture

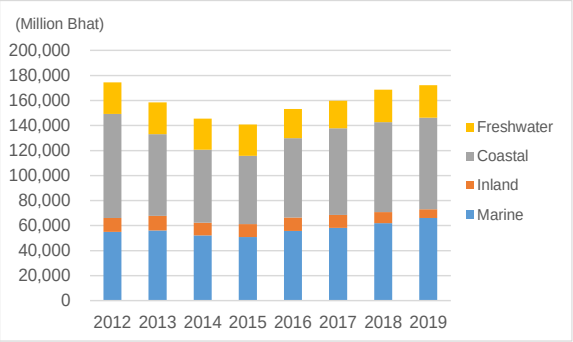
[4] A: Highly satisfactory, B: Satisfactory, C: Partially satisfactory, D: Unsatisfactory
[5] ③: High, ②: Fair, ①: Low
[6] Questionnaire survey with DOF.

production was 108.3 billion baht and 91.2 billion baht, accounting for 62% and 57% of the total value, respectively[7].



Source: Data from Fisheries Statistics of Thailand 2019.

Figure 2: Fishery and Aquaculture Production



Source: Data from Fisheries Statistics of Thailand 2019.

Figure 3: Fishery and Aquaculture Value

While fishery production was declining, exports were increasing (72.8 billion baht in 2012 and 190.1 billion baht in 2018). The increase in export value even when fishery production was not keeping pace with the increase in domestic consumption suggested a significant need existed for both export and domestic consumption of Thai fish and shellfish. In particular, for aquaculture production, which had shown a significant downward trend in both production volume and value, high-quality and efficient fishery production was needed to improve the market value and disease resistance. In addition, it was pointed out that economic activities, including aquaculture, had weakened key ecosystems such as mangroves, coral reefs, and seagrasses, and thus the maintenance and improvement of ecosystems needed to accompany aquaculture production.

3.1.3 Consistency with Japan's ODA Policy

The project was consistent with Japan's ODA Policy at the time of ex-ante evaluation.

The basic approach to cooperation with Thailand was to build a partnership-based cooperative relationship characterized by an emphasis on dialogue, mutual benefits, and other factors. One of the priority areas of technical cooperation was "strengthening competitiveness for sustainable growth." The project was in line with this priority area because it aimed to improve the productivity and safety of fish and shellfish, Thailand's main exports.

In light of the above, this project was highly relevant to Thailand's development plan and development needs, as well as Japan's ODA policy. Therefore, its relevance is high.

[7] Ministry of Agriculture and Cooperatives of Thailand (2021) *Fisheries Statistics of Thailand 2019*.

3.2 Effectiveness and Impact[8] (Rating: ③)

3.2.1 Effectiveness

3.2.1.1 Project Outputs

(1) Output 1

Research related to DNA marker development was conducted for all target fish species. As particularly significant results, 11 and two DNA markers were developed for tiger grouper and hybrid grouper, respectively. In addition, nine loci were obtained from informative DNA markers of grouper species for parental analysis, and evaluation of high-growth traits proceeded. Genetic linkage maps[9] showing 183 and 130 DNA markers were developed for tiger grouper and giant grouper, respectively. This research was the world's first case of genetic linkage mapping of grouper species and was a major achievement. Based on these maps, three families of tiger grouper and one family of hybrid grouper were produced. Regarding penaeid shrimp, seven and five DNA markers were also obtained for the analysis of the shrimp families of whiteleg shrimp and black tiger shrimp, respectively, and high-growth and disease-resistant families were established for black tiger shrimp. Other loci were identified using DNA samples from Asian seabass, and parental analysis was conducted to identify hypoxia tolerance, bacterial disease resistance, and high-growth traits.

The number of DNA markers developed, the number of genetic linkage maps created, and the number of lineages developed, all of which were set as indicators, exceeded the plan, and therefore Output 1 was achieved.

(2) Output 2

The surrogate broodstock technology was a new theme for the Thai side. Focusing on giant grouper[10] and Mekong giant catfish[11], which require seven to eight years to mature, research was conducted on the establishment of donor cell processing methods, the search for appropriate recipient species, transplantation operations, and related techniques (transplant cell tracking, etc.).

Indoor hatchery for research on surrogate broodstock technology
(Suranaree University of Technology)

[8] Sub-rating for Effectiveness is to be put with consideration of Impact.
[9] Map showing the location of genes on chromosomes.
[10] It is known that grouper species are slow-growing because they sexually mature as females and then change sex to males. Giant grouper needs seven to eight years to mature, whereas tiger grouper, also in the grouper family, matures in about two years.
[11] The Mekong giant catfish is one of the largest freshwater fish in the world, growing to about 2 m in length and in rare cases to 3 m and 300 kg in weight.

Once the surrogate broodstock technology is established, it will be possible to reduce the size of the parent fish, improve the efficiency of selection and breeding of families with useful traits by shortening the maturation period, and conserve genetic resources by freezing germ cells. The project aimed to clarify the range of combinations of donor and recipient among these. Cell transplantation methods and related techniques were developed for the combinations of giant grouper (donor) and tiger grouper (recipient) and Mekong giant catfish (donor) and striped catfish (recipient).

All of the indicators set for the establishment of cell transplantation methods, identification of recipient species, and establishment of donor-recipient compatibility were achieved, and therefore Output 2 was achieved.

(3) Output 3

Research on the prevention and control of infectious diseases (Output 3) focused on grouper, Asian seabass, and penaeid shrimp. Microarrays [12] were developed for black tiger shrimp and two species of penaeid shrimp, and gene catalogs for six species were developed (giant grouper, tiger grouper, Asian seabass, black tiger shrimp, whiteleg shrimp, and Nile tilapia). Profiling of disease-resistant shrimp species was obtained, and 11 candidate immune genes for black tiger shrimp were characterized. In addition, vaccines for *Vibrio parahaemolyticus* and the white spot syndrome virus (WSSV) were developed. After the beginning of this project, acute hepatopancreatic necrosis disease (AHPND) caused by *V. parahaemolyticus*, known as early mortality syndrome (EMS), occurred in shrimp farms in China and Southeast Asia including Thailand, and became a major problem. At the urgent request of the Thai side, research to address this disease was added to the project. The latest genomic analysis of the EMS/AHPND was conducted and a diagnostic procedure based on polymerase chain reaction [13] (PCR) testing was developed. This procedure was adopted as a standard procedure by DOF in 2014 and as a standard method by the World Organization for Animal Health (OIE) in September 2016 (Column 1). For grouper and Asian seabass, numerous immune-related genes were identified. For Nile tilapia, 10 candidate antigens

Breeding of Groupers and Asian Seabass
(Krabi Coastal Fisheries Research and Development Center)

[12] A DNA microarray is an analytical instrument in which a large number of DNA fragments are densely arranged on a plastic or grass substrate to measure the gene expression level in cells.
[13] A testing method in which the genes of the virus to be tested are amplified and detected using a chemical solution.

for pathogenic microorganisms were identified and a vaccine for group B streptococcus was developed and field-validated.

