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Developing technologies for giant grouper aquaculture in Vietnam, the Philippines and Australia

9

ACIAR OUTCOME
EVALUATION SERIES

Developing technologies for giant grouper aquaculture in Vietnam, the Philippines and Australia

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2024

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Cover image: A Vietnamese farmer visiting their hybrid grouper fingerling ponds. Photo: Khanh Long.

Foreword

The Australian Centre for International Agricultural Research (ACIAR) is mandated under the ACIAR Act (1982) to work with partners across the Indo-Pacific region to generate the knowledge and technologies that underpin improvements in agricultural productivity, sustainability and food systems resilience. We do this by funding, brokering and managing research partnerships for the benefit of partner countries and Australia.

Giant grouper was identified as a high-value, fast-growing fish species with significant aquaculture potential for Vietnam, the Philippines and Australia. However, its economic potential was limited by inefficient commercial production of juvenile fish in Vietnam and the Philippines, due to a lack of knowledge about their maturation and spawning behaviour and the low larval survival rates.

To support this industry, additional research was needed on sustainable technologies for grouper breeding, genetic broodstock management and larval-rearing technologies. The 2 ACIAR Fisheries Program projects reviewed in this evaluation ran between 2012 and 2019 with the aim of closing the giant grouper breeding cycle and eliminating or reducing reliance on imports and the need to source giant grouper from the wild. The goal of the project was to establish a sustainable grouper industry in partner countries and strengthen the regional aquaculture industry.

As a learning organisation, ACIAR is committed to understanding the diverse outcomes delivered by the research collaborations we develop, to demonstrate the value of the investment of public funds, to continuously improve research design and capacity, and ultimately to improve the livelihoods of farming communities in our partner countries. This evaluation demonstrated the importance of understanding the market demand, the partner capacity and interest, and drivers of the whole value chain for achieving industry impact. It also highlighted the need for more rigorous design and monitoring of outcomes, as well as more formal and resourced extension programs.

This evaluation found that the projects contributed to the production and evaluation of hybrid grouper in Vietnam, which became a profitable and preferred crop for hatcheries and grow-out farmers. The ACIAR funded work also reduced the reliance on imported fingerlings and potentially decreased the pressure on wild grouper populations. Hybrid grouper were found to be advantageous for different farm sizes, including small-scale farms, as they offered opportunities for diverse crop choices and reduced investment risks. Overall, the evaluation found that improved availability of hybrid grouper aquaculture has had a positive and lasting impact on household income and wellbeing in the region.

Prof Wendy Umberger
Chief Executive Officer, ACIAR

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The evaluation team would particularly like to thank Dr Vu Van In from the Research Institute for Aquaculture No. 1, Dr Nguyen Huu Thanh from the Research Institute for Aquaculture No. 2 and Dr Truong Quoc Thai from the Research Institute for Aquaculture No. 3 for the care and time they gave to organising and hosting our visits to their marine research centres and their network of hatchery and grow-out farmers to discuss the project's involvement in the grouper industry. Their insights into all aspects of the project's implementation and outcomes were invaluable.

We would also like to thank all the project stakeholders and external experts who gave so generously of their time to participate in interviews and provided their thoughtful and diverse insights to this evaluation.

Abbreviations and acronyms

AUD	Australian dollar
ACIAR	Australian Centre for International Agricultural Research
DAFF/NFC	Department of Agriculture, Fisheries and Forestry Northern Fisheries Centre (Queensland)
ELISA	enzyme-linked immunosorbent assays
F1	first generation of a captive-bred population
FSH	follicle stimulating hormone
GGTG	giant x tiger grouper
IUCN	International Union for Conservation of Nature
JAF	John Allwright Fellowship
KEQ	Key evaluation question
LH	luteinising hormone
RAS	recirculation aquaculture system
RIA	Research Institute for Aquaculture (Vietnam)
RIA1	Research Institute for Aquaculture No. 1 (Vietnam)
RIA2	Research Institute for Aquaculture No. 2 (Vietnam)
RIA3	Research Institute for Aquaculture No. 3 (Vietnam)
SEAFDEC	Southeast Asian Fisheries Development Center
SEAFDEC/AQD	Southeast Asian Fisheries Development Center Aquaculture Department (the Philippines)
UniSC	University of the Sunshine Coast (Australia)
USD	United States dollar

Contents

List of tables

List of figures

Summary

This report presents the findings of the evaluation of the following Australian Centre for International Agricultural Research (ACIAR) research projects on giant grouper production:

- 'Preliminary trials on giant grouper maturation, spawning and juvenile production in Vietnam, the Philippines and Australia' (FIS/2012/037)
- 'Developing technologies for giant grouper (*Epinephelus lanceolatus*) aquaculture in Vietnam, the Philippines and Australia' (FIS/2012/101)

The projects were carried out in Vietnam, the Philippines and Australia from 2012 to 2019. The University of the Sunshine Coast in Australia, the Research Institute for Aquaculture No. 1 and later the Research Institute for Aquaculture No. 3 in Vietnam, and the Southeast Asian Fisheries Development Center Aquaculture Department (SEAFDEC/AQD) in the Philippines collaborated in the projects. The main goal of the projects was to establish a sustainable grouper industry in the partner countries and strengthen the regional aquaculture industry through a suite of scientific objectives aimed at closing the giant grouper breeding cycle to reduce reliance on imported and wild-caught stock.[1]

The primary purpose of this evaluation was to assess the projects' achievements, and to derive lessons for future ACIAR research programs.

This outcome-evaluation methodology uses a theory-based approach, developing a retrospective theory of change and testing project achievements against expected outcomes. Data gathering included the review of 67 project and related documents, a citation analysis of 14 research publications, a 10-day field trip to Vietnam and interviews with 47 stakeholders from the partner countries.

The evaluation focused primarily on the grouper industry in Vietnam, where progress on grouper industry initiation was more advanced and research-to-outcome pathways could be more fully explored. The discussion of project outcomes in the Philippines is mostly related to capacity development and regional dissemination, with minimal coverage in Australia due to the early withdrawal of the main implementing partner.

Evaluation limitations included:

- the inability of all evaluation team members to travel to Vietnam to fully assess research applications
- insufficient official data relating to grouper industry development
- the reliance on research partner supply networks to identify interview participants in Vietnam limited the understanding of the project's reach among broader industry participants.

Key evaluation questions were:

- **KEQ 1:** How appropriate was the design of the project to the context?
- **KEQ 2:** What outcomes (intended and unintended) has the project achieved or contributed to?
- **KEQ 3:** What can ACIAR learn from the design and implementation of this research-for-development project?

The following summary presents these findings according to key evaluation questions (and sub-questions, where relevant), including reference to the outcome levels they correspond with in the project's theory of change.

1 Closed cycle captive breeding is a system in which captive adult females are fertilised by captive adult males under managed conditions and their offspring are reared to reproductive age and produce their own offspring. Importantly, it is carried out in isolation from wild populations. Wild-caught animals may still be required occasionally to introduce new genetic material and avoid inbreeding.

Key findings

1

How appropriate was the design of the project to the context?

The evaluation found that the project design was initially well-aligned to partner-country priorities. At the time, giant grouper presented a promising opportunity for aquaculture development, driven by their general lack of availability and high prices. All partners were interested in achieving breeding breakthroughs that could establish grouper domestically as a viable, high-value crop.

However, in response to growing interest and market demand for giant x tiger grouper (GGTG) hybrids, the project in Vietnam shifted its focus midway to hybrid grouper, which were ultimately more suitable for Vietnam's growing conditions and markets. In Australia, early success with spawning meant that the giant grouper industry was already under way by the commencement of the second project.

In the Philippines, the limited amount of mature broodstock available during the project hindered progress and a shift to other priority commercial crops changed the focus of research after the project ended. The change in priority in Vietnam could not have been foreseen at the outset, and the project design was sufficiently flexible to adapt to and support the new focus on GGTG hybrids there.

There was also a reasonable alignment with partner capacity to participate in and benefit from project activities. The project design specifically sought scientific solutions to address priority bottlenecks in giant grouper production. From the outset, research centre partners in both Vietnam and the Philippines displayed a high level of interest in engaging in 'good' science, and actively sought collaborations that would develop their high-level research capacity. Despite this preference, the evaluation found that the project could have included greater emphasis on more readily implementable solutions in the context of partner-country industry capacity.

2

What outcomes (intended and unintended) has the project achieved or contributed to?

Despite being primarily interested in outcomes, this evaluation also focused on project outputs to address the evaluation questions of interest to ACIAR.

Intermediate outcomes

Capacity building in partner research organisations

The project's capacity-building program was a significant strength with strong outcomes. Knowledge and skills in research capacity, experimental design, data analysis, scientific writing and understanding of English were effectively transferred to individual researchers through their participation in a program of formal training and research collaborations. The engagement of postgraduate students and early-career researchers with the project led directly to other career and training opportunities, such as:

- promotion within their organisation (2)
- university positions (1)
- postdoctoral research positions (2)
- government funding for new projects (2).

The project also facilitated organisational capacity-building by upgrading and building new facilities, and by supporting development of breeding protocols and standardised information for consistent, ongoing application by future research staff. The increased capacity of marine finfish teams left a lasting legacy in the form of attention to scientific rigour for ongoing research – especially in Vietnam where most researchers continued in their roles. However, the loss of key project team members at the end of the project in the Philippines limited SEAFDEC's ability to continue the research, although some individuals continued to conduct related research in other organisations. The project also promoted gender equity in research opportunities, with trainee selections perceived by partner organisation staff to be merit-based.

Scientific outputs and their quality

The project achieved notable scientific outputs, overcoming biological and technological challenges to achieve outcomes related to giant grouper breeding. These outputs included:

- the development of sustainable technologies for grouper breeding, such as:
  - broodstock handling, monitoring and spawning synchronisation
  - sex reversal and optimal sex ratios for breeding
  - practical sperm preservation techniques
  - hormone production, including new delivery methods and treatments
  - improved nutrition and biosecurity
  - genotyping to identify parental contribution to reduce inbreeding and enable species identification
- successful spawning of giant grouper
- the significant discovery that giant groupers are diandric protogynous hermaphrodites by the identification of primary males, leading to the potential to raise smaller broodstock
- development of improved methods for fertilised egg and larval production (including live feeds)
- the successful production and evaluation of GGTG hybrid grouper.

These outputs were considered by industry peers to be the result of high-quality research, thus providing and sharing fundamental knowledge and valuable tools for a better understanding of giant grouper reproduction and hybrid production.

Use of knowledge by partner countries

The use of knowledge and methods developed by the project was varied among partner countries and practical application appeared to reduce over time – particularly with the switch to less-demanding hybrid grouper production. Some methods, such as hormone use for sex reversal and spawning induction, giant grouper male spawning and hybrid production, had significant impact and continue to be applied consistently in Vietnam. Other methods, such as genotyping for genetic diversity management and cryopreservation of sperm, were useful during the project but are not currently being implemented in Vietnam. However, Australia is making continued use of genotyping technologies to reduce inbreeding through its broodstock management program.

Broader influence of the research

Project research collaborations lead to 14 published papers, co-authored by the University of the Sunshine Coast (UniSC) team and at least one of the partner organisations. These were made accessible to a wider audience through publications in high-impact journals, other international journal publications and conference presentations. Several highly cited papers demonstrated the reach and significance of the research findings to the wider research community. The project's impact extended beyond the partner organisations, as the research techniques and findings were applied to other grouper, finfish and other aquatic species in partner countries and beyond.

Ultimate outcomes

Contribution to initiating a sustainable grouper industry in partner countries

The initiation of a sustainable giant grouper industry in partner countries faced various challenges and achieved different levels of success. In Australia, the initial partner withdrew due to commercial reasons, and the industry there was established independently of the project. In the Philippines, the Southeast Asian Fisheries Development Center (SEAFDEC) struggled to produce giant groupers or other hybrids beyond research numbers due to the limited availability of mature broodstock. While some knowledge-sharing with an informal industry partner may have benefited their production, the extension of giant grouper as a crop was not achieved domestically. In Vietnam, although research institutes made significant progress in spawning giant grouper, their focus shifted to GGTG hybrids, and the following findings relate mostly to these.

In Vietnam, Research Institute for Aquaculture No. 1 and No. 3 (RIA1 and RIA3) achieved reliable production of GGTG hybrid grouper fertilised eggs and limited numbers of fingerlings to supply to industry using project-ready giant grouper males. They also increased fingerling survival rates from a low of 2% to a high of 10%. The timing of their production, however, calls into question the project's claim in its final report of the introduction of a 'new' crop, as these were already being farmed in Vietnam. In addition, the contribution of the RIA to the overall hybrid grouper industry appears to have occurred in parallel with a number of private industry actors who used their own technologies to produce significant quantities of fertilised GGTG eggs.

These private producers operate independently without direct technology transfer from the research institutes, indicating hybrid grouper production would likely have occurred in Vietnam without intervention by the project. However, the attention of these private producers to quality and ensuring the ongoing sustainability of grouper production is not well understood.

It was challenging to estimate the capacity of the grouper industry to meet current demand due to limited industry data available in Vietnam. A key element of the project's definition of 'sustainability' was the reduction in imports and their associated biosecurity risks. The contribution of the RIA's fertilised eggs to overall domestic fingerling production does appear to have led to a reduction in the importation of fingerlings – estimated at 50% in 2017 and 20% in 2022. Local scarcity persists in the November to March period and the 20% deficit is still met by imports, with their associated risk.

Impact on household income and other gendered measures of welfare

The impact on household income of improved availability of hybrid grouper fertilised eggs and fingerlings has been significant, both for those who buy directly from the RIA (attributable to the project) and from other private producers. Although not rigorously assessed, evaluation findings suggest that profitability and benefits from hybrid grouper farming have endured and possibly increased since the initial socioeconomic study conducted by the project in 2017. In 2022, GGTG hybrid grouper were identified by a majority of hatchery and grow-out farmers interviewed as their most profitable crop, with growers preferring them over other species. Perceived benefits were mostly related to the profits they generated. The suitability of hybrid grouper for different farm sizes, including small-scale farms, was highlighted as an advantage, as they offered opportunities for diverse crop choices and reduced investment risks.

While women could participate in and benefit equally from all aspects of grouper farming, the persistent division of labour based on perceived physical strength and dexterity did not detract from the considerable family benefits. Only a slight change to women's roles was evident, possibly resulting in additional job creation for specific part-time roles in hatcheries for weaning and grading juveniles. Overall, the improved availability of GGTG hybrid grouper aquaculture has had a positive and lasting impact on household income and wellbeing.

Key findings (*cont.*)

Environmental outcomes

The evaluation found that data on the impact of project activities on wild grouper population pressure was limited. The claim in the project's final report that the project had generated a 'major' shift from wild-caught to aquaculture-reared farming could not be adequately substantiated by this evaluation. There is still evident sourcing of wild broodstock for aquaculture purposes in Vietnam, and there is speculation that GGTG hybrid production may be putting increased pressure on tiger grouper populations, where female broodstock are required. Rather than a 'major shift', there may have been a reduction in the sourcing of wild fingerlings in the project-influenced areas in Vietnam due to the increased availability of cultured hybrid fingerlings (locally grown and imported). This may have plausibly led to a reduced impact on wild-caught species – at least in areas with adequate access to hybrid grouper fry – although this could not be quantified.

The possibility that not all hybrids are sterile may adversely impact wild populations. If fertile hybrids are able to breed with wild grouper, this risk of this happening needs to be further evaluated. However, this is a risk common to all other Southeast Asian countries where GGTG hybrids are currently farmed.

Contributing factors

Success factors observed by this evaluation included:

- The project was managed by a highly regarded and adaptive project team from UniSC.
- The availability of high-quality students from all partner countries, and an approach to capacity building that championed scientific rigour and supported individual career development, created a receptive and supportive learning environment.
- The focus on higher-level science and its documentation, while challenging, had many benefits, including a lasting legacy of fundamental knowledge and scientific rigour in ongoing research in partner organisations.
- High-calibre research papers were developed collaboratively, coinciding with a growing regional interest in grouper.
- The willingness of project partners to adapt to changed market demand provided opportunities – particularly the GGTG hybrid grouper in Vietnam – and the project design and team were flexible enough to respond.

Factors that hindered success included:

- Using a project proposal format that encouraged ambitious impact articulation led to unrealistic expectations about commercial outcomes, which were in turn difficult to measure.
- The project proposal lacked a complete analysis of the needs of the whole grouper production chain and the limits of the project's role in it. This hampered the development of realistic, measurable outcomes commensurate with project inputs. These should have been limited to hatchery-level proof of concept rather than industry-wide impact.
- The limited involvement of commercial partners in project development and delivery in Vietnam and the Philippines reduced capacity for broader impact within partner countries.
- A deeper analysis of differing partner capacity and interest at the broader industry level at proposal stage may have led to separate, more targeted outcome objectives for each country.
- Articulation and resourcing of domestic extension programs in Vietnam were missing from the output-to-outcome pathway of the design.
- Challenges in achieving an appropriate balance between high-level science and industry implementation in developing-country settings were not adequately addressed by project activities.
- The switch of focus to the GGTG hybrid grouper reduced advances in giant grouper culture and closing the life cycle effectively.
- The withdrawal of the Australia-based partner reduced the expertise of the project team in the key area of larval culture, and the loss of the Philippines research team at project end reduced organisational capacity to continue to build on the research.

These factors are discussed in full later in this report.

3

What can ACIAR learn from the design and implementation of this research-for-development project?

The project targeted a largely promising species for industry development within the context of substantial partner-country interest in high-level scientific solutions to bottlenecks in the giant grouper breeding cycle. It achieved significant advances in breeding technologies and larval culture, benefiting not only giant grouper but also other marine fish species. Researcher capacity was developed in partner organisations, leaving a legacy of improved fundamental knowledge and scientific rigour in ongoing research. The project employed 2 main pathways to initiating industry uptake:

- sharing knowledge through research papers and regional training programs
- providing direct extension mechanisms to the grouper industry in partner countries.

The first pathway was successful in disseminating knowledge through research publications and SEAFDEC's training programs, with benefits in Southeast Asia and beyond. The research findings were also adapted for other marine species. However, the second pathway faced mixed success. The Philippines experienced difficulties in producing enough grouper for wider distribution and had limited domestic industry uptake. Vietnam saw greater success, but only after the pivot to GGTG hybrid grouper.

In Vietnam, extension programs effectively transferred knowledge to local hatcheries and growers, increasing the uptake of hybrid fertilised eggs and fingerlings. This led to a reduced reliance on imported hybrid grouper stock, potentially reduced pressure on wild grouper stocks, and importantly, generated real profits for participating farmers. However, the success in Vietnam, although significant, may have occurred independently of project intervention. There was evidence of parallel private-sector domestic production, and challenges were encountered in engaging these private-sector enterprises to improve production practices. This may ultimately have implications for industry sustainability, as disease management, species purity and genetic diversity, and quality of production could be compromised.