Indicators were linked to the development of microarrays, characterization of immune-related genes, characterization of candidate vaccine antigens, development of vaccines for pathogenic microorganisms, and development of disease control management methods. All of these activities were performed as planned or better, and thus Output 3 was achieved.

Column 1: Efforts for Rapid Adaptation of the Developed Technology

After EMS/AHPND became a problem in Thailand and other Southeast Asian countries, the University of Arizona first identified the pathogenic microorganism, and then the competition to develop a diagnostic method began among the research group at the Mahidol University in Thailand, the research group at the Cheng Kung University in Taiwan, and the research team in this project (DOF and TUMSAT). The three groups succeeded in developing the testing method at about the same time, but the research team in this project was the first to publish their results officially in a research paper. The research team in this project was successful in choosing a Japanese journal (*Fish Pathology of the Japanese Society of Fish Pathology*) as the submission destination, rather than an international journal, to avoid the possibility of peer review by competitors and a longer time to publication. The Fisheries Section of OIE meets regularly to collect information on outbreaks of infectious diseases from various countries. Because of the rapid spread of EMS/AHPND in the world after the outbreak, OIE identified it as a designated infectious disease. Diagnostic methods for EMS/AHPND were discussed at OIE and the methods of all three groups were adopted as standard methods.

Source: Prepared based on the interview result of TUMSAT.

(4) Output 4

Finding alternative protein sources for aquaculture (Output 4) was a goal aimed at ecosystem conservation by reducing the use of fish meal, a natural resource. The research targets were banana shrimp, whiteleg shrimp, and tiger grouper. A prototype broodstock diet for banana shrimp was developed. Several options were selected as alternative protein sources, and prototype diets were developed through feeding trials. For alternative broodstock diets for whiteleg shrimp, the optimum level of selected plant protein feed ingredients was determined, and PCR analysis was completed. Alternative diets were also developed for tiger grouper, and prototypes were evaluated.

As for indicators, diets for feeding trials and alternative protein sources were developed, and therefore Output 4 was achieved.

(5) Output 5

Output 5 was the development of the technology for the detection and reduction of

chemical hazards. In particular, to address the global problem of malachite green[14] (MG) residues, Thailand has spent a great deal of money and time monitoring the residues in fish and shellfish for export. However, this was not sufficient for domestic distribution, and the accumulation of MG in bottom sediment in hatchery ponds was considered a problem[15]. In the project, an ELISA (enzyme-linked immunosorbent assay)[16] analysis method for detecting leucomalachite green (LMG)[17] in feed, breeding water, and bottom sediment was validated and confirmed to be practicable under international standards. The analytical method demonstrated nearly three times better screening ability than conventional testing methods from the monitoring results of seabass and tiger grouper at aquaculture facilities. In addition, a prototype LMG detection kit was developed as a research output.

As for indicators, a prototype of an identification kit for the detection of chemical hazards and technologies for the reduction of chemical contamination was developed, and thus Output 5 was achieved.

3.2.1.2 Achievement of Project Purpose

The Project Purpose (advanced technologies for sustainable aquaculture and high-quality products are developed in species targeted) was achieved, as determined in the terminal evaluation. As mentioned above, traits suitable for aquaculture were identified through the development of DNA markers related to high-growth and disease resistance (Output 1), and research on surrogate broodstock was conducted to shorten the growing period (Output 2). Diagnosis methods and vaccines for the prevention and control of infectious diseases were developed (Output 3), and methods for detection and reduction of chemical hazards were developed (Output 5), which led to strengthening breeding techniques to ensure food security. In addition, the development of alternative protein sources to replace fish meal (Output 4) would contribute to the sustainability of fishery resources. These research outputs complement each other and work synergistically to improve the quality and sustainability of aquaculture (Project Purpose). In the terminal evaluation, clarifying and sharing the vision of "aquaculture technology for food security in the next generation" was recommended. In the ex-post evaluation, by asking DOF and four universities about this definition, it was confirmed that they had a common understanding of the relevance and complementarity between food security and the project's research.

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[14] Malachite green is a blue-green organic dye that was once widely used in aquaculture as an antimicrobial agent, but its use was banned after reports of carcinogenicity. Contamination by malachite green residing underground has been a problem. https://www.jst.go.jp/seika/bt2018-10.html (accessed on January 10, 2022).
[15] *JST Completion Report*, p.14.
[16] ELISA is an analytical method that provides the antigen or antibody of interest in a sample solution.
[17] Metabolites of malachite green.

Indicators of the Project Purpose were, as shown in the following table, (1) the number of targeted species, (2) the number of researchers who acquired skills, (3) the number of scientific papers that disseminate research results, and (4) the number of workshops and others that disseminate the research results. Regarding Indicator 1, it was pointed out in the terminal evaluation that "there was one target fish species for which all technologies were developed, and further integration and perfection of technologies is needed." However, target fish species were appropriate for research development in each area from the time of application of the project research[18], and the research was completed as planned. Indicators 2, 3, and 4 were achieved more than had been planned.

Table 1: Achievement of the Project Purpose

Project Purpose	Indicator	Actual
Advanced technologies for sustainable aquaculture and high quality products are developed in species targeted.	1. The number (at least 3) of species targeted on improved aquaculture technologies	Achieved. • New aquaculture technologies were developed for five research areas, targeting nine target species (giant grouper, tiger grouper, hybrid grouper, Asian seabass, black tiger shrimp, whiteleg shrimp, banana shrimp, Nile tilapia, and Mekong giant catfish).
	2. The number (at least 60% of members) of researchers who acquired skills of advanced aquaculture technologies.	Achieved. • 58 of 93 Thai researchers (62%) acquired the advanced technologies in training courses in Japan as of the time of terminal evaluation. It was judged by the terminal evaluation team that most of them were capable of utilizing and sustaining the acquired technologies.
	3. The number (at least 50) of scientific journals, technical reports, educational brochures, conference proceedings/abstracts, and/or newsletters.	Achieved. • Japanese and Thai researchers coauthored 75 scientific papers, among which Thai researchers prepared 35 papers as lead authors. No technical reports, educational brochures, or newsletters were developed.
	4. The number (at least 10) of workshops and/or seminars for education of skills and/or dissemination of project outputs.	Achieved. • 11 seminars, 11 conferences, and four symposiums and workshops were organized for the dissemination of research outputs (26 in total).

Source: Terminal Evaluation Report, questionnaire answer from DOF.

In light of the above, the project achieved its purpose.

3.2.2 Impact

3.2.2.1 Achievement of Overall Goal

As explained earlier, the project had no established Overall Goal, and thus in the ex-post evaluation, it was set as "making efforts for social implementation of the research outputs related to the development of aquaculture technologies targeted by the project."

[18] Interview with TUMSAT. Target species are clearly stated in the Implementation Report for JST from the first year.

As shown in the table below, efforts have been started for social implementation based on the project's research outputs, and therefore it is judged that the Overall Goal has been achieved.

Regarding the patent applications (1), DNA markers related to the growth traits of tiger groupers were considered valuable intellectual property and a contribution to future industries, and the Japanese researchers took the lead in patent applications. As for discussions with private companies (2), a vaccine for *Streptococcus pyogenes* in tilapia was developed, and discussions with Japanese veterinary pharmaceutical manufacturers were initiated along with field verification during the project period. Although the discussions were suspended due to the impact of COVID-19, the manufacturer has participated in the succeeding SATREPS project, "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market" (hereinafter referred to as "the succeeding project"), and its relationship with Kasetsart University, the research institution on the Thai side, has continued. With regard to the approval of vaccine (3), because regulations for the approval of aquatic vaccine have not yet been established in Thailand, Kasetsart University has worked to obtain certification to meet Good Manufacturing Practice (GMP) industry standards to replace it. Regarding the verification of disease diagnostic procedures (4), as explained earlier, DOF adopted the EMS/AHPND diagnostic method as its standard method. It has been utilized not only for individual shrimp but also for research facilities. It is also used as a kit for detecting chemical hazards (5) in the water quality and sediments in hatchery ponds. For the diffusion of the developed technologies (6), non-fish meal diets were mainly disseminated to private companies and farmers. There are cases in which research outputs have been diffused to farmers during the prototype verification, cases in which they have been introduced to private companies and farmers through lectures and seminars, cases in which the technologies for feed production have been transferred to producing organizations, and so on. In another case, universities and distributors have provided developed fish diet and vaccines to distributors and farmers, not for the large-scale commercial purpose, but rather to return the research results to society and to generate research funds. To establish the regional network (7), DOF has shared the research outputs in international seminars. Among these efforts, ongoing efforts (2, 6, and 7) have been made by implementing agencies or in the succeeding project.

PCR test for EMS/AHPND diagnosis of shrimp (DOF)

Table 2: Achievement of the Overall Goal Expected in the Ex-post Evaluation

Topic	Achievement	Related output
(1) Patent application of DNA markers for breeding	Ongoing. • In 2016, TUMSAT and the Japan Fisheries Research and Education Agency applied for and registered a domestic patent in Japan for a "method of identifying brown-marbled grouper with growth genetic traits." • In 2017, TUMSAT and DOF applied for an international patent for a "method of identifying brown-marbled grouper with growth genetic traits." It was in the stage before the review at the time of ex-post evaluation. • In 2017, TUMSAT and DOF applied for a patent in Taiwan for a "method of identifying brown-marbled grouper with growth genetic traits." It was in the process of responding to the rejection by modifying it for the patent grant at the time of ex-post evaluation.	Output 1
(2) Discussion with private companies	Ongoing. • Discussions began in 2016 with a Japanese veterinary pharmaceutical manufacturer for the commercialization of a vaccine against type B hemolytic Streptococcus infections in tilapia. The discussions have been suspended due to COVID-19. The manufacturer is participating in the succeeding SATREPS project, and it has aimed to market the product in Thailand.	Output 3
(3) Approval (preparation) of vaccine	Ongoing. • Veterinary vaccines have not been manufactured following the standards required in the pharmaceutical manufacturing industry (Good Manufacturing Practice; GMP) in Thailand yet, and there has been no official registration system for veterinary vaccines. Only vaccines from overseas have been registered. The research team at Kasetsart University has established the GMP section within the faculty and has been in contact with the Food and Drug Administration for fish vaccine registration under its regulations. The research team has been working on obtaining GMP certification for the production of veterinary vaccines.	Output 3
(4) Verification of disease diagnostic procedures	Efforts completed. • The developed EMS/AHPND diagnosis procedure was adopted as a standard procedure of DOF. It was added to the diagnostic manual of the laboratory of DOF.	Output 3
(5) Verification of kits for detection of chemical hazards	Efforts completed. • The EMS/AHPND diagnostic method for shrimp has been applied not only to individual shrimp but also to water and sediment testing to select infected individuals and prevent disease. This has allowed individual infections to be prevented more than they were before.	Output 5
(6) Diffusion of developed aquaculture technologies	Ongoing. • Alternative protein sources for shrimp were disseminated to aquaculture companies in Thalang District, Phuket Province during the project period. • Since the time of project completion, Chulalongkorn University has been producing rALFPm3-added feed (not for commercial use) with a grant from the Agricultural Research Development Agency (ARDA) and support from the succeeding SATREPS project. • With advice from Japanese researchers during the project period, Kasetsart University, in collaboration with Ubon Ratchathani University, provided training to farmers on the use of fish vaccines and the effects of antibiotics on the environment and human health. Ubon Ratchathani University subsequently began to conduct lectures on vaccine development. • DOF conducted the following seminars for social implementation: 1) How to produce alternative diets replacing fish meal for grouper by the Coastal Aquaculture Research and Development Center (CARDC) of Phang-nga (2018-2019, for the Chaipattana Foundation). Because the market for grouper was small and private companies were not interested, technology transfer was provided to NGOs.	Outputs 3, 4

Topic	Achievement	Related output
	2) Grouper aquaculture and feed management (2018, for grouper farmers in Phuket Province). 3) EMS/AHPND diagnostic procedure for shrimp and their surrounding environment (2018-2019, for DOF laboratories). • Walailak University established a sector for the production and sales of probiotic products in 2017.	
(7) Development of the regional network for aquaculture technology development	Ongoing. • The Government of Thailand shared information about EMS/AHPND of shrimp in the international workshop in which the UN Food and Agriculture Organization members participated in July 2017. • DOF made a presentation at the 19th International Symposium on Nutrition and Feeding in Fish in December 2021 regarding the following: 1) Development of the non-fish meal and non-fish oil feed for Asian seabass. 2) Application of protein hydrolysate from discarded fish to banana shrimp feed.	Outputs 3, 4

Source: Terminal Evaluation Report, Completion Report of JST, questionnaire answers, and interview results of DOF, Kasetsart University, Chulalongkorn University, Walailak University, CARDC of Chonburi, TUMSAT.

Considering the situation above, efforts have continued for social implementation based on the project's research outputs. Thus, it is judged that the project has achieved the Overall Goal.

3.2.2.2 Other Positive and Negative Impacts

(1) Utilization of the Research Outputs

The research conducted by the project has continued in the five areas (Table 3). In addition, new research has begun. For example, the research on molecular breeding (Output 1) has continued which resulted in the creation of genetic linkage maps of giant grouper and tiger grouper consisting of 289 and 475 DNA markers, respectively[19]. The research on surrogate broodstock (Output 2) has continued, too, and the birth of Mekong giant catfish from the transplanted recipient catfish in 2019 was a great achievement (see the table below). Regarding the technology for detection and reduction of chemical hazards (Output 5), research has been conducted for the field verification of nitrofuran detection and mass production of detection kits has been conducted. Based on these research outputs, several papers have been published including ones coauthored with Japanese researchers.

[19] Interview with TUMSAT.