Lessons for ACIAR revolve around better design and partnership choices. The project's ambitious goals exceeded its resources and science-based inputs, and the project lacked clear measures of industry impact. Although attempting to capitalise on the relative strengths of each country partner, the capacity and interests of the partner research organisations may not have been reflected in the shared outcome of industry initiation. The research partner chosen in the Philippines suited the regional knowledge-sharing aspirations of the project, but assisted less with the identification of local industry priorities. In Vietnam, the research partners had good influence within their limited industry networks, but were not resourced by the project to have broader industry reach and collaboration.

A more thorough design process, in which country partners articulated how they thought a sustainable industry could be established, would have helped to better define each research partner's outcome expectations and capacity to influence industry, and led to agreed measures of industry impact. This in turn would have either tempered expected commercial outcomes to be more aligned with project inputs and country partner capacity and interest, or ensured additional resources were provided to address all value-chain bottlenecks and assist in achieving broader industry sustainability.

Introduction

ACIAR is an agency within the Australian Government's aid program that focuses on agriculture and fisheries research for use in international development. Established in 1982, the purpose of ACIAR is to contribute to reducing poverty and improving livelihoods throughout the Indo-Pacific region by enhancing sustainable agriculture and fisheries through collaborative international research.

This report presents the findings of the evaluation of 2 ACIAR research projects on giant grouper production:

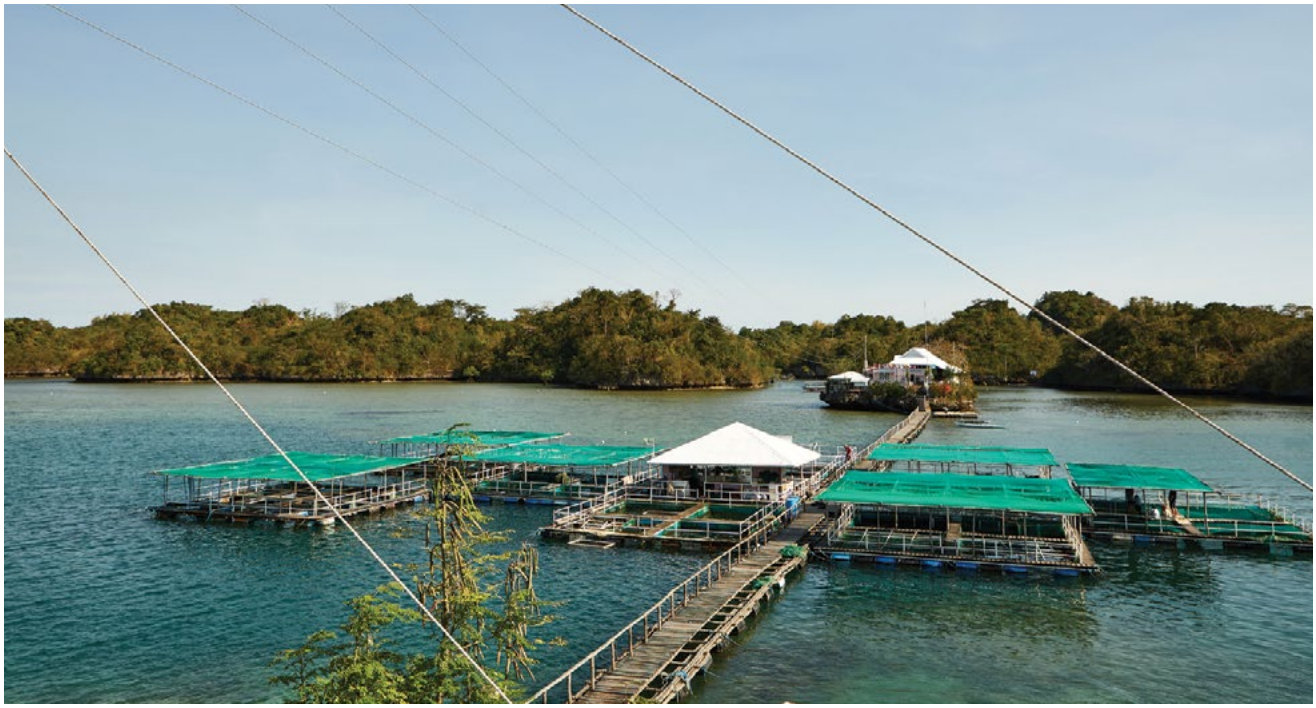
- 'Preliminary trials on giant grouper maturation, spawning and juvenile production in Vietnam, the Philippines and Australia' (FIS/2012/037) that ran from 2012 to 2013 and had a total budget of AUD146,000
- 'Developing technologies for giant grouper (*Epinephelus lanceolatus*) aquaculture in Vietnam, the Philippines and Australia' (FIS/2012/101) that ran from 2014 to 2019 and had a total budget of AUD1,673,533.

The projects were co-managed by UniSC and RIA1, and later RIA3[2] in Vietnam, in collaboration with the Southeast Asian Fisheries Development Centre Aquaculture Department (SEAFDEC/AQD) in the Philippines.

The Australian collaborating organisation from the outset was the Queensland Department of Agriculture, Fisheries and Forestry Northern Fisheries Centre (DAFF/NFC). The first project informed the development of the second, which started in January 2014 and concluded in September 2019.

This report provides an overview of the projects to be evaluated and their intended outcomes, describes the purpose and use of the evaluation findings (this section); provides the methodology and the framework for analysis and sets out the implicit theory of change (section 2); and details the findings and lessons for ACIAR (section 3).

The evaluation team comprised Helen Moriarty and Thai Van Nguyen (independent consultants) and Jane Symonds from the Cawthron Institute. They were supported by Dr Nguyen Huu Yen Nhi in Vietnam, who coordinated, managed and participated in the fieldwork component of the data collection in Vietnam. Cawthron Institute staff Leo Zamora, Alaric McCarthy, Seumas Walker and James Butler provided input and advice during the project evaluation, and Leteisha Prescott assisted with the citation analysis.



2 There are three research institutes of aquaculture in Vietnam under the Ministry of Agriculture and Rural Development: RIA1 is in the north, RIA2 is in the south, and RIA3 is in central Vietnam. The project initially partnered with RIA1 and then moved to RIA3 to make use of the warmer climate and longer breeding cycle.

Overview

Context of the project design

Groupers form the basis of the live reef food-fish trade in Southeast Asia. Prior to project commencement, the giant grouper, *Epinephelus lanceolatus*, was identified as a high-value, fast-growing grouper species with significant aquaculture potential for the region. It was also identified as one of the most difficult species to culture, with its economic potential limited by inefficient commercial production of juveniles in Vietnam and the Philippines in particular. This was largely due to the lack of knowledge about their maturation and spawning behaviour and low larval survival rates.

Although it produces millions of eggs in a single spawn, the giant grouper's small larval size and specific feeding requirements results in survival rates of less than 3–5%. Options for sourcing fingerlings in the early 2000s consisted of harvesting juveniles from the wild, which was believed to put a strain on wild fish populations, or purchasing and importing fingerlings from Taiwan, which potentially posed biosecurity risks.

In recognition of the high priority of giant grouper as a high-value crop and the apparent rewards to be gained from successful closed-cycle production, ACIAR became involved with aquaculture in Southeast Asia in the 1990s. To address ongoing commercial production issues, ACIAR built on 2 previous projects:

- 'Improved hatchery and grow-out technology for grouper aquaculture in the Asia–Pacific region' (FIS/1997/073)
- 'Improved hatchery and grow-out technology for marine finfish aquaculture in the Asia–Pacific region' (FIS/2002/077).

These projects led to a significant improvement in larval survival of tiger grouper (*Epinephelus fuscoguttatus*) and mouse grouper (*Cromileptes altivelis*), and a better understanding of their culture requirements. They were also the basis for the 2 projects at the centre of this evaluation, which developed a set of research objectives around 3 substantive areas relating to giant grouper:

- development of reliable captive-breeding technologies to enhance seed production
- genetic broodstock management
- larval-rearing technologies.

The aim was to close the giant grouper breeding cycle, as shown in Figure 1, and eliminate or reduce reliance on imports and the need to source giant grouper from the wild.

Project outcomes

The initial project design was built around 4 objectives:

Objective 1: Develop reliable giant grouper captive-breeding technologies

- Determine earliest age for sex reversal
- Develop protocols for synchronised spawning

Objective 2: Explore the potential of germ-cell transplantation and surrogate technologies as alternative approaches to giant grouper seed production

- Determine age of larvae amenable to germ-cell transplantation and carry out transplantation trials
- Determine optimal stage for collecting germ cells (type A spermatogonia) for transplantation
- Develop cryopreservation protocols for male giant grouper germ cells
- Develop molecular methods to advance sexual maturation, and induce spawning and sex reversal

Objective 3: Develop reliable larval-rearing technologies for giant grouper

- Develop optimal larval-feeding techniques.
- Characterise larval development using transcriptomics and stable isotopes

Objective 4: Apply genetic approaches to broodstock management

- Apply genetic markers to prevent inbreeding and to enable genetic selection
- Explore hybridisations to achieve desirable traits

A fifth objective was added at a later date.

Objective 5: Build capacity in the form of knowledge transfer and training in larval rearing, genetics and biotechnology as it applies to giant grouper aquaculture

- Ensure full technology transfer and extension with all project partners

The overarching aim of the project was expressed throughout the proposal as establishing or initiating a sustainable aquaculture industry for giant grouper in Vietnam, the Philippines and Australia, and/or Southeast Asia.

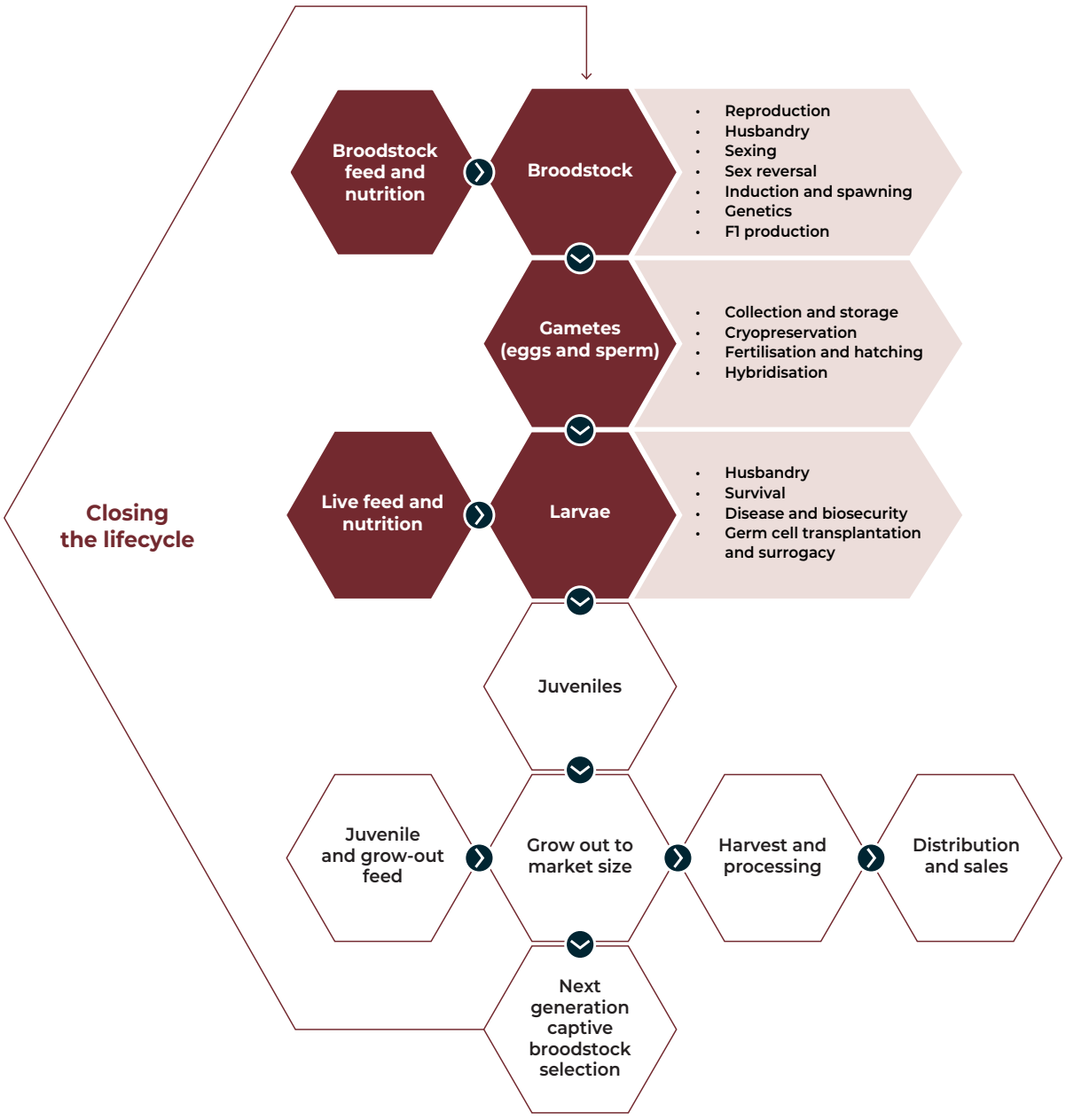


Figure 1 Grouper production cycle

Note: Red hexagons represent the focus production areas/life stages targeted by the project. Key research areas are identified with bullets.

Purpose and use

ACIAR commissioned this evaluation as part of its Outcome Evaluation series to explore:

- the nature and quality of its research on giant grouper production
- how the research was translated or packaged to contribute to establishing a sustainable aquaculture industry
- the impact of this contribution on people engaged in the industry more broadly.

More importantly, this evaluation looks at the methods and approaches used to achieve these outcomes and impacts in order to derive lessons for improving the design and implementation of future research programs. These lessons will also be used in the development of a larger, follow-on project in Vietnam in particular. Evaluation findings will also contribute to the ACIAR Performance and Results Framework, specifically in relation to ACIAR objectives of:

- reduced poverty among smallholder farmers and rural communities
- building scientific and policy capability within our partner countries
- reduced environmental impact from the management of resource systems
- improving gender equity.

Audience

The **primary audience** for this evaluation report comprises the Fisheries Research Program Manager and related ACIAR staff, who are expected to use its findings to inform future project designs.

The **secondary audience**, who may have an interest in the findings for project accountability, comprises the Commission for International Agricultural Research and the Minister and Treasury, who will receive a summary of findings through quarterly reporting and aggregated reporting on performance.

The **tertiary audience** comprises the project team and research partners and participants in the program, who may have an interest in the outcomes of the project approach and implementation.

Scope

While the project had activities and intended outcomes related to all 3 partner countries (Australia, the Philippines and Vietnam), the bulk of this evaluation focuses on Vietnam. Project-related progress on grouper industry initiation was most advanced in Vietnam, and it presents the most complete setting in which to explore the research-to-outcome pathways. The focus on the Philippines is limited to design aspects and the appropriateness of the research focus to the context, as well as capacity impacts and wider knowledge dissemination and use. The unanticipated withdrawal of the main Australian partner during early project implementation meant that the scope of exploration into outcomes in Australia was limited.

Key evaluation questions

This evaluation sought to answer 3 key evaluation questions (KEQs) that were finalised in consultation with ACIAR during the evaluation planning phase. The KEQs focus on 3 broad areas:

- the appropriateness of the original design and how this might have influenced achievement of outcomes
- the actual outcomes and any influence and trends towards impact
- the lessons that can be drawn from these.

The sub-questions highlighted in bold in Table 1 indicate where the bulk of the evaluation's efforts focused in accordance with ACIAR priority areas of interest. The remaining sub-questions had a 'lighter' touch.

Table 1 Key evaluation questions and sub-questions

Question	Evaluation criteria	Sub-question
KEQ 1: How appropriate was the design of the project to the context?	• Relevance • Design/ strategy	KEQ 1.1: What was the project's theory of change, and how appropriate was it to achieving the expected outcomes?
		KEQ 1.2: How well did this project align with the priorities and capacity of the Vietnamese and Philippine governments?
		KEQ 1.3: How well did this project interact with or complement other ACIAR projects or those of other development partners in the partner countries?
KEQ 2: What outcomes (intended and unintended) has the project achieved or contributed to?	• Effectiveness • Gender equity • Sustainability	**Science and capacity**
		KEQ 2.1: What were the scientific outputs? Were they of sufficient quality and quantity to achieve project outcomes?
		KEQ 2.2: To what extent were the partner organisations and relevant individuals able to utilise project-related scientific methods and outputs?
		KEQ 2.3: What individual/organisational capacity building occurred in partner research organisations to facilitate project outcomes, and were opportunities for male and female research staff to participate equitable?
		KEQ 2.4: How influential has the research produced been in the relevant field, including for other large finfish/in other countries?
		Sustainability, welfare and inclusion
		KEQ 2.5: How has the project contributed to its stated longer-term outcomes, and did the underlying assumptions hold true?
		KEQ 2.6: What have been the impacts of improved grouper aquaculture on household income and other gendered measures of welfare? Have they been enduring?
		KEQ 2.7: What environmental outcomes have occurred as a result of project activities?
KEQ 3: What can ACIAR learn from the design and implementation of this research-for-development project?	• Learning	KEQ 3.1: What were the most effective pathways and mechanisms of change?
		KEQ 3.2: What were the factors that hindered effective achievement of outcomes?

Methodology

Development of an overarching program logic

Initially conceived as an impact assessment that would focus on the achievement of broader goals, this evaluation focuses further down the outcomes chain. It includes outputs and the expected end-of-program (ultimate) outcomes, and looks at trends towards broader impacts. This is a theory-based approach, which involved developing and testing the project's retrospective theory of change – a logical description of the hierarchy of intended inputs, outputs, expected time-bound outcomes and expected pathways for change.

The original project proposal (design) did not map out an explicit theory of change, although many of these elements were set out in the document. To provide this clarity and enable assessment of the project's design assumptions and eventual contribution to outcomes, the Evaluation Lead developed a theory of change based on the original proposal document and through interviews with key informants who were engaged in the initial design process (Figure 2).

Data collection and analysis

Table 2 outlines the evidence collected to inform this evaluation's findings and lessons learned.

Collected data was analysed using the following methods:

- Relevant sections of **documentary evidence** were analysed following identification and entry into an evidence table structured around KEQs and sub-questions.
- **Key informant interviews** were transcribed from recordings or recorded as interview notes, synthesised and entered into a spreadsheet structured around KEQs and sub-questions. These were then thematically analysed, including limited quantification of responses where relevant.
- A citation analysis of project-generated knowledge products was conducted.
- Data from all sources was brought together to provide the basis of findings KEQs and expected project outcomes.

Details of the links from KEQs to data collection sources, methods and analysis are summarised in Appendix 1.