Table 3: Continuation of the Research Activities

Outputs		Continuity as of the Ex-post Evaluation
Output 1: Molecular markers for selective breeding at the molecular level (growth, disease resistance, stress) are developed.	Continuation of the research	• Research on molecular breeding of groupers has continued at TUMSAT and the DOF. Genetic linkage maps consisting of 289 and 475 DNA markers were created for giant grouper and tiger grouper, respectively. • For Asian seabass, joint research has continued at TUMSAT and the DOF to develop DNA markers. Several sequences of genetic information have been identified. Methods for the identification and selection of phenotype traits for parental analysis have been established. New families for the analysis have been identified and sustained at three local centers of the DOF. The National Center for Genetic Engineering and Biotechnology (BIOTECH) under the National Science and Technology Development Agency (NSTDA) has joined the research. • For the shrimp species, research was in progress at Walailak University, but an accident at the facility (power outage, generator failure) resulted in the total loss of black tiger and banana shrimp with WSSV-resistant and high-growth traits. However, later in 2019, individuals with the same traits were found again, and the breeding program has continued.
	Continuation of the research in the current SATREPS project	• Research to develop molecular markers for the detection of disease resistance and other informative traits of Asian seabass, to verify genetic diversity in banana shrimp, and to develop molecular markers for disease resistance has continued. • Sampling and genetic diversity analysis to confirm the genetic diversity of Asian seabass and banana shrimp has been ongoing. The development of molecular markers for the detection of disease resistance and other informative traits has been planned for novel farmed fish.
	Start of the new research based on the project output	• Molecular breeding techniques developed by the project have been used to select genetically diverse brooders, and breeding research on banana shrimp and seabass has been underway since 2020 at the DOF. • Based on the molecular breeding techniques of black tiger shrimp, research on whiteleg shrimp and tilapia breeding has been conducted at Walailak University.
Output 2: Surrogate broodstock technology for aquaculture is developed.	Continuation of the research	• TUMSAT and the DOF have continued research to establish donor-recipient relationships for giant grouper and tiger grouper. Giant grouper takes 7-8 years to reach maturity, and males are obtained through sex change after mature females grow further, so it takes time to raise and maintain parent fish. • TUMSAT and Suranaree University of Technology have continued research on Mekong giant catfish. In 2019, research results showed that the Mekong giant catfish had been successfully born from a transplanted recipient catfish (striped catfish). The genetic resources are stored at the DOF. • Research on surrogate broodstock technology has continued at the Suranaree University of Technology. Two graduates (PhD and MS) published scientific papers on germ cell transplantation.
	Continuation of the research in the current SATREPS project	• Research to develop germ cell transplantation techniques for the conservation of genetic diversity and genetic resources of Asian seabass, to improve germ cell technology of Thai native catfish, to conserve germ cells of banana shrimp and other species, and to develop cell transplantation techniques has continued. • The foundation of the germ cell transplantation system by identifying the maturation stage of the Asian seabass donor

Outputs		Continuity as of the Ex-post Evaluation
		and the developmental stage of a recipient suitable for transplantation, and verifying the efficiency of germ cell viability into the recipient gonads was established by March 2021. • Research on cryopreservation of testes and ovaries of catfish and seabass has been conducted at the Suranaree University of Technology.
	Start of the new research based on the project output	• Based on the research outputs on surrogate broodstock technology, Suranaree University of Technology conducted research on germ cell markers to identify germ cell formation, and four papers were produced on the same topic. • A new research project on genome editing and feeding of catfish has been considered using the technology and equipment obtained from the project.
Output3: Practical method for prevention and control of diseases are developed.	Continuation of the research	• For whiteleg shrimp, TUMSAT and a venture company from Tohoku University developed a kit in December 2017 utilizing technology from the Graduate School of Biomedical Engineering (dengue fever and other human infectious diseases, PCR-based testing methods) for early detection of infectious diseases in farmed shrimp through genetic testing. In this process, comparisons with conventional test results, etc., were made using samples examined locally by the DOF. Toward industrialization, tests were conducted in Indonesia and the Philippines (distributors) but have been suspended due to the prevalence of COVID-19. • Collaborative research between TUMSAT and Kasetsart University on vaccine development for Nile tilapia has continued. Regarding the said vaccine development, the researchers have been in contact with a Japanese pharmaceutical company and Thai food manufacturers (CP, Betagro). • The development of a bacterial vaccine has continued at Walailak University. • Research on shrimp immunity and antimicrobial peptides has been conducted at Chulalongkorn University.
	Continuation of the research in the current SATREPS project	• Research to develop vaccines and adjuvants for pathogenic biological infections of Asian seabass, vaccine evaluation methods, genetic tools for studying disease resistance in banana shrimp, and control methods for microbial infections in penaeid shrimp has been underway. • Sample preparation for the implementation of next-generation sequencing was conducted to study the biological defense response of banana shrimp to WSSV. Isolation of 13 phages from hatchery ponds was conducted to develop phage therapy methods for EMS/AHPND control and treatment in shrimp. • The genes for penaeid shrimp were cataloged, and cataloging of the gene for the banana shrimp was initiated.
	Start of the new research based on the project output	• Research has been conducted at Kasetsart University to characterize infectious disease pathogens in aquatic animals and to detect, prevent, and control diseases, including research on: 1) various diseases of freshwater and saltwater fish; 2) different types of vaccines to control bacterial diseases; 3) modules to detect bacterial diseases; and 4) probiotics for disease control in shrimp. • Chulalongkorn University has conducted research in collaboration with private companies on emerging infectious diseases of shrimp and molecular markers for breeding.
Output4: Alternative protein source replacing fish	Continuation of the research	• The DOF has continued evaluation of the prototype of fish meal replacement diets for tiger grouper.
	Continuation of	• Research has been underway to develop pre-shipment

Outputs		Continuity as of the Ex-post Evaluation
meal and broodstock diets are developed.	the research in the current SATREPS project	nutrient-enhanced feed and feeding methods for Asian seabass, the basic technology for the production of banana shrimp and other all-female shrimp, and efficient artificial breeding techniques for parent shrimp. • The scope of research was expanded to include not only feed development but also the development of feeding methods. By March 2021, research had been conducted on the growth effects of diets with progressively reduced fish oil in Asian seabass. • Research was conducted on the development of "artificial maturation diets for parent banana shrimp, new protein sources for shrimp larvae diets, and improved rearing methods.
	Start of the new research based on the project output	• The DOF has carried out research on the development of alternative protein sources for parent tiger grouper.
Output5: Technology for detection and reduction of chemical hazards in aquaculture system is developed.	Continuation of the research	• Research on the detection of malachite green residues, degradation products, and antibiotic residues has continued at Kasetsart University. In addition, a research exchange with the laboratory of a Japanese confectionery company has been underway regarding dye testing for hazards. • Field validation of nitrofurans detection and research for mass production of detection kits have been conducted at Kasetsart University.
	Continuation of the research in the current SATREPS project	• NA.
	Start of the new research based on the project output	• Research has been conducted at Kasetsart University on extending the detection system for various chemicals found in aquatic animals, including chloramphenicol.

Source: Questionnaire answers and interview results of the DOF, Chulalongkorn University, Kasetsart University, Walailak University, Suranaree University of Technology. JST Implementation Report of FY 2020 of "Utilization of Thailand Local Genetic Resources to Develop Novel Farmed Fish for Global Market."

(2) Capacity Development of Researchers

The DOF and the four universities have participated in the succeeding project as implementing agencies, and many of the researchers have continued the research (Table 4). Research on this project has continued as explained above, and new research has been started based on the project outputs.

Table 4: Continuity of Researchers in the Implementing Agencies

	Related Output	No. of researchers who participated in the project	No. of researchers who have continued working	No. of researchers who newly joined	No. of researchers who participate in the succeeding project
DOF	1, 2, 3, 4, 5	66	36	44	74
Chulalongkorn University	4	3	6	5	2
Kasetsart University	3, 5	7	3	6	16
Walailak University	1, 3	13	8	4	9
Suranaree University of Technology	2	6	1	3	12

Source: Questionnaire answers and interview results of the DOF, Chulalongkorn University, Kasetsart University, Walailak University, and the Suranaree University of Technology.

(3) Utilization, Operation, and Maintenance of the Equipment

The DOF and the four universities have continuously utilized the equipment provided by the project. The provided equipment has been managed using the list at the DOF. Regarding the equipment that has been set up at the local centers, the condition and the plan of operation and maintenance have been reported to the DOF every year. At the time of ex-post evaluation, only two pieces of PCR equipment had been broken at a local center. Since it is expensive to repair the two, the center has not fixed them and has used the other four pieces of PCR equipment, with which the research has been conducted without problems. At every agency, the provided equipment has been checked and utilized in the daily research.

3.2.2.3 Other Impacts

The following positive impacts have been confirmed, although it is difficult to separate the effects of this project from those of the succeeding project. No negative impacts on the natural environment have been reported. There was no land acquisition or resettlement.

(1) Realization of Social Implementation of the Research Outputs (positive impacts)

Social implementation expected in the short-, mid-, and long-term as results of the above-mentioned efforts is shown in Figure 1. Part of the expected social implementation has already been realized as shown in the following table. It was expected that non-fish alternative diet (2) and vaccines (3) would be produced for large-scale commercialization, but actually the university in charge of the research and an NGO trained by the DOF have sold the products on a small scale from which farmers have obtained benefits. Regarding the disease diagnosis (4) and detection of chemical hazards (5), as explained earlier, a diagnosis method was developed during the project period and officially disseminated nationwide by the DOF, thus realizing the social implementation of these research outputs early on.

Probiotics products developed by the project research outputs (Walailak University)

Table 5: Realization of Social Implementation

Topic	Efforts	Achievement
(1) Seed production and sales by private companies	• Patent application for DNA markers for breeding	Not realized. • It takes time to gain seed with the selected traits stably, and thus neither the DOF nor private companies have proceeded to production.
(2) Production and sale of non-fish alternative diet by private companies	• Discussion with pharmaceutical companies	Partially realized. • An NGO (Chaipattana Foundation) started the production of a non-fish alternative diet for grouper but suspended production and sale in 2019 due to its organizational restructuring and internal situations.
(3) Vaccine production and sales by private companies	• Approval (preparation) of vaccine	Partially realized. • Walailak University has produced probiotics products for shrimp and wholesaled them to three distributors in the southern region and one distributor in the northern region.
(4) Conduct of disease diagnosis by DOF	• Verification of disease diagnostic procedures	Realized. • The DOF has conducted 400 diagnoses of EMS/AHPND for aquaculture companies and farmers each year.
(5) Conduct of test for detection of chemical hazards by DOF	• Verification of kits for detection of chemical hazards	Realized. • The DOF has conducted tests of water quality and sediments in hatchery ponds based on the EMS/AHPND diagnosis procedure.
(6) Utilization of developed technologies by aquaculture companies and farmers	• Diffusion of developed aquaculture technologies	Partially realized. • Grouper aquaculture farmers purchased non-fish diets from the NGO and used them in the provinces of Phang-nga, Phuket, and Krabi. • Shrimp aquaculture farmers in the southern and northern regions have purchased probiotic products for shrimp from the distributors and used them.
(7) Dissemination of developed technologies to the Southeast Asian region.	• Development of the regional network	Not realized.

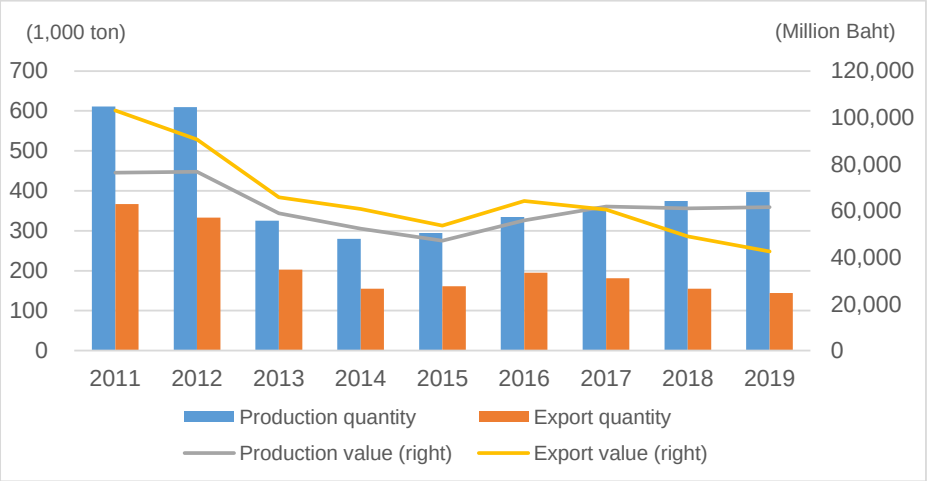
Source: Prepared based on the questionnaire answers and interview results from DOF, Kasetsart University, Walailak University, and Chaipattana Foundation.

(2) Positive Impacts Brought by the Developed Disease Diagnosis of Shrimp

As explained above, the project developed a method for the diagnosis of EMS/AHPND. After an outbreak of the disease, the production of shrimp drastically decreased in 2013, and since then it has been gradually recovering (Figure 4). Responsive research activities were added right after the outbreak of the disease, which resulted in the development of a diagnosis method at the early stage. This method was promoted nationwide at the initiative of the DOF. Shrimp is a major aquaculture product in Thailand, and it is thought that these efforts could prevent a large economic loss.

Aquaculture companies and farmers became to invest more in water quality management after the outbreak of EMS/AHPND, and the production cost increased, which has made them less competitive internationally, according to the DOF. Thus, some companies and farmers have given up shrimp aquaculture, and it was presumed that the

production of shrimp would not return to the pre-disease levels[20]. On the other hand, it is noteworthy that the scientific literacy of aquaculture companies and farmers has been improved through the nationwide promotion of the EMS/AHPND diagnosis method at the DOF's initiative (Column 2).



Source: Prepared based on data from DOF.