Table 2 Data collection

Method	Stakeholder group	Number of interviews/ documents reviewed	Interview quote code
Semi-structured interviews	ACIAR staff	3	G
	FIS/2012/101 personnel	4	A
	End-of-project review team	2	A
	Vietnam partner organisation staff	9	R
	Philippines partner organisation staff	4	P
	Hatcheries[a]	13	H
	Grow-out farmers[b]	10	F
	External experts	4	E
	Total	**48**[c]	
Document review		**67**	
Citation analysis		**14**	

(a) The term 'hatchery' is used throughout this report to describe grouper production facilities, which include hatcheries with broodstock that produce grouper seed; hatcheries that buy grouper seed; and hatcheries that buy smaller juveniles (<3 cm) and grow them to <10 cm for sale to grow-out farms. Some hatcheries also combine grow-out operations.
(b) Grow-out farms purchase fingerlings from hatcheries directly or through middlemen and grow them to plate size for sale.
(c) 7 key informants were interviewed twice.

Limitations

It is important to acknowledge the factors that may have compromised the rigour of these evaluation findings.

Only the Evaluation Lead travelled to Vietnam to conduct interviews. They were limited in their understanding of the scientific research outcomes and their implications for ongoing application within the research centres. The aquaculture specialist, tasked with assessing the scientific outputs, was limited to interviewing remotely, and found the technical details provided in some interviews in relation to specific project research findings were not always clear. Not being present to discuss these issues in more detail limited the evaluation team's understanding of the ongoing use and practical application of novel project approaches.

There was practically no official data available on the status of the grouper industry in Vietnam in terms of the level of farmer engagement or production numbers. Information on the sequential development of the sector in Vietnam, and the timing and expansion of hybrid groupers, was also patchy. In addition, recent data on production numbers of research centres and private producers was provided verbally, with no documented records available for cross-referencing, meaning its accuracy is limited.

Nearly all the grow-out farmers and most of the hatchery operators interviewed in Vietnam were close contacts of RIA staff. This had 2 main limitations:

- less-purposive selection of stakeholders according to socioeconomic background, with a likely over-representation of more informed and successful farmers
- less-observable pathways and mechanisms for knowledge transfer and benefits of the project's inputs beyond these close network members.

Scientific output analysis was mainly focused on English-language publications and some publications or articles in other languages may have been missed.

Theory of change narrative

The initial project design was explored through a review of project documents and interviews with past and present research program managers and the project team to better understand and make explicit the intended pathways from inputs and activities to outcomes. A more detailed theory of change was developed retrospectively to map out the logic of the design against which to reasonably measure project outcomes (Figure 2).

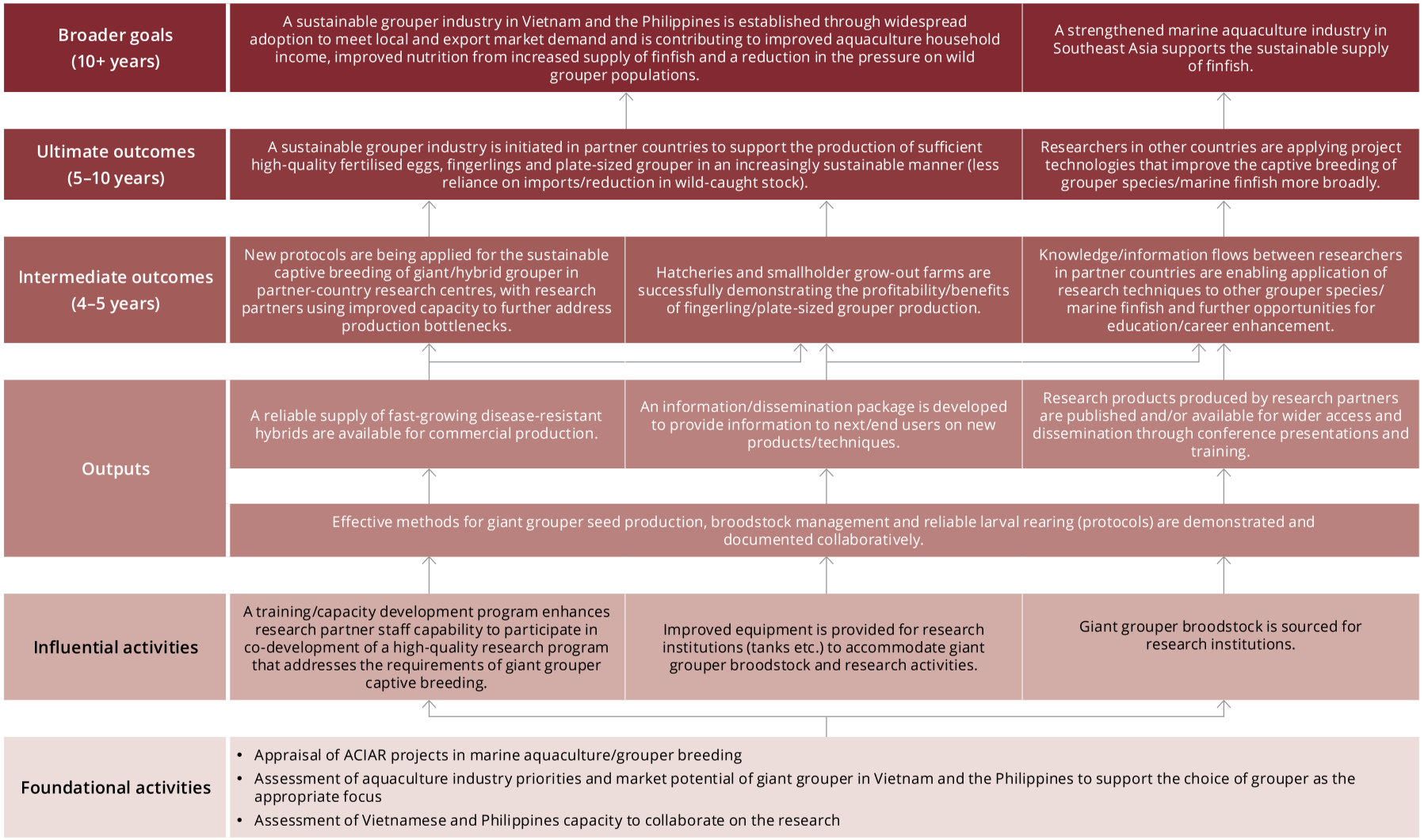


Figure 2 Retrospective theory of change

The project has 2 **broader goals** that it was expected to contribute to within a timeframe of 10 years or more:

- to establish a sustainable grouper industry in Vietnam and the Philippines, which, over time, would increase aquaculture household income, improve human nutrition and reduce the pressure on wild grouper populations in partner countries
- to **strengthen** of the marine aquaculture industry in Southeast Asia more broadly, principally through the involvement of a regional fisheries research organisation (SEAFDEC/AQD) with a mandate to engage widely.

These are ambitious societal- and regional-level goals. Progress towards their achievement was expected to be influenced by many developments in addition to the project.

Contributions to these broader goals were expected to occur through the achievement of 2 **ultimate outcomes**:

- to initiate a sustainable grouper industry in partner countries
- to enable application of project technologies by a wider number of researchers internationally, where the technologies would be adapted to the captive breeding of grouper species and finfish more broadly – thus widening the potential to impact the region's aquaculture industry.

The first of these ultimate outcomes was constrained by the production of sufficient high-quality fertilised eggs,[3] fingerlings and plate-sized giant grouper to meet local and export market demand in an increasingly sustainable manner.

Both ultimate outcomes were to be achieved within a timeframe of project end and 5 years beyond.

The achievement of these ultimate research outcomes were directly supported by 3 **intermediate outcomes**:

- effective protocols for sustainable captive breeding of groupers, with research partners using their improved research capacity to address emerging production bottlenecks
- production of new/improved fertilised grouper eggs by hatcheries, and the purchase and grow-out of fingerlings by aquaculture farmers, to demonstrate the success and profitability of the species
- knowledge-sharing between partner-country researchers to enable application of the techniques to other grouper species and finfish and provide a basis for further education/career development opportunities for individual researchers to ensure capacity development continues.

As a project heavily focused on scientific research objectives, a series of outputs were expected to be produced as a culmination of the research program. These were to be completed within the first few years of the program to facilitate achievement of intermediate outcomes. The cluster of outputs were premised on the development of effective methods for giant grouper seed production, broodstock management and reliable larval rearing, which would be demonstrated in partner-country research institutions (i.e. the original project science objectives).

Although the focus of the project was principally on giant grouper as a priority crop, the project proposal also stated that production of 'a reliable supply of fast-growing disease-resistant grouper hybrids available for commercial production' was an expected output.

Documentation of the methods used, knowledge produced and technologies applied was to be packaged and disseminated to 2 main audiences, as described in Table 3:

- scientists
- next and end users.

Table 3 Users of project knowledge

Initial users	Next users	End users
• Research teams in partner institutions (RIA1 and RIA3, SEAFDEC/AQD) and in Australia • Extension agents (internal and external)	• Demonstration hatcheries • Demonstration grow-out farmers • Other potential fertilised egg producers (private sector) • Individual scientists (outside the research team) in partner countries or internationally	• Hatcheries at scale in partner countries • Grow-out farmers at scale in partner countries • Aquaculture industry regulators (partner countries)

3 The term 'fertilised egg' is used throughout to include those before hatching in preference for the term 'seed', which is often used to include anything from fertilised egg to fingerling stage.

Formal training offered by SEAFDEC was also an important mechanism for knowledge transfer to both next and end users.

Outputs were expected to be achieved through 3 **influential activities**. These were centred around capacitating partner research facilities to participate in and contribute to a high-quality research program to address the requirements for and barriers to giant grouper captive breeding. Apart from initial cross-partner training opportunities and ongoing peer-to-peer learning through collaborative research, capacity enhancement also involved the provision of equipment suitable to the needs of broodstock management, and the sourcing of quality giant grouper broodstock (Philippines) on which to conduct the research.

Underpinning the project design were a set of **foundational activities** that provided the basis for the assumptions on which the likelihood of project success was based. These provided the context for the project rationale and included assessments of:

- previous ACIAR projects in the area of grouper breeding
- the market potential for grouper to support its selection as the species of focus
- the capacity and interest of the partner countries to participate (largely carried out through implementation of FIS/2012/037).

It is important to note that beyond the project's 4 original objectives, which can be considered to have been conceived at the output level, the project documentation did not include any specific indicators to measure success of achievement at the higher outcome levels of the theory of change. However, the expectation of contributing to widespread adoption to meet local and export demand indicated a considerable aspiration for significant attribution of project activities to grouper industry initiation.

Findings

This section presents the evaluation findings, which are broadly structured according to the key evaluation questions and sub-questions. The theory of change developed for the project is used as a reference point to ensure that findings about outputs and outcomes are presented in a structured way. The design assumptions are presented and discussed under the section on KEQ 3 findings.

Illustrative quotes provided throughout this section are attributed to participant codes to maintain the anonymity of respondents. Where relevant, the number of interviewees who expressed a particular view is indicated (in brackets).

1. How appropriate was the design of the project to the context?

KEQ 1.1: What was the project's theory of change, and how appropriate was it to achieving the expected outcomes?

KEQ 1.2: How well did this project align with the priorities and capacity of the Vietnamese and Philippine governments?

KEQ 1.3: How well did this project interact with or complement other ACIAR projects or those of other development partners in the partner countries?

This section focuses on the initial alignment of the project design to the context at the time, in particular the priorities and capacity of the Vietnamese and Philippines partners (KEQ 1.2), with a lighter look at its complementarity with existing ACIAR and partner-country projects relevant to giant grouper (KEQ 1.3). KEQ 1.1 is addressed in the previous Methodology section, which includes the retrospective theory of change, and in the section below on KEQ 3 findings, which examines effective pathways and factors that influenced success.

Alignment with partner-country priorities

Initial focus on giant grouper

At its commencement in 2012, the project design had a high level of alignment with stated partner organisation priorities. According to the project proposal, justification for selecting giant grouper as the initial species of interest included its:

- high annual profit margin
- fast growth rate
- relative scarcity in Asian markets
- potential to reduce poverty, if made available to poor farmers with limited land (in Vietnam in particular), by providing high-value species that could be farmed in lower quantities.

Although production methods were already established in Taiwan, giant grouper aquaculture was in its infancy in Vietnam and the Philippines. In 2012, neither country was able to produce giant grouper, despite successfully breeding lower-value grouper species. Both countries were prioritising the development of a range of higher-value species to increase production for domestic consumption and export. Giant grouper represented an attractive opportunity to expand this diversity.

Australia also had an interest in giant grouper, with the building of a large recirculation aquaculture system and with the initial partner, DAFF/NFC, having recently achieved reliable spawning and larval rearing. Acknowledging Australia's limited capacity to compete on productivity and supply levels with a region that dominates aquaculture production, Australia was positioning itself as a leader in giant grouper reproduction and rearing technology and extending these to industry.

The majority of interviewees confirmed the appropriateness of the focus on giant grouper, as well as verifying the **'strong desire' (G3)** of Vietnam and the Philippines to close their breeding cycle. In line with the ACIAR mandate to operate at the invitation of partner countries, Vietnam in particular welcomed the collaboration with '**outside help' (R2)** to address their inability to achieve spawning on a previous government seed bank project. Philippines partners pointed to the mandate of SEAFDEC to respond to regional priorities rather than just those of the Philippines Government, with giant grouper emerging as a species of high interest. **'A value species that were getting good prices at the time. I can see why they chose it.' (A4)** **'It was logical to choose that species. Reasonable at the start.' (G3)**

Change in priority to GGTG hybrid grouper and lower-value species

One respondent, however, queried why giant grouper was the initial focus rather than **'other great grouper species … you can culture and eat … easier species that could be more easily taken up.' (G2)**[4] Another questioned the extent of the 'sector pull' in the Philippines in particular, with the giant grouper priority coming from SEAFDEC, a regionally focused research institute, rather than a government organisation with a more specific mandate to directly support the domestic grouper industry. Indeed, as the research program progressed, this initial focus on giant grouper as a partner-country priority shifted to a lesser component of the initial project design, and hybridisation, in particular GGTG hybrids, became more of a focus.

Although already available and farmed in Vietnam (perhaps using imported fingerlings prior to project commencement), interest in GGTG hybrids in Vietnam had grown in earnest by 2016. The project leader in Vietnam became aware of the importation of giant and tiger grouper fingerlings and broodstock into the Khanh Hoa province of central Vietnam. They recognised the many advantages of GGTG hybrids as a crop and signalled a desire to focus more on their domestic production to reduce reliance on importation. **'We only learnt this during the running of the project from the direction of the farmers. They knew the hybrids better, and the market for them was better. So we followed the direction of the farmers and the market. If we had persisted with the giant grouper only, maybe we would have the bigger fish, but people couldn't sell them.' (R1)**

GGTG hybrids were widely considered by interviewees to:

- be easier to breed than pure giant grouper, as gametes can be collected manually (strip spawned) from both sexes of tiger grouper. It is possible to extract milt from male giant grouper but the females are larger and it is too risky to collect eggs.
- need less-sophisticated facilities to hold breeding stock (especially for smaller hatcheries)
- be easier to rear through the larval stages
- be better suited as live fish for the domestic tourist trade, because they survive better in restaurant tanks and are of a size demanded by restaurants.

'They are more robust towards disease, they have higher survival rates, they may develop slightly faster.' (A3)

In the Philippines, by project end, there was also a stated priority shift (driven more by the Philippines Government than SEAFDEC) to prioritise lower-value, mass-produced species that could be farmed and eaten by most low-income farmers/consumers. This may also be due to the lag in achieving sufficient giant grouper breeding success in the Philippines, and the absence of a significant supply of fingerlings to the commercial sector to stimulate industry interest. By the time of this evaluation, in the face of difficulties with giant grouper spawning and the shift in preference to GGTG hybrids, 3 key informants (P3, R1, R2) were questioning the need to focus on production of pure giant groupers in their research centres at all, when they could get access to cultured males or milt relatively easily.

Key informants familiar with the project's genesis thought that the shift of focus to GGTG hybrids in Vietnam could not have reasonably been anticipated when the project was conceived. The project team was sufficiently agile to support this new focus, as much of the technology developed was applicable to GGTG hybrids. '**Because [of] its hatchery technology focus that was worked on, the male giant grouper focus is still very relevant (to the hybrids). [I] don't see a big issue with the focus.' (A3)** This capacity to respond to changed priorities also supports the finding that the project initially aligned well to partner priorities (especially through the inclusion of the hybrid output), although perhaps more so in Vietnam than the Philippines.

These successes and challenges are discussed in more detail later in this report.

4 At least 47 grouper species, plus 15 grouper hybrids, have been trialled or are currently used in aquaculture (Rimmer and Glamuzina 2019).

Alignment with Vietnamese and Philippine research capacity

High level of interest in scientific solutions to bottlenecks and sufficient capacity to engage

Based on the findings of the initial FIS/2012/037 Small Research Activity, the second project design took the view that closing the giant grouper life cycle – breeding entirely in captivity – was the only tenable approach to securing their independent production in the 3 countries. It would halt the sourcing of fry from the wild and the associated decline in fish stocks, and reduce the exposure of partner-country industries to diseases, genetic bottlenecks and fluctuating supplies. These considerations were also applicable to hybrid grouper production. The Australian partners were well placed to provide the necessary scientific solutions. Specific bottlenecks to increased productivity were to be addressed by the scientific research objectives outlined above.

At the time of the project's conception, key informants responsible for its design confirmed their belief that all the proposed science was appropriate to the bottlenecks identified. At that time, engaging in higher-risk science was believed to be part of the ACIAR mandate, especially where significant gains for partner countries were anticipated if the research was successful. This view was strongly supported by project partners who also expressed a desire to engage with Australia in 'good' science. **'[Vietnam said] we don't want Australians here to show us how to breed fish. We want 'new science' and to publish in peer-reviewed journals.' (A2)** In addition, the decision to partner with UniSC and its academic staff meant that there were incentives to engage in the type of high-end research the project staff had expertise in: **'...genetics, endocrinology, reproductive control etc.' (A3)**

Incentives in the Philippines

As a research organisation, SEAFDEC had succeeded in closing the breeding cycle on other species and was well equipped, with access to molecular laboratories and inland and sea cages. SEAFDEC's project leaders also had high-level breeding expertise. SEAFDEC had an informal relationship with a local commercial company that had access to broodstock, and a well-established training program to achieve regionwide knowledge-sharing and industry training. However, SEAFDEC had limited access to mature broodstock during the project and was hampered by poor water quality – both of which reduced its ability to progress.

Incentives in Vietnam

RIA1 had 80 giant grouper broodstock available from past attempts at breeding through its own seed bank project, as well as the facilities to maintain them. This was later supplemented by the project when it moved to the RIA3 facility to capitalise on its warmer temperatures and extend the breeding cycle. Research staff had some experience in genetic selection (oysters in ACIAR FIS/2010/100) with capability to engage in the genetics work, and many had good practical skills in fish reproduction.