Figure 4: Production and Export of Shrimp

Column 2: Improvement of the Scientific Literacy of Aquaculture Companies and Farmers

Shrimp production has been recovering due to the development of the EMS/AHPND diagnostic method, but it has been estimated that it may not return to its previous level. On the other hand, the nationwide diffusion of this diagnostic method has improved the scientific literacy of aquaculture farmers, leading to improved management. First, unlike other countries, Thailand has promoted the EMS/AHPND diagnostic method throughout the country, which improved the scientific literacy of aquaculture farmers. Specifically, aquaculture companies and farmers had previously only waited for disease outbreaks to subside, but now that they understand the causes of the disease, they can avoid the risk factors. Understanding that disease response would reduce their profitability, farmers and companies made a business decision either to continue their business by improving quality and adding a safety perspective such as traceability and EMS diagnostics or to stop shrimp farming (switch to other species or switch to a different industry) without pursuing short-sighted profit. Compared to other neighboring countries, Thailand has a well-developed traceability system up to export. Some companies (e.g., Thai Union, a Thai seafood processing company) have been able to export to the United States by communicating the safety of their products. Second, farmers' understanding of EMS/AHPND enabled them to point out contamination at private aquaculture hatcheries, and this information was instantly disseminated. As a result, aquaculture hatcheries with inadequate contamination control measures were unable to continue their operations. In addition, as a consequence of prioritizing the sustainability of the aquaculture business, the area of shrimp hatcheries decreased as a result of avoiding overcrowded shrimp aquaculture, converting some of the ponds to reservoirs for water quality control, or shifting to other fish species. Thus, it is expected that shrimp production will remain at around 300,000 tons per year, but that the aquaculture industry as a whole will become more mature, and Thailand is expected to maintain a stable position in the global shrimp supply.

[20] Interview result of DOF.

Source: Prepared based on the interview results of DOF and a Japanese trading company.

(3) Positive Impact of the Joint Research

Networks between researchers and private companies were expanded through the project. For example, a university conducted joint research with a private company on vaccine development. The joint research was in line with the interests of both parties: the university benefited from verifying research results, getting financial support, and using the private company's facilities and equipment, while the private company benefited from the preparation of the advanced technology for commercialization. The project also invited private companies to seminars to promote exchanges. As another example, Japanese researchers introduced a Japanese cement manufacturing company to Walailak University. The company was engaged in the development and commercialization of materials in the field of water treatment and the development of technology to improve the environment of aquaculture ponds. The university conducted field verification of the company's water-quality-stabilizing materials for aquaculture[21]. The company has since commercialized the product, which has been sold in Thailand, Taiwan, and China.

(4) Positive Impact related to Biodiversity

At the time of project completion, the compatibility of the Mekong giant catfish (donor) and striped catfish (recipient) was under observation. After project completion, Suranaree University of Technology and TUMSAT continued joint research on the surrogate broodstock technology, and Mekong giant catfish were born from striped catfish. The genetic resources have been stored at the DOF. The International Union for Conservation of Nature and Natural Resources (IUCN) has listed the native Mekong giant catfish as a critically endangered species (CR),[22] and the project has contributed to the conservation of this rare species.

(5) Capacity Development of Young Japanese Researchers

Many Japanese associate professors, assistant professors, and researchers were dispatched to Thailand. Communication with Thai researchers and attending presentations in international seminars have led to the development of their capacity, as they have organized public seminars by themselves after they returned to Japan.

[21] It is a purification agent named Ceraclean to improve water and bottom sediment quality. It is used in aquaculture ponds and golf course ponds, as well as in natural lakes and mud flats. The company's website explains that the application of this product has proven effective in increasing the weight and survival rate of cultured shrimp. https://www.taiheiyo-cement.co.jp/service_product/ceraclean/cultivation.html (accessed on April 10th, 2022, Japanese pages only).

[22] CR is rated as facing an extremely high risk of extinction in the wild in the IUCN Red List.

This project has achieved the Project Purpose of developing technologies for sustainable aquaculture and high-quality products and the expected Overall Goal of carrying out efforts for social implementation. As a result, some social implementation has been realized, such as provision of disease diagnosis services and production and sales of non-fish meal diets. In addition, other positive impacts were confirmed. Therefore, effectiveness and impact of the project are high.

3.3 Efficiency (Rating: ③)

3.3.1 Inputs

The following table shows the comparison between the planned and actual inputs at the time of project completion.

Table 6: Planned and Actual Inputs

Inputs	Plan	Actual
(1) Experts	• Long-term: Coordinator (number of experts, PM not stated) • Short-term: Molecular breeding, surrogate breeding, immunology and vaccine development, alternative feed development, hazard factor analysis, etc. (number of experts, PM not stated)	• Long-term: 2 persons (66.37 PM) • Short-term: 17 persons (19.20 PM)
(2) Trainees received	NA.	58 persons
(3) Equipment	Laboratory analyzers, DNA analyzers, PCR equipment, high-performance liquid chromatography (amount not stated)	Analyzers for molecular breeding, DNA analyzers, PCR equipment, etc. (approximately 1.6 million yen)
(4) Operational costs	Information not available.	Approximately 60 million yen
Japanese Side Total Project Cost	353 million yen	408 million yen
Thai Side Total Project Cost	Amount not stated. (Personnel costs of the counterpart staff, project office, laboratory, and rearing tank of the implementing agencies, facility including hatchery pond, etc.)	151 million yen (Allocation of 116 counterpart staff, their personnel costs, consumables, reagents for analysis, office utilities, expert office space at DOF, laboratory of the implementing agencies)

Note: PM stands for person/month.
Source: JICA internal documents, questionnaire answer from DOF.

3.3.1.1 Elements of Inputs

Seventeen researchers (short-term experts) were dispatched from Japan. A total of 102 dispatches were made, and most of the dispatches were for a week or so at a time. The number of Thai researchers received was 58 (68 trips in total), but, as mentioned above, the research proceeded as planned, and 75 papers were jointly authored, which was more than planned. Therefore, it is judged that the joint research was implemented smoothly. In the project, 13 research groups were organized in five research areas, where 116 Thai

researchers participated. It was pointed out in the terminal evaluation that there was "insufficient information sharing due to the complicated implementation system." However, all groups held progress report meetings every year, and networks among researchers were created; this point was not considered a problem in the ex-post evaluation survey. All of the provided equipment except for two broken PCR machines have been utilized, which can be interpreted to mean that the equipment selection was appropriate.

The Thai side made inputs equivalent to 151 million yen, and it can be said that the project was implemented as a partnership.

3.3.1.2 Project Cost

The actual project cost on the Japanese side was 408 million yen against the planned 353 million yen. Reasons for exceeding the plan include (1) an increase in the number of researchers dispatched as research progressed, (2) the invitation of Thai researchers to the kick-off meeting, (3) a change from local purchase of reagents used for the analysis of DNA markers and immune-related genes to procurement in Japan, and (4) the hiring of project support personnel. In particular, the Thai side asked JICA and JST to take urgent action against EMS/AHPND, which became a major problem in Southeast Asia in early 2013. JICA and JST conducted a situational review and, as a result, joint research to respond to EMS/AHPND, which had not been originally planned, was added to the project scope. As it was an additional activity related to the technology for reducing infectious diseases (Output 3), the PDM was not revised accordingly. However, JICA and JST documents confirmed that the budget for FY2014 was increased and joint research was initiated[23]. This research activity led to the identification of the toxin gene and the development of a diagnostic method using PCR testing the following year (2014). Therefore, it is judged that the project cost was commensurate with the outputs of the added scope.