Some limitations in capacity to make progress on aspects of the research program

Although the 2020 end-of-program evaluation (O'Connor unpublished) and some interviewees stated that the science the project focused on was fundamental to establishing an advanced closed-cycle aquaculture system, there were a range of views about its appropriateness to the varying capacity levels of partner countries at the time.

At least 4 respondents suggested that simpler approaches may have complemented the research focus. For example:

- better handling techniques to improve broodstock management (included as a more formal aspect of project activities)
- support for heating tanks to prolong the breeding season
- optimising basic hatchery techniques and environmental control.

Particular approaches that were considered challenging for partner countries to apply beyond their use as a research tool included:

- germ-cell transplantation and surrogacy[5]
- the use of transcriptomics and NextGen molecular barcoding.[6]

Nevertheless, the strong research focus was also credited by several respondents with having contributed significantly to instilling greater rigour in the ongoing research programs of Vietnamese partners in particular. The full achievements of the scientific research program and their application to industry are discussed in more detail later in this report.

5 Surrogate broodstock technology involves the production of donor-derived gametes in surrogates and comprises transplanting germ cells of a donor into recipients of a different strain or different species. An example application is reducing the time required to breed fish by using a recipient species with a short generation time to produce gametes of a species with a long generation time.

6 Transcriptomics is the study of the 'transcriptome', meaning the complete set of all the ribonucleic acid (RNA) molecules (called transcripts) expressed in an entity, such as a cell or tissue. NextGen molecular barcoding allows all DNA sequences in a mixed sample to be amplified and identified. It was used to identify different organisms present in live feed samples.

Interaction with other ACIAR/donor projects

As discussed above, this project design capitalised on the learnings gained from 2 ACIAR projects in the Asia-Pacific region on tiger and mouse grouper that had led to a significant improvement in larval survival. There was little evidence of other ongoing projects focused on giant grouper production during the time of the project's implementation. Respondents noted there may have been 'other smaller bits and pieces' being undertaken simultaneously, but few could identify specific programs of any significance.

Project partners in the Philippines confirmed that there were 2 other grouper species being bred at the time (by SEAFDEC), as well as a possible government fisheries project, but SEAFDEC interviewees were unaware of the details.

In Vietnam, the ACIAR project took up where an unsuccessful government-run giant grouper spawning project had ended. The ACIAR project used the original broodstock, optimising use of this significant resource. The government program had experienced successes with humpback and mouse grouper, as well as hybridisation. In 2012, ACIAR and government projects operated separately, with separate broodstock and different teams, although they shared algae/rotifer and facilities.

Despite the seeming lack of opportunities for leveraging off other locally relevant programs, interactions and collaborations did occur more broadly. The Project Lead used her extensive international network to advance the project by inviting a noted Taiwanese professor to a workshop in the later stages of implementation. The professor exchanged information with project partners on improving the survival rates of all grouper species, particularly in Vietnam. This involvement lasted almost 2 years and was a highly regarded contribution.

2. What outcomes (intended and unintended) has the project achieved or contributed to?

SCIENCE AND CAPACITY

KEQ 2.1: What were the scientific outputs? Were they of sufficient quality and quantity to achieve project outcomes?

KEQ 2.2: To what extent were the partner organisations and relevant individuals able to utilise project-related scientific methods and outputs?

KEQ 2.3: What individual/organisational capacity building occurred in partner research organisations to facilitate project outcomes, and were opportunities for male and female research staff to participate equitable?

KEQ 2.4: How influential has the research produced been in the relevant field, including for other large finfish/in other countries?

SUSTAINABILITY, WELFARE AND INCLUSION

KEQ 2.5: How has the project contributed to its stated longer-term outcomes, and did the underlying assumptions hold true?

KEQ 2.6: What has been the impact of improved grouper aquaculture on household income and other gendered measures of welfare? Have they been enduring?

KEQ 2.7: What environmental outcomes have occurred as a result of project activities?

This section begins by focusing on the achievements at the output and intermediate outcomes levels in the project's theory of change. Although this is an outcome evaluation, it was important to also examine project outputs. It includes a discussion of the capacity-building program that supported the research collaborations (KEQ 2.3), the quality of the science and research outputs (KEQ 2.1), the immediate and more ongoing application of knowledge and skills by initial users in partner countries (KEQ 2.2) and the influence of research outputs more broadly (KEQ 2.4). This is followed by a section reporting on findings at the ultimate outcome to broader goal levels (KEQ 2.5–2.7), noting some overlap at the intermediate level.

Capacity building in partner research organisations

Individual capacity building

Capacity-building outcomes were a significant strength of the project. The project leader was a world-leading fish reproductive biologist and, together with the multidisciplinary team at UniSC and (initially) DAFF/NFC, they transferred significant knowledge and methods to the partner organisations. Individual capacity-building outputs included:

- training of technical staff, interns, industry and university undergraduates
- development of postgraduate students (3 PhD and 2 MSc) and early-career researchers
- new knowledge transfer to established researchers.

Student education and staff exchanges between UniSC and the partner organisations produced significant scientific outputs, both during and after the project. This also led to successful scientific careers for individuals involved, including those who have:

- completed (or are conducting) their PhD studies overseas (3)
- gained promotion within their organisation (2)
- taken up university positions (1)
- taken up postdoctoral research positions (2)
- successfully obtaining government funding for new projects (2).

One John Allwright Fellow[7] in the Philippines was promoted based on their research outputs from the project.

Feedback from the students and staff who received training was very positive. The project enhanced their research capacity in many ways, including the ability to obtain competitive scholarships based on their publication track records, and important research methodology training. **'I also learnt the way to do the research, the way to search references, the way to write reports and the way to do the presentation.' (R3)** It also provided a good grounding in fish reproductive biology and physiology, as well as many different laboratory techniques. **'I was introduced to marine fish breeding, marine fish farming and all the physiology and molecular techniques.' (P1)**

Two of the students now studying overseas have applied what they learned to their new studies, **'I was able to apply [the knowledge] in my masters, during my thesis, and then now. It really helped me in my career.' (P4) 'Predominantly what I know now, the skills that I have, I am taking advantage of here and doing my PhD, it was all developed during my involvement with the giant grouper project.' (P1)**

Staff exchanges, training, writing and co-authoring publications and presenting at conferences, led to the significant upskilling of the marine finfish teams at SEAFDEC and both RIAs in a wide range of disciplines (for example, reproduction, spawning, genetics, larval rearing, live-feed production and biosecurity) and techniques (for example, biopsies, hormonal induction, enzyme-linked immunosorbent assays (ELISA), cryopreservation, genotyping, bioinformatics, rotifer and copepod production, and recombinant hormone production).

World-leading senior UniSC researchers, who are experts in their field, supported the career development of the students and early-career researchers involved and provided them with opportunities to progress and showcase their success. In addition, they encouraged the team to learn from the challenges and setbacks that inevitably eventuated when working with challenging new marine finfish species. The process of capacity development, knowledge transfer and support also included many additional benefits, such as increased expertise in experimental design, data analysis, scientific writing and research rigour, and improved English language skills (making other English-language publications and information more accessible).

Project staff within the partner organisations were also then able to train other staff and students within their organisations, including wider dissemination through training courses and workshops. It was also mentioned that once the success of new methods was demonstrated, there was an increased willingness by staff to apply new and improved methods rather than keep doing things the traditional way. This has helped generate continuous year-on-year improvements of the live hybrid rearing practices in Vietnam with much improved survival.

Gender equity of research opportunities

The evaluation explored equity in accessing project training opportunities during key informant interviews. The process for selecting individuals was consistently described by the interviewees as fair, with no indication given of perceived bias. Male and female students and staff were seen to be provided with opportunities for postgraduate studies and training based on merit. Several interviewees also noted that the involvement of a female project leader, together with a senior female researcher at SEAFDEC and early-career female researchers from UniSC, provided good role models for the team.

In Vietnam there were fewer women involved in the research team, but opportunities were provided through education and training. This led to a promotion for one of the female staff following an MSc at UniSC. In Australia, early-career female researchers from UniSC have gone on to further develop their scientific careers. Two female research assistants at SEAFDEC who were trained at UniSC have continued their scientific careers: one has a teaching position at a University in the Philippines and the other is a postdoctoral researcher in France.

7 The John Allwright Fellowship (JAF) provides scientists from partner countries currently or recently involved in ACIAR research projects with the opportunity to achieve postgraduate qualifications at Australian tertiary institutions. The main aim of the JAF is to enhance scientific research capability in ACIAR partner-country institutions.

Organisational capacity

The project invested in upgrading and building new facilities to accommodate giant grouper broodstock research work, including nursery tanks/ponds and additional sea pen facilities. It also provided the opportunity for SEAFDEC to collect new giant grouper broodstock. It provided funding for all the partners to maintain their giant grouper broodstock resources and for RIA3 and SEAFDEC to keep F1 captive offspring for use as future broodstock. These broodstock resources are still being used. At SEAFDEC, where production has shifted to other species, the giant grouper broodstock and their F1 are currently used for training purposes and other research, albeit less production related. Some of these F1 are now sexually mature. New equipment was also purchased and, at SEAFDEC, specialised equipment from other parts of the organisation was made accessible to researchers.

To transfer the knowledge developed by the project and apply project-related techniques, multiple protocols were developed for consistent application among trials and organisations. This ensured that standardised information could be passed on to other staff and be effectively applied to other projects and species. The protocols also formed the basis for training materials, lectures and methods in publications, in addition to the provision of protocols for industry to apply. Another important outcome was the skills the research teams acquired in their application of more rigorous scientific methodology, appropriate experimental design, and accurate, reliable data collection, analysis and reporting. This provided significant research capacity that is being applied to new projects within the organisations, further ensuring their success.

One barrier to continued organisational capacity was the loss of several key project team members at SEAFDEC at the end of the project. Although some knowledge transfer to other staff was completed, and protocols were developed, the number of dedicated marine fish aquaculture researchers was also reduced, limiting the ability of SEAFDEC to continue the giant grouper research and further optimise and apply the methods they had developed. In Vietnam, organisational retention of project-trained staff has been remarkably strong, with only one of the formal project team leaving the RIA partners since the project ended. He has taken up a government position that will have lasting impact on the quality of ongoing finfish research in Vietnam.

Overall, the project's capacity-building program has had a strong and lasting impact on the individuals involved, resulting in a collegial and unified project team, and ongoing career benefits. Much of this improved capacity has been institutionalised through the documentation of protocols and the improved research capacity of the Vietnam research institutes in particular. The broader outcomes of this improved capacity are discussed in more detail below.

Scientific outputs and their quality

At the outset of the project there were many biological and technological bottlenecks to overcome to achieve reliable giant grouper broodstock spawning and production of juveniles. Giant grouper is a very difficult species to spawn and individuals mature at a large size. Very little was known about their reproductive biology and larval survival was very poor. To address these challenges, the project successfully implemented a combination of practical and more technically challenging approaches to determine which methods were best applied to meet project objectives.

Notable scientific outputs of the project included:

- the development of sustainable technologies for grouper breeding (for example, broodstock handling and monitoring, optimal sex ratios for breeding, sex reversal, practical sperm preservation techniques, hormone production including new delivery methods and treatments, improved nutrition and genotyping to reduce inbreeding and for species identification)
- the significant discovery that giant groupers are diandric protogynous hermaphrodites by the identification of primary males
- the development of improved methods for fertilised egg and larval production (including live feeds)
- the successful production and evaluation of hybrid GGTG grouper
- successful spawning of giant grouper by the RIAs and SEAFDEC and production of F1 juveniles, albeit at low numbers at RIA1 and SEAFDEC.

By the end of the project there was a reliable supply of male giant grouper sperm for hybrid production and some F1 pure giant grouper have been produced by all partner organisations. However, it was still difficult to reliably produce large numbers of giant grouper F1. This was hindered at SEAFDEC by weather events and low maturing broodstock numbers, and at RIA1 by the shift to RIA3, plus the shift in focus to hybrids. RIA3 has since successfully provided farmers with fertilised giant grouper eggs (the last batch was a relatively small amount (1 kg) in 2022), but overall, hatcheries and grow-out farmers are much more interested in hybrids.

The most challenging research objective was the development of germ-cell transplantation and surrogate technologies. Despite the difficulty of working with grouper larvae, progress was made and the feasibility of transplantation was demonstrated in Australia and at SEAFDEC. This was a novel approach to producing giant grouper gonads in a smaller maturing species and provided fundamental knowledge about grouper larval development.

Details of the methods and results were documented and provided in the project annual reports, the publicly available final report, published protocols, conference presentations and multiple scientific papers. More information about the number, quality and impacts of the publications are provided below and in Appendix 2. The methods successfully developed are summarised in Table 4, with more details of their application presented below.

The FIS/2012/101 end-of-project review concluded that, 'FIS/2012/101 has been a very high-quality research program that has achieved excellent scientific outcomes. This project has been an outstanding example of the application of innovative approaches to address fundamental fish production questions' (O'Connor et al. unpublished). Many of these were considered to be 'building blocks' that were essential to moving production forward. The current evaluation team has not found any new information to question the high quality of the project's scientific research outputs.

Table 4 Methods developed and likely level of application and industry impact

Method	Level of innovation	Current application by the RIAs (GG or GGTG)	Industry impact in Vietnam (GG or GGTG)
Broodstock sex reversal (methyltestosterone)	Low to moderate	5	5
Improved understanding of broodstock reproduction and nutrition	Low to moderate	5	5
Synchronised spawning	Low to moderate	5	5
Identification and use of primary males (diandry)	Moderate	5	5
Hybrid production	Low to moderate	5	5
Broodstock genotyping	Moderate	3	2
Sperm storage and cryopreservation methods	Low to moderate	2	0
Biosecurity (NVV)	Low to moderate	5	5
Improved live-feed production and larval rearing	Low to moderate	5	5
Genetic improvement – NNV resistance	Moderate	0	0
Larval transcriptomics and molecular barcoding	High	0	0
Recombinant hormones and delivery mechanisms	High	0	0
Assays for FSH, LH and vitellogenin	Moderate	0	0
Mucus-based sexing	Low to moderate	0	0
Germ-cell transplantation and surrogacy	High	0	0

Level of innovation
Low = Routine application of an established method already developed in other species
Moderate = New approaches and applications of methods not routinely applied but also being developed by other researchers
High = Cutting-edge research involving novel approaches and technically challenging methods; if successful, they change how research is done and/or provide a new way of doing things

Current application by the RIAs
0 = not applied; 5 = definitely applied

Industry impact in Vietnam
0 = no impact; 5 = definite impact

Notes: NNV – nervous necrosis virus; FSH – follicle stimulating hormone; LH – luteinising hormone

Utilisation of knowledge by partner countries

The project context has significantly changed since its onset. Many of the methods developed, or improved, by the project are now being applied for hybrid production. Others have not been applied or have had less impact, due to changing priorities and/or the technical difficulty and cost required to optimise and implement them. The loss of trained SEAFDEC researchers at project end also had an inhibiting impact in the Philippines. The following discussion therefore relates mostly to utilisation of knowledge within Vietnam through RIA1 and RIA3 networks.

Table 4 summarises the main methods developed, the level of innovation required to develop the methods, the current application by the RIAs and the likely impact on the Vietnamese giant grouper/hybrid industry within RIA's immediate network. The scores are based on project reports, protocols and other documents, as well as interview data. Although not able to be verified by direct observation during the visit, the combined sources of data provided a moderate degree of confidence in the ratings.

All the methods listed in Table 4 directly or indirectly provided valuable knowledge or tools for better understanding giant grouper reproduction and/or hybrid production. In addition, many have since been applied in other species, despite not having been applied to giant grouper or hybrid production after the project ended. This includes some of the methods that required a high degree of innovation, more time and further funding to be optimised before they could be applied (for example, production and application of recombinant hormones) and methods such as germ-cell transplantation that are very technically challenging.

The knowledge and practical training that the partners gained in reproductive biology, broodstock management, larval rearing and live-feed production have had enduring positive influences. The methods that continue to have the most impact include:

- the use of hormones for sex reversal (for example, methyltestosterone)
- the control and synchronisation of giant grouper reproduction including the use of gonadotropin-releasing hormone (GnRH) implants
- giant grouper male spawning (wild and F1)
- GGTG hybrid production
- improved awareness of nutritional requirements (broodstock and larvae)
- the development of improved larval feeding using copepods and small rotifers
- improved biosecurity and production protocols (for example, better larval stocking densities and environmental control).

This does not mean that all these methods are currently fully optimised, but they have provided a foundation on which to build a successful hybrid industry and produce giant grouper for ongoing production, albeit at low numbers. This has seen hybrid production in RIA1 and RIA3 grow considerably, with improved fertilisation rates and larval survival, and this in turn has generated funding for the RIAs to maintain their broodstock resources.

Challenges to the application of particular tools

The use of genotyping to understand spawning contribution and improve the management of genetic diversity was very useful during the project and this approach continues to be applied by the Australian industry. However, in Vietnam, genotyping of new giant grouper broodstock is not currently taking place although the skills and equipment are available. The genotyping data of the original broodstock can still be applied as the individuals are identifiable (tagged) and some are still being used for spawning. Use of this information when the wild giant grouper males are crossed to giant grouper females appears to be limited. It will be more important to consider this if F1 captive giant grouper are crossed together, as these individuals have a higher risk of being related given the small number of wild male broodstock used as parents. Crossing closely related broodstock increases the risk of inbreeding and also reduces the overall genetic diversity of the offspring. However, it is unclear whether crosses between F1 giant grouper males and females are currently being made. For the production of hybrids, the relatedness of the parents is not an issue. RIA researchers recognise that the future implementation of genotyping and the development of a genetic management plan for giant grouper and other grouper species (particularly tiger grouper, if female populations are to be reliably reproduced) would be useful. However, it was not a current priority with the focus on hybrids.

Some interviewees indicated that sperm cryopreservation or extending the duration of sperm storage was useful for the production of hybrids. One interviewee (R4) mentioned it was no longer needed, as male giant grouper spawn using their current broodstock management regime, and broodstock supply (a mix of wild and F1 males) is reliable, with giant grouper sperm supply not a limiting factor. If extended storage was used more widely to ensure a reliable supply of sperm when the eggs of the tiger grouper become available, its application and impact would be rated more highly.

The larval transcriptomics and diet barcoding research provided useful baseline knowledge during the project and helped researchers to better understand larval feeding, which then led to improved live-feed composition (for example, copepods and small rotifers) that is more suitable for specific stages of larval development. However, the transcriptomics and barcoding methods are not being used at present. They are expensive and useful research tools rather than an approach the industry would apply in the short term. Nonetheless, the information generated will be useful in future projects for the development of artificial diets for larval rearing.

Sexing broodstock is a vital part of broodstock management, but handling the fish and conducting invasive biopsies to collect gonad samples is stressful and can damage the fish. An alternative, and less stressful, non-invasive skin mucus-based vitellogenin[8] detection assay for sexing broodstock was developed. However, it is not currently used by RIA staff. Interviewees commented that the cost and time to get the result from the laboratory inhibits its use, compared to a gonad biopsy that provides an immediate result. A cheaper, real-time Yes/No test for the presence of vitellogenin based on the assay would be very useful to broodstock managers.