3.3.1.3 Project Period

The actual project period was 60 months (May 2012 to May 2017) against the planned 60 months (March 2012 to March 2017). It was as planned.

In light of the above, the project period was as planned, and it is judged that the project cost was commensurate with the produced outputs. Therefore, efficiency of the project is high.

[23] *JST Implementation Report of FY 2013*, JICA internal documents, and the Mid-term Review Report.

Column 3: Roles and Contribution of the Japanese Experts Who Encouraged Social Implementation

The project was aimed at the production of the developed vaccines and fish diets by private companies as part of the social implementation of the research results. The following two factors promoted efforts toward social implementation from the early stage. First, the project was implemented not only through research and information sharing by the implementing agencies but also through the involvement of private companies. Specifically, at the end of each fiscal year, an open meeting on the research results was held in Bangkok, and Thai companies and Japanese companies in Thailand related to the research field were invited to the meeting. The invited companies were those with which the Japanese and Thai researchers had previously had a cooperative relationship, and such companies were selected because the researchers felt comfortable conducting joint research within the project. The purpose of the meeting was not only to report the results of the project but also to introduce the developed technologies to the invited companies. In fact, an interested Japanese company started discussions with the implementing agency in Thailand regarding the commercialization of the vaccine under study, and the company has been participating in the succeeding project as a Japanese cooperation organization. Second, TUMSAT has long accepted exchange students from foreign countries, including Thailand, and the Japanese researchers who worked as experts in the project have continued joint research and exchange with former exchange students for more than 20 years. Many of the former exchange students have obtained key positions in the DOF, fishery-related research departments of universities, and research sections of private companies. Based on the network and relationship of trust with them, research activities proceeded smoothly in the project, and, as mentioned above, the project succeeded in involving organizations other than the implementing agencies in joint research activities.

Source: Prepared based on the results of interviews with the DOF and TUMSAT.

3.4 Sustainability (Rating: ③)

3.4.1 Policy and Political Commitment for the Sustainability of Project Effects

The development policies of the Government of Thailand have driven the development of sustainable, high-quality aquaculture technologies and their social implementation. Based on the government's plan, *Kitchen of the World*," the 12th NESDP (2017-2021) set forth a policy of promoting increased fish and shellfish production through technology development in the aquaculture industry. The *Strategic Plan* (2017-2021) of the DOF also set out four strategic objectives: (1) increasing productivity and strengthening farmers, (2) developing the quality of value-added fishery products, (3) sustainable fisheries and fishery resource management, and (4) organizational management of the DOF. Concerning each strategic objective, the goals are: research and development (R&D) and technological innovation to reduce production costs (1), R&D and technological innovation to create added value (2), R&D to improve the efficiency of fishery resource management (3), and strengthening the capacity of staff and international networking (4).

Thus, the policy and political commitment to sustain the project effects have been secured.

3.4.2 Institutional/Organizational Aspect for the Sustainability of Project Effects

The section in charge of research has been clearly positioned at each implementing agency, and the personnel to sustain the research has been secured (Table 7). Concerns were pointed out in the terminal evaluation about personnel transfers within the DOF. However, it was confirmed in the ex-post evaluation that, although there were transfers within the headquarters and between centers for promotion, the research results have been compiled in publications, reports, manuals, and so on., and no problems have occurred to date.

There are five R&D divisions related to aquaculture at the DOF. For promoting social implementation, a technical management group has been established in each division. Their main responsibilities include evaluation of the research results of each division and selection of the research outputs appropriate for social implementation. In addition, they have worked on the diffusion of aquaculture technologies, demonstration of aquaculture hatcheries, implementation of pilot projects, involvement of relevant stakeholders, and so on. There have been 15 to 20 staff members responsible for social implementation, and they have received support from local centers. According to the DOF, the number of staff has been sufficient. As for the four universities, the research group has been clearly positioned in the relevant department of each university. Some universities answered that the number of researchers was not sufficient to expand the research scope, but considering the status of research continuation and realization of effects, it is judged that there has not been a problem.

Table 7: Organizational Setting for Research in the Implementing Agencies

	Section-in-charge and number of the staff
DOF	• The DOF consists of four clusters. The aquaculture cluster has the following divisions: (1) Inland Aquaculture Research and Development Division (154 researchers) (2) Coastal Aquaculture Research and Development Division (124 researchers) (3) Aquatic Animal Genetics Research and Development Division (34 researchers) (4) Aquatic Animal Health Research and Development Division and (27 researchers) (5) Aquatic Animal Feed Research and Development Division. (28 researchers)
Chulalongkorn University	• The Program in Biochemistry and the Marine Science Department are responsible for aquaculture technology development. The number of the academic staff, including researchers, is 10. The “number of staff is not considered sufficient,” as there are various topics and species of aquatic animals.
Kasetsart University	• The Department of Aquaculture (Faculty of Fisheries) and the Department of Biochemistry (Faculty of Science) jointly operate five research sections: disease characterization, pathogen isolation and characterization, disease detection development, disease prevention and control, and development of the detection of food-contaminating chemicals. Each section has three to five professors and researchers. The number of staff is “not considered sufficient,” but there is a plan to increase the number of doctoral students by two to three in the 2022 academic year. • The university prepares scholarships and a fast-track program that allows completion in a short period to attract young students’ interests.
Walailak University	• The Center of Excellence for Shrimp is in charge of aquaculture research and development. It has four professors and five researchers and the number is considered

	Section-in-charge and number of the staff
	"sufficient." • The university provides scholarships but the number of doctoral students has been decreasing. The university has a plan to develop a curriculum for students from other regions in the country and from foreign countries.
Suranaree University of Technology	• Related research is conducted at the Program of Biotechnology for Aquaculture (master of sciences and PhD courses) under the School of Animal Technology and Innovation of the Institute of Agricultural Technology. Three responsible lecturers and five researchers are assigned to the program, and the number of the staff is considered "sufficient" for research on sustainable and quality aquaculture.

Source: Prepared based on the questionnaire answers and interview results of DOF, Chulalongkorn University, Kasetsart University, Walailak University, and Suranaree University of Technology.

All of the implementing agencies have been also participating in the succeeding project, and each has established a joint research relationship with other research institutions. The DOF has concluded agreements on R&D and dissemination with three national universities and the NSTDA and has been also conducting joint projects with aquaculture farmers, agricultural cooperatives, and the Thai Frozen Food Association. Furthermore, the universities have conducted joint research with other national universities and research institutes, overseas research institutes, and private companies. For example, Suranaree University of Technology has carried out joint research on aquaculture feed with the National Institute for Agriculture, Food and Environment at the University of Pau and Pays de l'Adour in France. Kasetsart University has worked with private companies for joint research and received funds from the Program Management Unit for Competitiveness (PMUC). Under this grant program, companies are required to pay 10% of the total research cost as a guarantee that they promise to utilize and commercialize the research results after the research.[24]

Taking the above into account, it is judged that the institutional and organizational aspects of the implementing agencies have been sufficient.

3.4.3 Technical Aspect for the Sustainability of Project Effects

As mentioned earlier, the project's ongoing and new research has continued in all research areas since project completion. In addition, collaborative research has been carried out in the areas of molecular breeding, control of infectious diseases, efficient feeding and rearing, and germ cell transplantation. These areas have much in common with Output 1, Output 3, Output 4, and Output 2 of this project, respectively.

For the DOF, research on surrogate broodstock technology was the first effort in this project, and since it needed specialized equipment, "advanced techniques are required

[24] PMUC (Program Management Unit for Competitiveness) is a research grant agency established under the Office of the National Higher Education Science Research and Innovation Policy Council (NXPO) of Thailand, with the aim of promoting the commercialization of research results. It provides grants according to the level of the research institution.

compared to other research areas, but in other areas, their techniques for continuing research have been sufficient." The DOF has worked on capacity building through seminars, workshops, and on-the-job training (OJT) for its staff, including new researchers at headquarters and researchers at local centers. The four universities have also been conducting OJT for new researchers and joint research with other institutions, in addition to research in the succeeding project. For example, in addition to participating in the succeeding project and other research projects with external funds, Chulalongkorn University has been maintaining research skills by conducting interactions among research groups within the university and providing short-term training for teachers, students, and post-doctoral researchers.

The research equipment has been utilized daily, as mentioned above.

In light of the above, considering the status of research continuation and equipment utilization, it is judged that techniques of the implementing agencies have been sufficient.

3.4.4 Financial Aspect for the Sustainability of Project Effects

The budget for research projects related to aquaculture and fisheries at the DOF is shown in the table below. The director, who took office in 2017, has placed a strong emphasis on research, and the budget has been increasing. In addition to this, the DOF has applied for research grants from external research institutions and has continued research. The headquarters and local centers have prepared the annual operational plan, in which the cost of repairing research equipment and purchasing supplies has been accounted for.

Table 8: Budgets for Research of DOF

Unit: Thai Bhat

	2017	2018	2019	2020	2021	2022 (plan)
Revenue	1,526,200	4,741,600	4,908,265	11,075,946	13,061,600	32,146,440
Expenditure	1,526,200	4,741,600	4,908,265	7,024,697	NA	NA

Source: Prepared based on the questionnaire answer form DOF.

Although strict financial data were not available from the four universities, the research budgets of three universities, including the budgets from the universities and research grants, have tended to remain about the same or increase slightly since the project completion. This budget has covered the operation and maintenance of research equipment. Chulalongkorn University had a research budget of about 8 million baht in 2017, which has decreased to 7 million baht since 2021. According to the university, more emphasis has been placed in recent years on applied research for adding value than on basic research on fish and shellfish diseases, and the government has expected more investment from the private sector in the shrimp aquaculture industry, as the government has relied much on the

private sector. Walailak University has generated about 600,000 baht per year (40% of development costs) from the sale of probiotic products. In addition, Kasetsart University has received income from paid services (laboratory experiments and research) for private companies.

Although some financial data could not be strictly confirmed, considering the status of research continuation and equipment utilization, it is judged that there has been no issue in the financial aspect of the implementing agencies.

No major problems have been observed in the policy background, the institutional/ organizational, technical, and financial aspects. Therefore, sustainability of the project effects is high.

4. Conclusion, Lessons Learned and Recommendations

4.1 Conclusion

The project aimed to develop new aquaculture technologies in Thailand by conducting research in five areas that complemented each other: molecular breeding, surrogate broodstock, infectious disease control, non-fish-meal alternative diet, and detecting and reducing chemical hazards. This is in line with the Thai development policies and needs, as well as Japan's assistance policy, and thus the project relevance is high. In all five areas, research outputs were produced according to the plan. The developed technologies have been applied to the target fish species, and because of the joint research, the researchers' capacity has been improved and the research results have been publicly disseminated. Furthermore, efforts have been made to put the research outputs to practical use, and social implementation has been realized, such as the implementation of disease diagnosis services and the production and sale of non-fish alternative meal diets. In addition, several other positive impacts were confirmed, such as the early development and domestic and international approval of diagnostic methods for shrimp diseases that were prevalent, and the improvement of scientific literacy among farmers and private companies. Therefore, the effectiveness/impact of the project is high. The project period and cost are judged as commensurate with the outputs, and the efficiency is considered high. Regarding sustainability, the policy background and the institutional/organizational, technical, and financial aspects are all sufficient for the development of sustainable and high-quality aquaculture technologies and their social implementation. Thus, the project sustainability is high.

In light of the above, this project is evaluated to be highly satisfactory.

4.2 Recommendations

4.2.1 Recommendations to the Implementing Agency

(1) The Chaipattana Foundation has suspended the production of non-fish meal diets for two years due to internal circumstances. The prospects for its resuming production do not appear to be great due to the lack of high consumers' demand for grouper in the southern region. The knowledge and technology for developing alternative feeds replacing fish meal for grouper can be applied to feeds for other fish species. It is recommended that the DOF continue the marketing research on alternative feeds, apply the knowledge and technology gained from the project to fish species with higher needs, and encourage NGOs or private companies with manufacturing systems for production.

(2) New research based on the research outputs of the project and in the succeeding project has been conducted. It is recommended that the DOF continue to disseminate the research outputs to other countries in international seminars or by publishing academic papers and drive research on aquaculture technologies in the Southeast Asia region.

4.2.2 Recommendations to JICA

None.

4.3 Lessons Learned

Involvement of research institutions and private companies with the basis and potential for social implementation

Efforts toward social implementation have been made since the project period and have been partially realized. In the project, not only the DOF, which is in charge of R&D and dissemination of aquaculture technologies, but also universities that have conducted research in the technological fields for sustainable and high-quality fishery production were selected as implementing agencies. The DOF is a government agency, and, under its direction, the shrimp disease diagnostic method that the project developed has been disseminated nationwide. In addition, because of its public status, the DOF cannot directly implement projects with private companies, but there are many local centers with research and dissemination functions, and thus the research outputs of the project (disease diagnosis, facility inspection, etc.) were able to reach farmers directly. On the other hand, by pursuing joint research with private companies, the universities were able not only to verify the research outputs but also to start discussions for future commercialization. This joint research was in line with the interests of both parties: the universities benefited from verifying research results, obtaining financial support, and using the private companies' facilities and equipment, while the private companies benefited from the preparation for commercialization of the universities' professional research. In this way, the SATREPS project could make efforts toward social implementation even during the project period by

involving private companies that could play an important role in social implementation and universities that have experience in commercialization.

(End.)