The collaboration between SEAFDEC and UniSC, and the training of students, led to the development of multiple cutting-edge methods, especially around the production of recombinant hormones (follicle stimulating hormone (FSH) and luteinising hormone (LH)), new methods for hormone delivery, and ELISA assays for measuring the hormones and vitellogenin. All are important tools for understanding and manipulating grouper reproduction and were used in the project to develop important protocols, such as the ability to sex broodstock non-invasively and detect when females are transitioning to males by measuring LH levels and the condition of the fish (Palma et al. 2019a, 2019b, 2019c; Dennis et al. 2020; Nocillado et al. 2022). This grouper-specific reproductive toolkit of hormones and assays is now available to optimise the timing of hormone treatments to achieve sex reversal at an earlier age in males and induce spawning, further advancing giant grouper reproduction. This also has the potential to significantly reduce male broodstock rearing costs and handling stress. However, the shift in focus towards hybrid production in Vietnam and the continued need for only a few males for spawning has, for the time being, reduced the need for these tools. This may change if the number and size of the broodstock companies increase.

Tools with more immediate application

Research on viral nervous necrosis[9] highlighted the risk of importing stock from overseas and the need for improved biosecurity. The molecular detection of the virus is continuing and biosecurity awareness appears to have improved, including the testing of some batches of juveniles prior to supplying to farmers.

The project improved the live-feed protocols for giant grouper, including improving the rearing conditions (for example, density and larval handling), the correct use and timing of copepod feeding and the need for smaller rotifers and improved nutrient enrichment. Improvements in rearing protocols were also made. Larval production and survival improved as production shifted towards hybrids, as the larvae are easier to rear. This is an important ongoing focus of research and development.

The same tools/methods impact assessment used in Table 4 has not been applied to the giant grouper/hybrid production in the Philippines, as there is little evidence of ongoing production and the evaluation team was not able to secure interviews with staff currently working at SEAFDEC or in the broader industry. Ex-SEAFDEC project interviewees noted that the research focus now appears to be on the production of other marine fish species. Many of the staff involved in the project are no longer at SEAFDEC and there appears to be a reduced number of dedicated marine finfish aquaculture researchers on staff. Nevertheless, according to SEAFDEC project staff interviewees, results from the project have been incorporated into the ongoing training materials used by SEAFDEC for their marine finfish workshops and the results have been applied to other species (see below). Giant grouper broodstock are also still used for SEAFDEC's training programs.

8 Vitellogenin is the major egg yolk precursor protein and is predominantly found in females.

9 Viral nervous necrosis is caused by infection with the nervous necrosis virus and damages the central nervous system in susceptible fish species. It typically affects younger stages of fish (larvae, fry, fingerlings), although older, market-size fish can be affected as well. It can cause 100% mortality in the larval stages.

Broader influence of the research

The project was led by a globally recognised fish reproductive biologist with an extensive network of collaborators. This network provided important links and collaborations during the project and also led to new collaborations and opportunities after the project finished. Ten of the 14 papers published included co-authors from external organisations other than the partner organisations (Appendix 3). The following section looks at the intermediate outcomes of the research information flows, enabling application of research techniques to other grouper/finfish species in partner countries. International application is also discussed.

Scientific publications and conference presentations

The project's scientific research outputs available for wider access included journal publications and conference presentations. Eleven scientific papers (impact factors 2.5–5.14) were published on the grouper research in high-quality, peer-reviewed international journals. An additional 3 papers (impact factors 3.3–4.7) were published on other species (eastern bluefin tuna, sea cucumbers, yellowtail kingfish) due to project collaborations (Table 5 and Appendix 3).

A citation analysis conducted in May 2023 found individual paper citations ranged from 1 to 21 (Table 5 and Figure 3). The least-cited papers were published more recently (2020 to 2022). Four papers that have 15 or more citations are regarded as being highly cited papers. One paper (Anderson et al. 2018a) was selected by the *Journal of Fish Biology* editorial team as a highlighted paper (McKenzie 2018). This paper and Anderson et al. (2018b) provided important methods for gene expression analysis in grouper species.

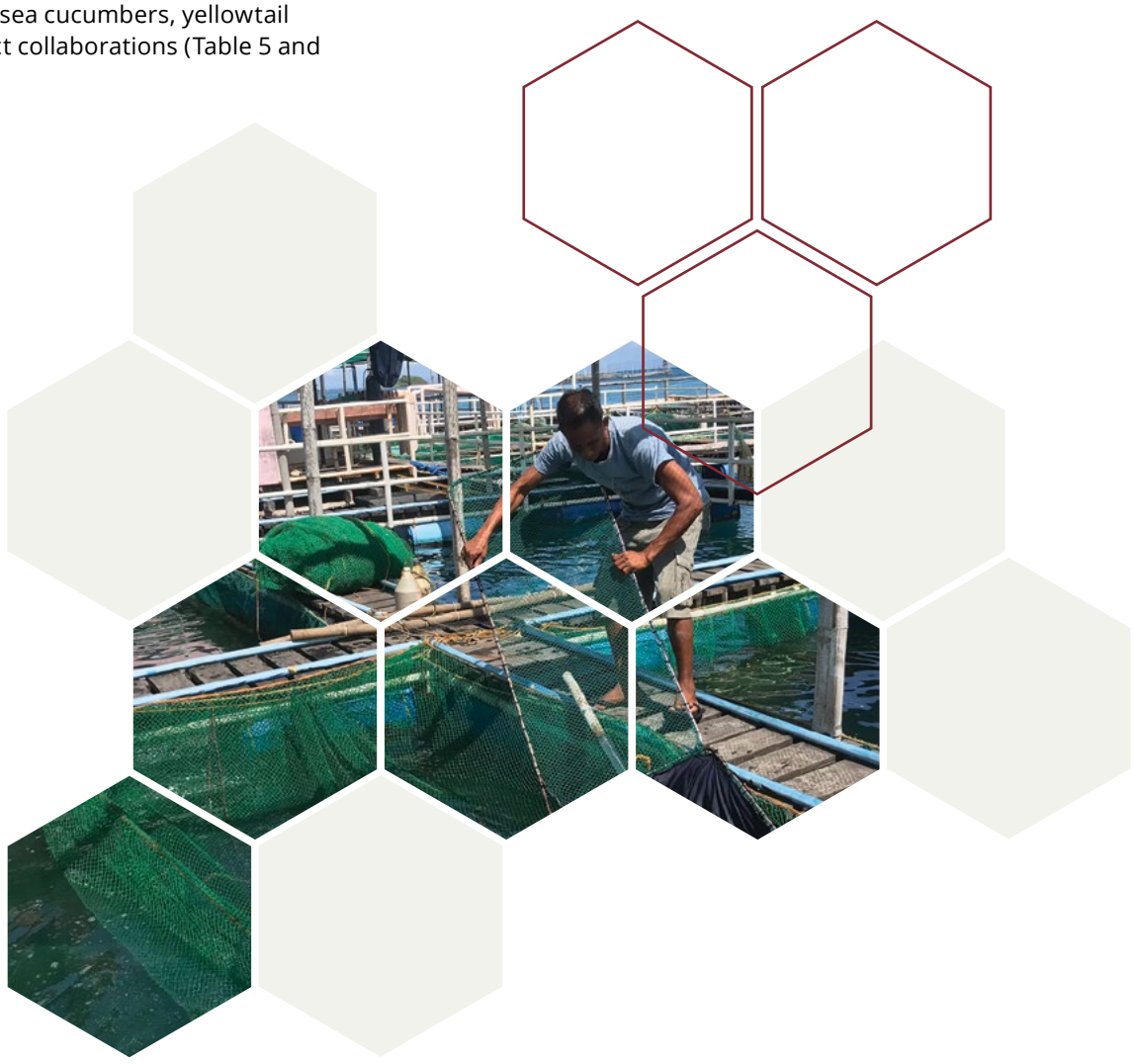


Table 5 Papers published in international journals, journal impact factors and citations

Research theme	Year	Authors	Article title	Journal	Journal impact factor[a]	Citations count
Reproduction grouper	2019	Palma P et al.	Gonadal response of sexually immature protogynous grouper (*Epinephelus fuscoguttatus*) to long-term recombinant follicle-stimulating hormone administration	*Biology of Reproduction*	4.16	21
Grouper aquaculture	2020	Dennis LP et al.	Hybrid grouper in Vietnamese aquaculture: Production approaches and profitability of a promising new crop	*Aquaculture*	5.14	20
Reproduction other	2019	Chieu HD et al.	Aquaculture breeding enhancement: maturation and spawning in sea cucumbers using a recombinant relaxin-like gonad-stimulating peptide	*Frontiers in Genetics*	4.77	19
Reproduction grouper	2019	Palma P et al.	Reproductive development of the threatened giant grouper *Epinephelus lanceolatus*	*Aquaculture*	5.14	15
Genetics	2016	Bright D et al.	A study into parental assignment of the communal spawning protogynous hermaphrodite, giant grouper (*Epinephelus lanceolatus*)	*Aquaculture*	5.14	12
Reproduction other	2019	Nocillado J et al.	Development of specific enzyme-linked immunosorbent assay for yellowtail kingfish (*Seriola lalandi*) follicle stimulating hormone using recombinant gonadotropins	*General and Comparative Endocrinology*	3.26	12
Larvae	2018	Anderson K et al.	A transcriptomic investigation of digestive processes in orange-spotted grouper, *Epinephelus coioides*, before, during, and after metamorphic development	*Gene*	3.91	11
Reproduction grouper	2019	Palma P et al.	Induction of gonadal development in protogynous grouper with orally delivered FSH DNA	*Marine Biotechnology*	3.73	11
Larvae	2018	Anderson K et al.	A transcriptomic investigation of appetite regulation and digestive processes in giant grouper, *Epinephelus lanceolatus*, during early larval development	*Journal of Fish Biology*	2.50	10
Genetics	2017	Knibb W et al.	Regional genetic diversity for NNV grouper virus across the Indo-Asian region – implications for selecting virus resistance in farmed groupers	*Scientific Reports*	5.00	10
Reproduction other	2019	Carnevali O et al.	Insights on the seasonal variations of reproductive features in the Eastern Bluefin tuna	*General and Comparative Endocrinology*	3.26	7
Reproduction grouper	2020	Dennis LP et al.	Development of a giant grouper luteinizing hormone (LH) enzyme-linked immunosorbent assay (ELISA) and its use towards understanding sexual development in grouper	*General and Comparative Endocrinology*	3.26	3
Larvae	2021	Dennis LP et al.	NextGen molecular barcoding of larval grouper diet in an extensive green-water pond system	*Aquaculture*	5.14	3
Reproduction grouper	2022	Nocillado J et al.	Intracellular production of recombinant GnRH1 in yeast, *Pichia pastoris*, and its potential as oral treatment to advance gonadal development in juvenile orange-spotted grouper, *Epinephelus coioides*	*Aquaculture*	5.14	1

(a) An evaluation of the relative importance of a journal within its field. It is a measure of the frequency with which the average article in a journal has been cited in a particular year. An impact factor of 3 or above is considered good.

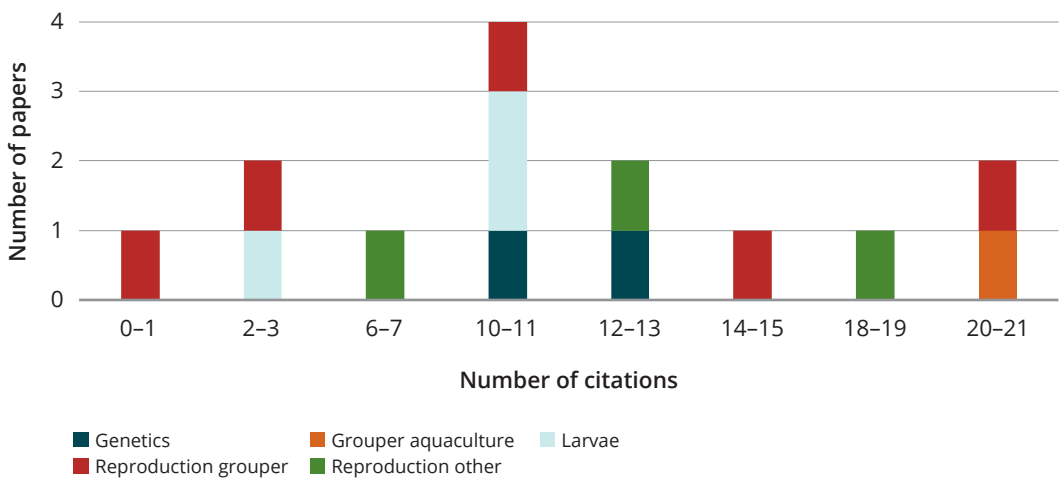


Figure 3 Citation analysis by research theme

To further assess the research interest generated by the 14 papers, the ResearchGate interest score was obtained for each paper. Seven of the papers received more interest than 80% of the other papers published in the field of aquaculture in the same year. An evaluation of why the papers were cited was also completed. In most cases, the citations referred to the methods and results from the cited papers.

Twelve of the papers involved authors from at least one of the partner organisations as well as UniSC authors. The papers provided students and early-career researchers with the opportunity to write and publish papers as first authors. One paper (Palma et al. 2019c) involved researchers from all 3 countries and encouraged collaboration and information sharing among the team. One of the authors said, **'The one paper I really was most proud of was the one on the reproductive development of giant grouper because that's the one published in *Aquaculture* ... that paper was really a collaboration of the data provided from Philippines team and then we got the data also from the Vietnam team and data also from Australia.' (P1)**

The document review also identified 5 grouper-related papers published by RIA staff in Vietnamese scientific journals during the project (Appendix 2).

During the project there were 7 international conference presentations, 5 of which were presented by partner-country participants. Three of the conferences were hosted by a partner country. This was a notable contribution for a project of this size and illustrates the project's capacity-building achievements.

The high calibre of the science was recognised by the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development. Peter Palma was awarded the prestigious Dr Elvira O Tan Award for the 'Outstanding Published Paper in the Aquatic Science Category' for his paper in *Aquaculture* (Palma et al. 2019c). This recognition is conferred to studies that make significant impacts in their respective fields (Pagador n.d.).

Other forms of research dissemination

The project partners have also shared information with external stakeholders through the production of online articles and protocols. A technical manual for hybrid grouper seed production edited by RIA3 staff was used to train 30 participants in hybrid production in Vietnam. RIA1 and RIA3 also trained a total of 45 Vietnamese university students through practical courses on seed production technologies during an ongoing process of annual practicum placements.

The SEAFDEC website provides links to information, a newsletter (*AQD Matters*), which featured an article about the project, and links to marine finfish training program schedules. During the life of the project, the final report stated that SEAFDEC ran 16 training courses on marine finfish and grouper culture (including project-related research revisions) with a total of 181 participants from 18 countries (70% from the Philippines, 12% from other Southeast Asian countries and 13% from the Middle East, Africa and the Pacific Islands), 43% of whom were women. The evaluation was not able to update these numbers to include those trained from 2019 to 2022.

Application to other grouper, finfish and aquaculture species in partner countries

Optimising broodstock management, spawning and larval rearing is a common challenge for researchers and aquaculture companies involved in producing reliable sources of good quality fertilised eggs and larvae. Although some challenges are species-specific, much can be gained by applying the techniques developed in one species to another, and this was an intended intermediate outcome of the project.

The evaluation found evidence from interviews that project-related research findings and techniques were applied to other species within the partner organisations. In Vietnam, the RIA's techniques were applied to multiple species. **'We've applied them successfully to mouse, humpback, orange-spotted and other fish species similar to grouper – like cobia. [We also] started producing copepods for other fish species to improve their survival.' (R2)**

A Vietnamese researcher not involved in the project was already planning new approaches based on information from the project, including for rabbitfish larvae, which, like giant grouper, have a small mouth size.

DNA genotyping and bioinformatics analysis methods are now being developed by RIA staff for other priority species (for example, cobia and pompano) despite not being applied by them to the giant grouper and hybrids. In addition, they are developing F1 DNA markers (single nucleotide polymorphisms) that have benefits compared to using microsatellites. This genetic analysis has the potential to result in improved genetic management for these other species in the future.

At SEAFDEC project protocols were also applied to other finfish such as milkfish. **'What I also did was the application of the techniques that I had learned, on our milkfish, the local species. I studied early puberty. So was also trying to explore the use of hormones to induce gonad development in milkfish.' (P1)**

SEAFDEC staff also helped other students apply the techniques developed by the project for their research. For example, the vitellogenin ELISA was used by one student to demonstrate the effects of pollution on tilapia.

Australian researchers continue to work on the reproductive physiology of multiple finfish species and apply several of the technologies, from novel recombinant hormone production and delivery and hormone assays, through to germ-cell transplantation, which are modified and improved to suit the species being studied. These methods are providing farming advancements and helping to conserve endangered species. The aim is to commercially produce the recombinant hormones they have developed to provide reliable access and cost savings, extending the impact more readily to other researchers and end users.

Other finfish examples in Australia include:

- development of an assay for FSH to understand reproduction in yellowtail kingfish using recombinant gonadotrophins
- induction of spawning using recombinant hormones and improving the broodstock nutrition of the endangered species Macquarie perch in New South Wales
- mulloway reproduction, including the identification of early markers for sex determination, the oral delivery of hormones and germ-cell transplantation.

This last project involves a PhD student from the project who is now a postdoctoral researcher with the New South Wales Department of Primary Industries.

The research has also been applied to non-finfish species. For example, collaboration between UniSC and Vietnamese researchers led to publications on 2 different sea cucumber species. One of these is a highly cited paper (Table 5), and the research developed a new artificial breeding approach for sea cucumbers using neuropeptides. This research also resulted in the successful production of offspring that have been supplied to industry.

Ultimate outcome and broader goal levels

This section discusses research contribution at the ultimate outcome and broader goal levels of the theory of change, and touches on demonstration outcomes at the intermediate level. It briefly addresses the application of project technologies to other grouper and finfish species internationally, before looking at the project's role in initiating a sustainable grouper industry in partner countries (KEQ 2.5) and the impact of this on partner-country household income and wellbeing (KEQ 2.6). Findings on environmental impact are discussed with respect to sustainability (KEQ 2.7) and the impact on Southeast Asia more broadly is also looked at – mainly through SEAFDEC's training program (KEQ 2.5).

Application of technologies to other grouper species and marine finfish in other countries

The discussion above detailed the wider dissemination activities and the significant reach of the research products internationally through highly cited published papers. In addition to this, the SEAFDEC team incorporated a range of research findings and novel techniques into their training materials and lectures for grouper and other finfish production. This information was then disseminated to various stakeholders in Southeast Asia and countries in other regions through training workshops and university lectures. These workshops are still ongoing.

This knowledge transfer will likely have positively influenced the production of other finfish by the stakeholders and students involved. One example is a group of trainees from Cambodia who attended a SEAFDEC workshop. **'As part of their training, we induced spawning and did breeding work with giant groupers … when they returned to Cambodia they reported that they were able to do their own induced spawning work using both sea bass or the barramundi and also groupers. And they reported they were able to produce their first batch of grouper and sea bass fingerlings.' (P3)**

Three of the staff that left SEAFDEC are currently based at universities. One is overseas where they lecture on finfish reproduction and have incorporated knowledge and expertise they gained through the project into their lecture materials.

The innovative tools developed (for example, molecular analysis of larval feeding, microsatellite genotyping, hormone induction, recombinant hormone production and novel delivery systems, ELISA hormone assays and mucus testing for sexing) can be applied to multiple grouper and other aquatic species and will benefit the aquaculture research and commercial communities on an ongoing basis, including other researchers in Southeast Asia.

While the evaluation has not quantified the extent of actual application of this knowledge in other countries, some examples of application were identified. For example, during the project a conference poster was presented with overseas collaborators on Atlantic blue fin tuna reproduction (Carnevali et al. 2018). Capability development through the project has also seen staff who are now studying overseas transfer their skills to new species of commercial interest (for example, European sea bass and spotted wolffish) to overcome reproduction bottlenecks (Le François et al. 2021, Superio et al. 2021). The international publications citing the project's research cover a range of species, including other grouper and fish species, in addition to review articles with wide reach across the fish reproduction community.

Two international experts in fish reproductive biology were interviewed to provide their feedback on the quality of the science and its broader impact. Both were provided with the project report and some of the published papers prior to the interviews. Both were positive about the research and its breadth.

'I'm very impressed by the work that's been completed, the techniques and the results, I consider them to be very good and a really good advance in the field that they've been working on. I can also see that aspects of the results will have been very useful to industry.' (E2) Although this interviewee was not aware of the research prior to the interview, the recombinant hormone research was very relevant to their research. **'The oral administration of the recombinants or the use of the plasmids rather than the actual hormones is important information to consider for using those techniques in other species.' (E2)**

This opinion was also expressed by the second expert, who indicated that the demonstration that DNA could be used to orally deliver FSH (Palma et al. 2019b) was significant progress in the field. Overall, both experts felt the research was appropriate with a good mix of applied and innovative research. The benefits of the germ transplantation research were considered to be longer term, but were also of interest.

Contribution to a sustainable grouper industry in partner countries

While the project's contribution to SEAFDEC's research capacity was significant, the direct contribution of SEAFDEC to the grouper industry in the Philippines was minimal. This was largely due to difficulties experienced in producing either pure or giant grouper hybrids in any volume beyond those for research purposes. The end-of-project review concluded that, by project end, the limited number of broodstock available meant the institute 'still has to develop its expertise in giant grouper breeding' (O'Connor et al. unpublished).

Although there may have been some knowledge-sharing and practical transfer of broodstock management and spawning techniques with an informal industry partner, this evaluation was not able to substantiate the nature, extent and use of this. Nevertheless, the project's final report indicated that 'all available grouper fingerlings are sold and a waiting list exists for all species cultured (including giant grouper)', offering this as evidence that the grouper industry would continue to grow there (Nocillado and Elizur 2021).

In Australia, the project partner that had already succeeded in closing the life cycle of giant grouper using their own expertise withdrew around 2014 due to their unforeseen commercialisation. Tasked mainly with working on the larval stages and grow-out technologies, they were no longer in a position to share intellectual property. In an attempt to maintain an industry link in Australia, the project formed an informal partnership with another Queensland-based company – the second private company to set up commercial grouper hatchery facilities in Australia. Informal arrangements consisted of the project providing technical assistance while the company provided broodstock and access to their facilities for experiments. The project's 2018 annual report indicated that the project helped in their initial spawning of tiger grouper while awaiting maturation of their giant grouper population (Nocillado and Elizur 2018). In 2023, the informal partner company confirmed it had not had success with tiger groupers and has ceased breeding them. It is currently only engaged in grow-out of giant grouper, but plans to commence spawning by the end of 2024 with assistance from the initial, Australia-based commercial company. As the original contact person within the second company had left by the time of this evaluation, specific details on project assistance and its uptake were not available.

While initial expectations of initiating the grouper industry in Western Australia and the Northern Territory have not yet been realised, several interviewees said that knowledge-sharing with the Australian grouper industry and application in practice included:

- genotyping work and some of the work looking at the genetics of the different populations, which helped to explain the levels of inbreeding in Taiwanese sourced giant grouper and strengthened the genetic diversity in their breeding populations: **'I think that sort of work is useful to reference back and to make further advances on' (G3)**
- looking at the contribution of individual fish on a spawning run and targeting mid-run spawning where the project demonstrated there was more genetic diversity.

'These were important contributions we made in the Australian industry … adoption is not necessarily known, but at least they know.' (G1)

However, when referring to the hormonal treatment and larval feeding aspects of the research, one interviewee commented on the larval feed transcriptomics research. **'[Our] techniques will not be replaced by the more complicated methods the project produced. While there were interesting outcomes … it doesn't change what we do.' (G3)**

With direct contributions to industry initiation being more peripheral in the Philippines and Australia, the bulk of the following discussion relates to industry initiation in Vietnam, where successes were more apparent.

Giant grouper production

Following significant project success in spawning giant grouper for the first time in Vietnam at RIA1 in 2012 (under FIS/2012/037), RIA3 reported in 2023 that they could reliably produce fertilised eggs in significant quantities to meet customer orders. Both RIA1 and RIA3 have F1 populations for future breeding programs. However, due to the overwhelming preference and demand for hybrid grouper, RIA1 had reportedly produced no fertilised giant grouper eggs since the project moved to RIA3, and RIA3 produced only one viable kilogram to fill an order in 2022.

Other fertilised grouper eggs produced in the research facilities (excluding GGTG hybrids) included:

- 30 kg of orange-spotted and 2 kg of tiger grouper in 2022 (RIA1)
- 1.2 kg of giant x orange-spotted grouper in 2019–20 (RIA3).

This is a good indication of the current refocus of the research institutes from all other grouper species to GGTG hybrids, noting that RIA3 currently has a Vietnamese Government-funded red grouper research project under way.

The RIA1 hatchery reported producing their first GGTG hybrids in 2008 with Vietnamese Government funding, producing experimental amounts of around 1 kg from 5 to 7 broodstock. In its 2014–15 annual report, RIA1 suggested it had produced hybrid grouper fingerlings annually since 2011 – though whether this was from its own broodstock was unclear.

Following a lull in production during the COVID-19 pandemic, total annual production of fertilised eggs in 2022 was 20 kg in 3 to 5 batches at RIA1 and 20–40 kg in 7 to 9 batches at RIA3. Both research centres reported a capacity to produce much more (up to 80 kg) depending on orders and demand. Interviewees estimated the fertilisation rate to be 70–80%, with an 80–90% hatching rate at both facilities. Both research centres kept a portion for their own fingerling production. RIA1 sold to 3 hatcheries and RIA3 sold to 6 to 8 hatcheries, mostly in adjacent provinces.

RIA1's spawning season is from late April to late July, when it produces enough eggs to fill its orders. In other months, it buys from RIA3 in central Vietnam to maintain its supply of fingerlings to clients. RIA3's spawning season is from April to November.

RIA2 only started to produce hybrid grouper in 2022, with broodstock of 4 giant grouper males (now 50 kg) and 40 tiger grouper females (4–5 kg) all sourced from the wild around Binh Thuan province. It produced 2–3 kg per batch for experimental purposes. RIA2 hopes to increase its future production using their own knowledge and protocols.

All 3 research centres are limited in fingerling production by their hatchery space and facilities, which are prioritised for research rather than production purposes. Both RIA1 and RIA3 maximise the space available, as the GGTG hybrid fingerlings are an important source of income for the research centres to supplement staff base incomes and ongoing research projects. Relevant fingerling production numbers are shown in Table 6.

The data indicates that RIA1, at least, had the capacity to produce hybrid grouper prior to project commencement – albeit in smaller numbers. Clearly, the project enabled a more rapid increase in production. In the years since the project ended, both research centres have made significant progress in improving their production of fertilised eggs during the available spawning months. They have also succeeded in improving larval to fingerling survival rates (from a low of 2% to a high of 10%), and continue to provide a reliable supply of GGTG hybrid eggs and fingerlings to their network of nearby hatchery grow-out farmers. Perceptions of seed quality are discussed below.

Table 6 Hybrid grouper fingerling production

Production data	RIA1	RIA3
Year of first production	2011[a]	2016–17
Initial number produced	25,000	12,400
Survival rate of initial batches: larvae to fingerling	2–5% (6–8 cm)	0% (4–5 cm)
Number produced in 2019 (at project end)	450,000 (6–8 cm)	30,000
Number produced in 2022	300,000	100,000
Survival rate: larvae to fingerling	8% (6–8 cm)	7–10% (5–7 cm)
Hybrids as a percentage of all fingerling production	90%	70%
Sale price[b]	USD0.15/cm	USD0.12/cm
Purchasers[c]	70–80 grow-out farmers, 3–4 traders	5 grow-out farmers

(a) An experimental amount was anecdotally reported in 2008, produced with Vietnamese Government support
(b) June 2023 exchange rate
(c) Sales patterns were difficult to quantify as different informants provided very different estimates and did not appear to keep records. Farmers also buy for their neighbours and distribute to reduce transport costs, blurring the actual number of customers.

Sources: FIS/2012/101 2016 and 2018 annual reports; interviews with RIA hatchery staff

Private-sector hybrid grouper fertilised egg production

Project reporting indicated that continued reliance on imported hybrid grouper fingerlings was due to a major bottleneck in the availability of locally produced fertilised eggs, which was estimated to be restricted to only 4 hatcheries nationwide (Dennis et al. 2020). However, interviews with RIA staff and hatchery operators in 2023 indicated that, in addition to the RIAs, there are now at least 7 Vietnamese producers that have broodstock and are currently producing fertilised eggs. They are all in central and southern Vietnam (3 in Khanh Hoa, 2 in Vung Tau and one each in Binh Thuan and Ninh Thuan). At least one of these was thought to have started production as early as 2013. Their combined capacity was estimated by an industry informant to be around 2 t of fertilised eggs annually. Although this quantity could not be verified, 4 interviewees (including 2 RIA staff) verified the presence of 2 producers in Vung Tau with an estimated production of 800 kg/year each, accounting for the bulk of the current local production.

All 7 of these producers were believed to be operated by Taiwanese migrants. According to RIA interviewees, they had brought their own broodstock and management techniques to Vietnam from Taiwan, and had little to no relationship with any of the RIA, operating independently of and in parallel to them. In other words, local hybrid grouper breeding and rearing technology was not extended to these industry operators by the RIAs when they were setting up their breeding programs. Interviewees from the RIAs in particular were of the view that these producers were more profit-driven and less concerned about the quality of the eggs they produced, pushing their fish to spawn repeatedly if the price was high. Current estimates from an industry source put combined fingerling production at 15 million per year (to 10 cm). This information could not be confirmed, as the evaluation team was unable to contact these producers directly. However, hatchery interview data suggests they may have been suppliers to industry since at least 2013.

Sources of knowledge and immediate impacts on productivity

Hatcheries

Of the 9 hatcheries interviewed, 7 were direct RIA contacts. They heard about hybrid grouper from the RIA and most started hybrid grouper fingerling production in 2016, with the earliest starting in 2015 (Table 7). This reflects the close ties of the interviewees with the RIA, with 3 also being former RIA staff. The remaining 2 hatcheries learned about hybrid grouper from Chinese/Taiwanese contacts.

Technology transfer was assessed in relation to any 'new' techniques or practice change that occurred as a result of farming hybrid grouper compared to other crops. Hatchery interviewees indicated that there were only a few differences required for producing hybrid grouper fingerlings, mostly related to labour intensity – with some hiring additional staff to ensure fish size grading was done in a timely manner to prevent cannibalism by larger fry, and to assist with weaning onto processed food. Both of these tasks were often done by women, working on a part-time basis.

Other changes related to facility improvements and changes in feeding practice, with some hatcheries growing their own rotifer and algae. Facility improvements included:

- building a large roofed area over fingerling ponds to trap heat and extend their seasonal capacity (in the north) (1)
- lining earthen ponds (2)
- expanding the number of concrete tanks (1).

Otherwise, most hatcheries relied on their existing hatchery technology and practice to produce GGTG fingerlings.

Of the 9 hatcheries interviewed, 6 got most of their information from their RIA contacts, with 3 indicating some type of training/materials provided, while all had on-site and phone contact. Hatching rates achieved ranged between 10% and 90%, with most consistently reporting 80–90%. There was relatively high confidence in knowledge of hatchery practice, with only one interviewee mentioning they were **'a little nervous' (N6)** in the hatching and larval growth phases. Nevertheless, 4 hatchery operators were most interested in receiving new information related to knowing the quality of the eggs they were buying, while only one mentioned information on feeding. The preferred method of information delivery for 5 interviewees was by phone, and one wanted to access online videos of hands-on methods so they could see various techniques to assist their learning.

Grow-out farms

Half of the 10 grow-out farmers interviewed started growing hybrids in 2012. One sourced theirs from the RIA1 trial, another sourced theirs from China and another sourced theirs from a private company in central Vietnam in 2013. Eight of the grow-out farms had previously grown orange-spotted grouper, 3 had grown giant grouper, and one had grown a small amount of dusky tail grouper. Four of the grow-out farms initially heard about the hybrids through personal contact with the RIA, while others heard from other industry contacts.

For 8 of the grow-out farms, extension of information was provided by a mixture of sources (for example the RIA, feed agencies and neighbours), including intermediaries from China and Taiwan (2). Only 2 sourced their information solely from the RIA, and 3 were direct neighbours of the RIA1 broodstock manager. Delivery of information through these sources was primarily through face-to-face discussions, with one relying on the internet and another communicating with the RIA by phone.

Little difference in practice was noted by 6 of the interviewees in growing out hybrid grouper compared to other species farmed previously, with some indicating they were easier. There were few specific changes to grow-out facilities noted beyond the addition of an aerator, and the deepening of ponds to keep the water cooler. Practice change included:

- increased cage cleaning
- parasite/disease control through immersing fish in freshwater when small (2)
- some changes to feeding:
  - feeding pellets at the early stages of grow-out (6)
  - feeding less often than other crops (Cobia, snails) leading to reduced labour needs (3).

For the majority, labour needs did not change, perhaps reflecting the dominance of smaller, family-only operators represented by interviewees.

Due to the similarity with other grouper species previously grown out and the availability of advice from other producers, confidence levels were relatively high for 6 interviewees, with only 3 indicating they had some doubts about the best methods.

Survival rates were reported to be variable, with 5 interviewees achieving around 70%, (lowest range 40–50%; highest range 80–90%). A few interviewees indicated specific information needs (for example, disease management, water quality and information about weather warnings). Preferred delivery methods included internet and video-based (3); however, 7 were in regular contact with RIA staff and could call on them for support as needed.

Photovoice study

In the time since both hatchery and grow-out farmer participants first started producing hybrid groupers, initial changes to production methods may have become less fresh in their memories. The project conducted a photovoice study in 2018 that documented changes to practice from adopting the project-related hybrids (Pierce unpublished). Fishery households were provided with cameras to photograph aspects of importance to them and then described the changes depicted in the photographs. Participants indicated several novel techniques additional to those above, such as:

- checking grouper fingerling health and ability to absorb food when newly released
- immersing fingerlings in antibiotic solution to increase survival
- monitoring growth and health
- ensuring food quality for growth
- checking larvae every day
- feeding rotifer, feeding yeast and checking density
- checking algae levels, harvesting and filtering
- cleaning filtration
- incubating artemia.

The study did not distinguish between hatcheries and grow-out farmers, nor did it establish the source of information for these changes, but it is likely that the information was provided by RIA contacts in the early stages of extension.

RIA's role in extension and capacity for broad industry reach

The project proposal expected that significant advances in giant grouper aquaculture technologies would be 'communicated to farmers'. It referred to the considerable capacity and mandate of SEAFDEC for technology transfer through established training programs, but project documentation provided little detail relating to the RIAs' extension capacity. Although they were expected to develop and present technical training manuals and information brochures to communicate technical and husbandry information throughout Vietnam, it was unclear if specific project resourcing was allocated to this activity. There was also little information in the project's reporting relating to actual extension activities in Vietnam and their effectiveness.

Interviews with RIA staff suggested that the only formal training that occurred was in 2019, close to the end of the program. While lack of funding for further training was cited as the reason, COVID-19 restrictions may have also reduced opportunities to repeat it. The project and the Vietnamese Government funded RIA3 to provide one technical workshop with other researchers, and one practical 3-day training course in hybrid grouper production for about 30 participants from Khanh Hoa province. Some participants were women, and at least 2 of the hatchery interviewees in that province recalled attending. This training was aimed at farmers who already had a solid understanding of mariculture, and while it included information on broodstock management and breeding, most participants did not have the facilities to apply it at the time. According to the RIA, the most useful sessions were the hatching, larval rearing and grow-out sessions. Although the course materials were not provided in their entirety since, RIA3 use parts of them in their obligatory annual information sessions,[10] and aspects may be incorporated into their annual student practicum intakes (10–20 students). Apart from this, the training material is available to download from the Khanh Hoa Government website, and it may have formed the basis of 4 other online articles on hybrid production currently available in Vietnamese.

Although conceived as research centres with technology transfer and extension functions, unless specifically funded, there was limited evidence of significant formal training or extension activities. **'There wasn't a plan to extend [breeding technology] beyond RIA, but if a company comes to us and asks for assistance, we will share the technology. Our budget is limited.' (R2)**

Knowledge transfer from the RIA entered the commercial sector informally in 2 main ways:

- information being communicated directly through personal networks of hatchery and grow-out farm owners
- former RIA staff applying their project-related grouper production knowledge directly in their own businesses.

Importantly, immediate information was available through direct phone access with key RIA staff. The RIA1 broodstock manager lived on the sea cages and provided assistance directly to nearby grow-out farmers. RIA3 staff were also engaged with at least 2 local hatcheries (both in Khanh Hoa) that were at the start of their hybrid grouper breeding programs, assisting them monthly with sex-determining biopsies and checking gonad development. The staff estimated that these hatcheries would be able to perform these tasks themselves after a year or so of face-to-face assistance. This hands-on assistance was seen as crucial to the effective transfer of technical skills. **'Training is useful to introduce the protocols quickly, but they can't learn everything from a training.' (R2)**

Given the project's expected change pathway through extension to industry, the RIAs did not appear to have the means to influence other potential growers outside their immediate networks. Although RIA3 does have a website, apart from the technical training manual referred to above, it does not appear to include other more accessible sources of information on grouper production (for example, explanatory brochures or YouTube clips demonstrating project-related techniques). Interestingly, even RIA2 did not have an intention to seek revised protocols or training materials from RIA3, as they were relying on their own expertise. Another significant local producer that was about to commence hybrid egg production was also relying on external sources for its broodstock management expertise (Box 1).

10 In Khanh Hoa province, information sessions must be provided to one commune per year for 5 years after receiving a government program.

Box 1: Hybrid grouper breeding intentions of a local commercial Vietnamese hatchery in Vung Tau

This hatchery and grow-out farm has 15 employees (including 5–6 women who worked part-time grading fish). It has been importing GGTG hybrid fingerlings since 2007, with a preferred model of buying at 3 cm and selling at 10 cm. Buying about 1 million fingerlings per year, the business keeps about half for grow-out and sells the rest. In 2017, a Taiwanese trader proposed a partnership. As part of the agreement, the hatchery received 500 giant grouper fingerlings sourced from Taiwanese-cultured stock, 120 of which were eventually kept for broodstock. Some of these are now producing milt (started at a weight of about 60 kg). The grow-out farmer believes the fingerlings are all female until they transition to male at around 30–40 kg. He judges their likely sex by size. He has also imported about 100 tiger grouper (both sourced from the wild and selected from farms).

In the next year or so, he plans to produce 100–200 kg of fertilised GGTG eggs per year to sell. The technical knowledge for the production of fertilised hybrid eggs will come from 2 of his technical staff, who are both Vietnamese. One trained in Malaysia, and the other will return from Indonesia where he has worked on a grouper farm. The farmer believes they have the knowledge he needs to be successful.

In terms of technical assistance from the RIA, the farmer knows it has a research and training function, but does not believe it has anything to offer large private companies in the way of knowledge/expertise. He said he had been invited to a training on groupers but did not attend because he thinks only the other commercial producers have information of benefit to him, and he prefers to learn from them. He believes the hybrids are very profitable compared to other species. He currently produces more sea bass than grouper but is planning on increasing his own production when he has his own eggs.

As the RIA's focus and mandate is on the promotion of sustainable aquaculture through proper broodstock management to maintain fertilised egg quality for the industry, its inability to influence either the local Taiwanese producers providing the bulk of the seed or potentially larger local hatcheries outside its personal networks suggests its extension role may be more limited than the project envisaged. One RIA interviewee suggested that the only solution to promoting sustainable production was through government regulation of private producer behaviour and practice, but also noted that **'There are regulations now, but [the fisheries department] can't enforce them. On the other hand, [RIA] have limited capacity to influence them as they are not interested in our information. They do things their own way. We would have to force them to change by developing and enforcing regulations.' (R5)**

The RIA's more immediate and effective extension influence on hatchery and grow-out farmer network productivity is discussed below.

Domestic capacity in Vietnam

Estimates of demand for hybrid grouper fingerlings and the current domestic capacity to meet this demand are made difficult by the paucity of industry data available in Vietnam. The following section draws on data from project reporting and interviews with hatchery operators and grow-out farmers. It must be acknowledged that during the COVID-19 period – especially from 2020 to the end of 2021 – the hybrid grouper industry was particularly impacted, as international and domestic tourism and value-chain operations were severely restricted. Interviewees were asked to talk specifically about the year 2022 as the last full production period, and any comparison in trends was made to 'pre-COVID' years. Testing of actual market demand potential was beyond the scope of this evaluation, which relies instead on the proxies of hatchery and grow-out farm ease of selling their crops, and perceptions of market capacity to absorb more than they had to sell.

Location of producers

Interviewees, including those from the RIA, confirmed it is impossible to accurately estimate the number of hatcheries that produce and sell hybrid grouper fingerlings, or how many fingerlings are sourced from where. It was explained, however, that while the department may know the approximate number of hatcheries and grow-out farms, the marine species each produces was less clear, given seasonal and market fluctuations.

Countrywide data supplied by the Department of Fisheries estimated that, in 2021, there were 51 hatcheries in Vietnam producing 509 million marine species fingerlings (grouper, cobia, barramundi, pompano, yellow/white fish, sea bass) to an estimated 3,795 mariculture grow-out farms – sea cage and pond.[11] Table 7 outlines their locations.

It is likely that the number of provinces engaged is higher, as respondents were relying on their personal knowledge and individual sales data. Traders may also sell to many more coastal provinces.

The socioeconomic study conducted during the project (Dennis et al. 2020) drew from data obtained in 2017 in one northern province (Hai Phong – 4 sea-cage farmers) and one central province (Khanh Hoa – 5 hatcheries and 3 earthen pond grow-out farmers). Only 3 of the 12 original participants could be contacted for resurvey, highlighting the fluid nature of the industry.

Production of fingerlings

Of the 9 relevant hatcheries interviewed[12], most typically purchased 1–10 kg of fertilised eggs per year at a price of USD1,710–2,560/kg. The price depended more on the time of the spawning season (more expensive at start and end) rather than on the source of purchase (RIA, local or imported). Prices were reported to have not changed significantly since before the COVID-19 pandemic.

Table 7 Provinces engaged in hybrid grouper production, by type of engagement

Region/province	Hatchery[a] – broodstock	Hatchery[a] – fertilised eggs to juveniles <10 cm	Grow-out farm – juveniles to plate size
Northern Vietnam			
Hai Phong (inc. Cat Ba)	1 (*n* = 1 RIA1)	2 (*n* = 2 including RIA)	100 (*n* = 6 sea cage)
Thai Binh	–	1 (*n* = 1)	N/A
Nam Dinh	–	1 (*n* = 1)	N/A
Quang Ninh	–	N/A	N/A
Central/southern Vietnam			
Khanh Hoa	6 (*n* = 1 RIA3), 2 not yet in production	N/A (*n* = 5 including RIA)	N/A (*n* = 2 earthen pond)
Ninh Thuan	1	10 (*n* = 2)	N/A (*n* = 1 earthen pond)
Binh Thuan	1	-	N/A
Vung Tau	2	N/A (*n* = 2)[b]	N/A
Ben Tre	–	–	N/A
Kien Giang	–	–	N/A
Total facilities	**11**	**N/A**	**N/A**
Total interviewees	**2 (RIA)**	**13**	**10**

n number of interviewees
(a) The definition of 'hatchery' used was unclear and may not include nursery operations engaged solely in fingerling production
(b) Using a more targeted interview schedule with hatcheries that did not engage with RIA grouper

Source: 2023 evaluation interview data

11 Noting the definition of 'hatchery' used was unclear and may not include nursery operations engaged solely in fingerling production: Personal correspondence between RIA3 staff and the Department of Fisheries in 2023.

12 Interview data used in the analysis excluded the 2 RIA hatcheries and the 2 hatcheries from Vung Tau, which were collected using separate questionnaires and are reported separately.

In terms of capacity to meet their requirements, 5 hatcheries indicated they would like to buy more if they were available, with some indicating a preference to buy from the RIA. **'I would prefer to buy from RIA if they had more.' (H3)** This appears somewhat contradictory, as the RIA claimed it *could* produce more, but that it only produced as much as was ordered. Responses may therefore have been more related to seasonal scarcity. Four hatcheries said they had never imported from overseas to fill the seasonal gap, with some opting to grow other available species from November to March. Two northern hatcheries still purchased fertilised eggs from China.

The number of fingerlings produced annually ranged from 100,000 to 1,200,000 per hatchery, with 5 of the hatcheries interviewed producing more than 100,000 annually. Prices ranged from USD0.08–0.20/cm. Larger fingerlings (10 cm) attracted higher prices, reflecting their better survival potential. This price range also reflects seasonal demand and was similar to those pre-COVID-19. The majority of hatcheries sold fingerlings to grow-out farmers who either purchased them directly for themselves, or on behalf of neighbours to save on transport costs. Most hatcheries also sold to traders, who on-sell to grow-out farms in varying numbers and amounts. **'I produce about 400,000 fingerlings per year. I sell them to 4 to 5 middlemen and about 30 grow-out farmers.' (H6)**

Six hatcheries said they could sell more fingerlings if they could produce more. **'This species of grouper has never been in the state of being "available but unsold".' (H7)** Perceived constraints to production to meet this demand are discussed below.

Production of grown-out grouper

All 10 grow-out farms interviewed cultivated a number of fish species – if not all year round, then at least in the November to March period when hybrid fingerlings were not available. For the majority of farms, hybrids comprised 90% of their crop. Two sourced their fingerlings exclusively from the RIA, and one had never purchased from the RIA. Five bought from non-RIA nurseries in central Vietnam and one bought from Taiwan. Sources were not always clear, as the origin of fertilised eggs in the hatcheries in the central and southern regions of Vietnam were not known to the majority of buyers in the north, who bought them from traders.

The number of fingerlings purchased annually was on the lower side (5,000–10,000), possibly reflecting the recently reduced sea-cage farm sizes in Cat Ba, where the majority of respondents lived. Only 2 grow-out farms purchased 27,000–50,000 fingerlings per year. Most indicated they could buy as many fingerlings as they wanted in season, if they were prepared to order in advance or buy from multiple sources, while only one would have liked to buy more.

All grow-out farmers indicated they had no difficulty selling their crop in 2022. This was in contrast to the COVID-19 years, when the demand for and price of live grouper plummeted due to the suspension of local and domestic tourism (Vietnam Fisheries Magazine 2021). By 2022, the market had recovered to pre-pandemic levels.

Five farmers indicated they sold grouper on a daily basis (close to the Cat Ba tourist area) either directly to restaurants or to traders. All sold their crop as live fish and larger fish attracted a lower price, due to restaurant preference for plate-sized fish. Prices in 2022 were consistently reported as:

- 1.5–3 kg size fish = USD12.50/kg
- 3–4 kg size fish = USD11.50/kg
- 4–10 kg size fish = USD10.00/kg

These prices are consistent with those reported in the socioeconomic study using 2017 data (USD11/kg) and the 5 interviewees confirmed that they indicate a slight rise since pre-COVID-19 times.

Apart from being able to sell all their stock whenever they wanted, 2 of the farmers were confident they could sell more fish if they had them, suggesting unmet demand from the local live fish market. Data was not available on the amount of hybrid grouper sold in the export market, although the northern grow-out farmers indicated that traders who came from nearby China pre-COVID-19 had not yet returned. For both hatchery and grow-out operations, interview data indicates there is still potential to expand to meet local market demand for live fish, at least in the tourist areas.

Perceived barriers to productivity

The socioeconomic study (Dennis et al. 2020) concluded that there were 2 key constraints limiting the growth of the industry:

- lack of eggs, due to not enough or unproductive broodstock
- poor larval survival.

In 2023, these barriers were still evident, with 6 hatcheries indicating they could sell more fingerlings if they could produce more. The main barriers they identified included:

- insufficient fertilised eggs available, especially from November to March (3)
- poor larval survival rates (1)
- low staff availability (1) and their advanced age (1)
- fluctuations in demand that are difficult to predict (1).

Egg quality was not seen as a major impediment to improving productivity, with the majority of interviewees buying fertilised eggs from the RIA and other sources (1 non-RIA only). Two hatcheries thought the RIA's eggs were of better quality, while 3 who bought from both sources said there was no difference. **'Quality from RIA is better. They have good broodstock compared with others.' (H3) 'In my opinion, the quality of eggs produced in RIA and China is identical, with a hatching rate between 85% and 90%.' (H7)** Three hatcheries had no particular view either way.

The quality of fingerlings was seen by most grow-out farmers to be similar from the different sources, with 2 believing the RIA fingerlings were better quality.

For the grow-out farmers who indicated they could sell more if they produced more, the main barrier included the reduction in available sea-cage area as a result of the Vietnamese Government's policy to shift aquaculture operations from near-shore tourist areas. This was seen as having a major impact on the ability of grow-out farmers in the Cat Ba and Khanh Hoa areas in particular. This productivity barrier was mentioned by 5 hatchery operators and 7 grow-out farmers (including one with earthen ponds). Interviewees from the Ban Beo harbour of Cat Ba island estimated the number of grow-out sea-cage farms has reduced from 400 to 100 in recent years, as the government seeks to achieve UNESCO listing for the Ha Long Bay area and focus land and sea use on tourism (Thanh n.d.). The remaining sea-cage operators who were original residents of the Ban Beo area had to reduce their sea-cage area to 400 m^2. For some, this represents half their previous size, limiting the number of hybrids they can grow.

While reducing the production capacity of some producers in tourist areas, the Vietnamese Government's tourism policy is also clearly driving local demand for live fish in these areas, and contributing to their profitability. For those producers that are directly affected, the project's contribution to making higher-value hybrid grouper more available on Cat Ba island in particular may have assisted in lessening the impact of these changes on the continued viability of operating smaller farms. However, this assumption was untested by the evaluation.

Project's overall contribution to a sustainable grouper industry in Vietnam

Sustainability, as defined by the project, relates to self-sufficiency in fingerling production – reducing reliance on imports and wild-caught stock. This section has summarised productivity issues, while economic and environmental aspects of sustainability are discussed in the section below.

Project reporting of the hatchery industry's capacity to meet local demand for hybrid grouper fingerlings was estimated to be 50% in 2018 and up to 66% in the final report (Nocillado and Elizur 2021), although the basis for these claims was not elaborated. This evaluation found that by 2022, similarly unsubstantiated estimates from RIA interviewees had increased to around 80%, with the remaining 20% imported in the seasonal gap (November–March) when local broodstock were not spawning. These estimates roughly mirrored those of at least one industry representative (15 million fingerlings to 10 cm produced locally, 2.5–3 million imported annually), so may reflect an informed consensus.

While this indicates steady progress in improving the sustainability of the industry by reducing reliance on imports, it is difficult to assess the project's contribution. The historical estimates above of the timing of the arrival of hybrid groupers in Vietnam and their numbers and origin puts into question the project's claim of having initiated a 'new' crop in Vietnam. Interview data indicate that GGTG hybrid grouper were available in the country and being produced by other industry actors in Vietnam in parallel with, if not before, the project. While some interviewees credited the project with the hybrid grouper production 'boom', 4 interviewees indicated it would have occurred regardless. **'Even if there was no [project] the researchers and government would still have studied hybrid grouper. Project support helped [RIA] to get started earlier.' (R1)**

The availability of giant grouper milt contributed significantly to the RIA's capacity to produce locally. **'If the project improved the milting condition of the giants in any way ... addressing that particular bottleneck, then yes, it would have assisted with local production of hybrids. Otherwise they would have just imported.' (E1)**

Nevertheless, while the locally produced private hatchery fertilised egg and fingerling production now dwarfs that of the RIA-influenced hatcheries, the likely addition of 2–3 local hatcheries with their own broodstock from RIA3's personal network (which are about to commence spawning activities with RIA's assistance) will increase this direct contribution in the near future.

Aside from the direct impact on industry production, the many other positive contributions made by the project to research centres and indirectly to industry were identified as follows:

- supported partner capacity to adopt hybrid technology by demonstrating the value of the industry and creating industry confidence (3)
- addressed the initial bottleneck of giant grouper milt production (3) and timing (1)
- improved broodstock handling and maintenance and the importance of it to productivity (2)
- improved existing protocols, and more importantly, documented them (2)
- improved survival rates following hatching (1)
- raised awareness of biosecurity importance – not only in research centres, but in hatcheries and grow-out farms (1).

In addition, the contribution of the RIA's fertilised eggs to overall fingerling production did appear to act in combination to reduce the importation of fingerlings and the associated biosecurity risks. Seasonal gaps persist, however, and these continue to be filled by a combination of imports – mostly juveniles from Taiwan, Indonesia and China – and substitution with other fish species to fill the short-term lack of supply. There is still unmet local demand for plate-sized grouper (evidenced by the ease with which all producers can sell their stock), but this undersupply is also likely to be contributing to their profitability. The impact on the export market supply could not be reliably assessed, although, as most neighbouring countries already produce them in significant numbers, it is unlikely to be significant.

The major industry bottlenecks and challenges that were identified as having been inadequately addressed were due to low survival rates. This could be improved by addressing:

- optimal nutritional requirements of broodstock
- optimal nutritional requirements for larval development and fingerling production
- disease management.

The lack of genetic management plans was also acknowledged as an issue that needed attention by the RIA, and potentially throughout the industry.

Impact of improved grouper aquaculture on household income and other gendered measures of welfare

Household income

At the broader impact level, although this evaluation did not undertake a rigorous economic assessment of hybrid grouper productivity and profits, it is useful to compare the evaluation findings to those of the socioeconomic study (Dennis et al. 2020) in order to ascertain the extent to which profitability and benefits have been enduring.

The 2017 socioeconomic study concluded that hybrid groupers were a very profitable and promising crop. They were identified as being the most important crop for grow-out farms and the second most important crop for hatchery farms, with cobia being more profitable at the time for central hatcheries. In 2023, this remained true for grow-out farmers, while most hatcheries indicated that hybrid grouper were now their most important crop (Table 8).

While direct comparisons were not possible due to differing research methodologies, the highest annual gross margin observed in 2017 was USD18,032 (central pond grow-out), while the lowest was USD2082 (the second smallest sea-cage farm in the north) (Dennis et al. 2020). In 2023, instead of rigorously calculating the cost of inputs, participants were asked to estimate their annual profit. The data yielded ranges of USD84,900 to USD16,908 for hatcheries, and USD85,000 to USD8,500 for grow-out farms – a significant increase from 2017.

Profit estimates were 'best guess' only, and it was difficult for interviewees to separate out grouper profit data from the other species grown, especially as they are bought and sold in varying batch sizes throughout the year. These estimates may also reflect the maturity and progressively higher proportion of fingerlings and fish being produced relative to other crops.

In addition, 3 other proxies were used to indicate perceptions of profitability:

- ranking the species they currently farmed in terms of profitability
- intention to continue farming hybrid grouper, including intention to expand production
- whether any other species were preferred over hybrid grouper.

Table 8 Profitability and productivity of hybrid grouper

	Hatcheries	Grow-out farms
Estimated 2022 profit from hybrid (after investment)	• USD84,900 (1) • USD67,920 (1) • USD25,400 (1) • USD16,980 (1) • Five could not provide an estimate, but confirmed they made a profit	• USD85,000 (1) • USD42,660 (1) • USD38,000 (1) • USD20,865 (1) • USD8,500 (1) • Five could not provide an estimate, but confirmed they made a profit
Percentage of farm output that was hybrid grouper	• 10–40% (3) • 70–80% (2) • 80–100% (2) • N/A (2)	• 90% (5) • 30–50% (4) • N/A (1)
Profitability ranking compared to other species	• Hybrid most profitable (5) • Pompano most profitable (1) • Cobia second most profitable (3) • N/A (3)	• Hybrid most profitable (9) • N/A (1)
Intention to continue with hybrid production	• Continue with expanded production (6) • Continue with current production (2) • Continue and diversify (1)	• Continue with expanded production (3) • Continue with current production (5) • Continue and diversify (1) • N/A (1)
Other more preferred species	• None, hybrids are best (6) • Will try pompano (1) • N/A (2)	• None, hybrids are best (5) • N/A (5)

Source: 2023 evaluation interview data (9 hatcheries, 10 grow-out farms)

In 2017, over 90% of variable costs for all regions related to feed, fertilised eggs/fingerlings and labour – in that order – and the evaluation found this was still the case for both nursery and grow-out operations in 2023. Trash fish were still the preferred feed for grow-out farmers, and these were generally available in sufficient quantity, with minor shortages during periods of poor weather requiring substitution with pellet feed. The socioeconomic study concluded that, 'In the North, hybrid groupers have been added to the range of crops cultured but have not become entrenched due to a general lack of availability [and] slow growth in the colder weather may limit uptake' (Dennis et al. 2020). This does not appear to have remained true from the limited data available (3 hatcheries and 4 grow-out farmers), with 3 non-RIA hatcheries now producing fingerlings for distribution to grow-out farms in the area. It is not known whether the forced relocation of non-resident sea cages from Cat Ba back to their home towns has resulted in a net loss of producers or is simply a geographic reshuffle, which may not affect overall uptake.

Despite perceptions of slight increases in production cost, GGTG hybrid grouper were considered by far the most profitable crop in 2022, by hatchery and grow-out farmers alike. All interviewees signalled their intention to continue to produce them, with 6 hatcheries and 3 grow-out farmers intending to expand production. Notably, the grow-out farmers who indicated they would not expand were those constrained by recent size limits on their sea cages. The majority also indicated there was no other species they considered better for them to try in the near future, while high prices and market demand remained. **'No other species can replace it. Since it was introduced, it boomed straight away – much more quickly than pompano or cobia, so I don't want to farm them.' (F4)**

Not only do these findings indicate that profits from hybrids have been enduring since the project ended, there is also some evidence they have increased.

Gender aspects

Project reporting and the end-of-project review (O'Connor et al. unpublished) focused on gender as an issue only in the partner organisations, noting strong female representation in both leadership and research positions among program staff. At the end of the project, however, the gender equality aspects of the availability of hybrid grouper as a crop were examined through the 2018 photovoice study. This study concluded that while women had the ability to participate in and benefit equally from all aspects of grouper farming, restrictions remained around their level of physical strength and dexterity. This maintained a division of labour, although some women expressed a desire to move into roles at all levels (Pierce unpublished).

Although gender aspects of the introduction of hybrid grouper were explored in the interviews for this evaluation, it was difficult for interviewees to differentiate these from changes to fishery practice as a result of switching to hybrids. Interview data reinforced the existing division of labour, with 5 of the hatcheries indicating there was no change in gender roles from crops previously farmed. Of the 9 hatcheries interviewed, 5 employed only men, while 4 employed women on a part-time basis to wean and grade fingerlings. One hatchery was headed by a female director. Three suggested that hatchery work was too physically demanding for women – especially where it involved outdoor work, submersion in water for long periods or the use of machinery such as diesel water pumps.

For grow-out farmers, some sea-cage work (cleaning nets heavy with seaweed) was considered too physically demanding for women. Several owner-operators indicated their wife was either the CEO or the 'accountant' – depending on personal preference and capability for these roles – which is a common practice in household enterprises in Vietnam. Importantly, the introduction of hybrid grouper as a crop to either hatcheries or grow-out farms did not appear to have an immediate negative impact on women's engagement in the sector. There may be a small benefit from income generation through part-time roles in hatcheries, and significant benefits to hatchery and grow-out farm owners through increased household income.

Household wellbeing

Benefits to households from grouper farming were generally directly related to the profits they provided. For hatcheries, the range of benefits were identified by interviewees as follows:

- **They are a good product. Easy to grow-out and sell. Same benefits to my family/business as other fish – profits. (H6, H8)**
- **Support for family, money for children, savings, and next week we are travelling to Singapore and Malaysia for a week for holidays. (H1)**
- **The price in Taiwan for hybrid grouper is low. It's much higher in Vietnam. That's why I came here. To earn money for my family (who are in Taiwan). (H2)**
- **I can produce fingerlings March to November. They are easy fish to sell at different sizes. Cobia are more difficult because you have to sell them all at once. Hybrids are very profitable… if the weather is good. (H5)**
- **The greatest advantages of farming these grouper species for my family are expanding my production base and increasing my employees' incomes. (H7)**

Grow-out farmers also noted benefits relating to increased profits, including:

- **Hybrid profits contributed 80% of the payment for house we recently purchased. (F2)**
- **We have more money to buy things. (F3)**
- **My success with fish and their profitability allowed me to marry because I had money! (F4)**
- **I was able to repay my bank loan recently with the money from hybrids. (F5)**

In general, industry interviewees noted the suitability of hybrid grouper for a range of farm sizes, including smallholders, who could profit from participating in grow-out farming. **'Small-scale farming is suitable for grouper. You can be a really small producer with a small number of sea cages and still benefit. [You] can buy only 100 fingerlings which is enough to make a profit. Better for poorer farmers than shrimp, which has higher investment costs.' (R2)**

The fact that GGTG hybrids were considered a less risky crop than snails or shrimp was also a positive, adding to the diversity of crop choices. There is a risk, however, that the current popularity of hybrids may result in *less* diversity. Grow-out farmers previously grew a mixture of other crops. While many still do, these crops are being displaced by hybrids – at least in the spawning seasons and near the interview areas. **'I had red snapper, cobia, sea bass – but 5 years ago I replaced them with the hybrids.' (F6)**

The potential for the market to reach saturation, resulting in price falls, will need close monitoring by producers if they are to remain profitable. Currently hybrid grouper are sold only as a live product, but a product diversification strategy for alternative processing and marketing methods will probably be necessary to ensure sustainability.

Environmental impacts

None of the hatcheries considered there to be any negative environmental effects from their operations and none reported any conflict arising from discharge from their farms. Their main justification was that they did not use trash fish in their operations. Two indicated that if there was any change, it was a positive one, as they now kept their ponds cleaner to accommodate the needs of the hybrids.

Similarly, grow-out farmers noted no negative environmental impacts as a result of hybrid farming, with a slight improvement in the cleanliness of their cages. A Babylonia snail farmer also indicated that there was less trash fish pollution from hybrid grouper, as they consumed all of the fish rather than leaving the bones for disposal. An objective assessment of environmental impact at farm level was not undertaken by this evaluation.

Environmental outcomes

This section presents findings on environmental impact regarding the second project definition of sustainability: halting the sourcing of giant grouper from the wild and reducing impact on wild populations. It includes a discussion of the potential impact of the introduction of fertile hybrids to their wild habitats (KEQ 2.7).

Data limitations for assessing impact on wild grouper populations

At the ultimate outcome level, the final report claimed that the project had 'generated a major shift away from wild-caught to aquaculture-reared farming in Australia, Vietnam and the Philippines' (Nocillado and Elizur 2021). This claim could not be adequately substantiated by this evaluation. The shift towards cultured giant grouper was already under way in Australia, with no-take regulations enforced and giant grouper production established with limited project input. In the Philippines, as discussed above, the limited production by SEAFDEC likely had little impact on overall numbers of cultured groupers attributable to the project. Hybrid grouper cannot be sourced from the wild, and the impact overall of the increase in aquaculture of hybrid grouper in Vietnam is discussed below.

Data on impacts on wild grouper stock were not collected by the project, as the impact of their activities was considered an implied rather than a measurable outcome. **'Conserving the wild population was not really a big focus. We didn't follow up to see whether this [reduced pressure on wild population] actually occurred. [It was] not in our scope.' (G1)** In 2020, tiger and giant grouper were listed as Vulnerable and Data Deficient respectively on the International Union for Conservation of Nature (IUCN) Red List. In 2019, the IUCN indicated that orange-spotted grouper had been subject to intense fishing pressure. It was listed as Near Threatened prior to stocks being stabilised in part of its range, and it is likely it is still over-exploited in Vietnamese waters (Dennis et al. 2020).

Rimmer and Glamuzina (2019) concluded that, 'The development of full-cycle grouper aquaculture may have had positive impacts in terms of partially replacing the supply of live fish in the live reef food-fish trade and thus contributing positively to biodiversity conservation of groupers. However, there are no conclusive studies on this topic.' In addition, there is still some contention over the definition of 'wild caught'. The Food and Agriculture Organization of the United Nations counts any fish sold from a cage as cultured, even though its original source may have been the sea.

In 2019 the IUCN indicated that 42% of the 55 known aggregations of tiger grouper have either declined in abundance or been eradicated over the past 3 decades (IUCN 2019). With hybrid grouper now dominating production, one interviewee noted that this may actually be intensifying the pressure on the wild tiger grouper population, as there is a growing interest in collecting pure tiger females. **'Quite a lot of tiger grouper aquaculture used to happen, but with the move to hybrids, everyone just wants females now, so less pure tiger are produced.' (G3)** Whatever the true picture, 4 interviewees confirmed that while the Vietnamese Government has a strategy to increase aquaculture and reduce capture fisheries, they don't actively monitor wild grouper populations, so the actual impact is largely unknown.

Interview data showed that while there is still some sourcing of giant and tiger grouper broodstock from the wild in Vietnam (including recently by RIA2), they are rarely a source of fingerlings for hatcheries and grow-out farmers. Of the 9 non-RIA hatcheries, 6 reported they had never sourced fingerlings or stock from the wild. One had in the past but no longer did, and one intended to continue to source broodstock from the wild.

One operator said he was offered wild orange-spotted grouper in 2019 but didn't buy them because **'the survival rate was not good'** and pondered whether **'those who were selling them no longer do because they couldn't find buyers at the time'. (H8)** Another operator had been offered them in 2023, but didn't buy them as there was no market for them. Of the 10 grow-out farmers, only one reported having sourced fingerlings from the sea – humpback and orange-spotted grouper that were sold to the RIA for broodstock in about 2018.

The limited data from interviewees during this evaluation suggest that the combination of an increasing number of available cultured fingerlings, the current profitability of the hybrids and the reduction in the actual availability of grouper species in the wild may make their continued harvest less attractive. Rather than being a 'major shift', the observed lack of interest in sourcing wild stock in the project areas in Vietnam may be attributed to the growth in availability of cultured hybrid fingerlings. This may in turn have led to a reduced impact on wild-caught species – albeit in areas where adequate amounts of hybrid grouper fry are available. Continued efforts by the RIAs to close the breeding cycle with their F1 giant grouper, and the production of cultured tiger grouper to meet broodstock requirements for hybrids, would be a significant contribution to the sustainability of the grouper industry.

Other threats to the wild population from hybrid grouper fertility

Based on papers published from research in Malaysia, it is known that some GGTG hybrids can sexually mature. In 2016 a group at the Borneo Marine Research Institute, University of Malaysia Sabah reported it had successfully spawned GGTG broodstock (F1 generation) naturally in captivity for the first time, yielding high-quality eggs and larvae (F2 generation hybrids) (Ching et al. 2018). Other studies in Malaysia have reported the backcrossing of GGTG hybrid grouper to giant grouper in captivity (Tan 2021, Sariat et al. 2023).

According to interviewees, fertile hybrids have not been observed by RIA staff. However, comments made to RIA1 by Vietnamese farmers suggest that the GGTG hybrids farmed in Vietnam can sexually mature. Further information about the percentage, age/size and sex of the fertile individuals observed by the farmers was not ascertained. This is important information required to assess the potential risks from fertile hybrids, such as escapees breeding with wild grouper and/or breeding with each other to generate a self-sustaining population. As the market preference is for smaller hybrids, most hybrids may be harvested prior to sexual maturation, but this needs to be confirmed. It is beyond the scope of this study to provide a detailed risk analysis. As noted in the end-of-project review (O'Connor et al. unpublished), maturation in farmed hybrids requires further research to better assess the risks.

Contribution to a strengthened marine aquaculture industry in Southeast Asia

The project documentation did not elaborate on the extent of expectation for a 'strengthened' aquaculture industry in Southeast Asia. Beyond making available the research papers and the incorporation of aspects of the research into SEAFDEC's grouper and marine finfish training programs, there was no specific strategy for contributing to this broader goal beyond the partner countries. The contributions made by individual researchers from the region in applying or adapting project research methods and techniques to other species has been discussed above. While these may have had enduring impact on other marine finfish culture in those countries, this evaluation did not quantify their nature or extent.

3. Lessons for ACIAR from project design and implementation

KEQ 3.1 What were the most effective pathways and mechanisms of change?

KEQ 3.2 What were the factors that hindered effective achievement of outcomes?

Effective pathways of change

In terms of pathways of change, the project theory of change employed a typical research-for-development pathway. This involved the application of research findings to demonstration activities, broader knowledge-sharing of results among multiple audiences, then either adaptation or adoption, leading to sustainable outcomes. This was envisaged to take place through 2 distinct pathways:

- sharing knowledge with the domestic and broader global research community through publication of research papers and presentations, and through SEAFDEC's established training program regionally
- sharing knowledge with the partner countries and end users through SEAFDEC's domestic training program (Philippines industry) and the RIA's extension activities (Vietnam), communicating project-related improvements to grouper production directly to industry participants, resulting in broad adoption.

The first pathway was realised somewhat effectively at a regional level through the publication of high-quality research papers that were highly cited and led to the application of project research findings and techniques to other finfish in both partner countries and internationally. SEAFDEC's training program is also offered regionally, continuing the reach of project-related research that has been incorporated into training materials on finfish generally.

The second pathway has been less well realised in the Philippines, where there was limited giant or hybrid grouper product to extend to industry by project end. This was exacerbated by most of the key staff from the original team leaving at project end, which meant further work on closing the giant grouper life cycle ended, and opportunities to champion the crop were limited. Continuing sales of grouper fingerlings produced through SEAFDEC's research programs appear to constitute the only realisation of this pathway to broader adoption.

In Vietnam, the effectiveness of the second pathway was more apparent. Once the RIA was reliably producing fertilised hybrid grouper eggs, it was well placed to contribute to the initiation of a hybrid grouper industry though its extension function. This pathway was realised most effectively within the RIA's local network of hatchery and grow-out operators. Targeted, personalised information informally delivered on demand was effective in transferring the necessary information to hatcheries buying fertilised eggs and producing fingerlings – particularly around production of rotifers and copepods for early feeding. Grow-out farmers did not require much encouragement to 'adopt' the crop, as GGTG hybrids were already farmed in the country, which drove the project's switch to this more in-demand crop. In addition, due to end-user familiarity with rearing other grouper species, only limited knowledge-sharing was required to achieve reasonable survival rates and maintain profitability.

While this informal pathway for knowledge transfer may initially have been sufficient for extension of basic skills and knowledge to network members, as more sophisticated technologies are developed to assist in achievement of higher survival rates (for example, more efficient and sustainable feeding practices and better disease management), more formal, targeted assistance and resourcing for broader outreach materials and methods may be necessary if profitability is to be maintained. This may include online availability of materials and instruction.

In terms of technology transfer for spawning of broodstock, COVID-19-related delays mean that this is in its infancy among the RIA's networks. Only a few local Vietnamese producers with broodstock are attempting to produce fertilised hybrid grouper eggs with RIA assistance. Again, these small numbers will enhance the capacity of RIA staff to assist directly and transfer skills and knowledge. In terms of improving sustainability of the broader industry through transferring knowledge to industry operators outside its personal networks, RIA's capacity appears to be limited by both the lack of a regulatory function governing production quality and insufficient resourcing. This applies to the RIA's ability to reach private commercial hatchery operations of both international and local Vietnamese origin, where actors do not appear to value RIA's knowledge and expertise on sustainable broodstock management techniques. Relying on RIA's existing extension resources to influence grouper industry sustainability more broadly may have diluted this pathway's effectiveness. Future projects may need to address this by involving private industry partners directly or properly resourcing the RIA to build its capacity and profile as an influential technical specialist. This should include resourcing to achieve broader industry outreach.

The final part of the domestic adoption pathway entailed an increase in locally produced product leading to positive environmental and economic impacts. This was more apparent in Vietnam, where, regardless of industry influence, the increase in production of hybrid grouper fingerlings from both the RIA and other local sources appears to have led to a reduction in importation reliance. It is plausible that the increased availability of cultured fingerlings has also contributed to a decrease in demand for wild-caught fingerlings of currently less profitable grouper crops – albeit at localised levels. As both of these were the measures of 'sustainability' articulated in the project theory of change, this increased production of a cultured grouper variety locally has therefore contributed modestly to improving overall industry sustainability. The lack of accurate data on both importation and status of wild populations hampers proper assessment of the actual extent of this contribution. In Vietnam, it has clearly led to improved aquaculture household income, as unmet local market demand for GGTG hybrids in tourism locales keeps prices high, making them the marine species of choice for aquaculture households with access to these value chains.

Underlying design assumptions

Several underlying assumptions that underpinned the logic of the program were more or less examined during the design process, but perhaps remained as unknowns when implementation commenced. These must be viewed in the context of the primary focus on giant grouper, a lesser expectation about the production of hybrids, and an actively engaged Australian industry partner. In general, all but one assumption was at least partially borne out.

The giant grouper life cycle can be closed in a practical manner that can be successfully replicated in partner countries

This assumption has only partially been met. Australia continues to use wild broodstock and has a permit to source them to maintain genetic diversity. There are plans to start crossing the F1 giant grouper in the near future, eventually closing their breeding cycle.

Both Vietnam and the Philippines can spawn giant grouper. In Vietnam, giant grouper fingerlings can be produced reliably on demand rather than imported or sourced from the wild, and an F1 generation exists. However, the shift in focus to hybrids and the uncertainty around the intention of the research institutes to pursue a closed grouper life cycle combine to raise the question of whether it is still a desirable goal, rather than whether it could be achieved. Clearly, the project has provided significant capacity in Vietnam and the Philippines to close the giant grouper life cycle, including maintenance of genetic diversity, if and when this is beneficial to the industry.

Demand for/interest in giant grouper as a profitable high-value crop is equally high in Vietnam and the Philippines

This assumption did not hold true in either the Philippines or Vietnam for giant grouper. However, demand for GGTG grouper in Vietnam surpassed all expectation and remains high – perhaps to the detriment of potential further gains in giant grouper productivity.

Feed constraints can be overcome by project end to ensure profitability, sustainability and support expansion

This assumption partially held true in Vietnam. One of the constraints to fingerling production is their low survival rate. By project end, attention to rotifer and copepod development and feeding protocols for hybrid grouper likely contributed to an increase in larval survival rates. While grow-out farmers are mostly dependent on trash fish, which compromises the sustainability of an expanding industry, trash fish is still the preferred feed source compared to the existing processed feeds available. Few farmers indicated difficulty in obtaining sufficient trash fish, and hybrids remain one of the most profitable marine species to farm under the current feed conditions. The current ACIAR investment in addressing this productivity barrier through engaging with aquafeed companies in Vietnam (FIS/2021/121) is an indicator that feed constraints remain a bottleneck that, when effectively overcome, can improve industry sustainability.

Project-related fingerlings will be both profitable to produce (by hatchery farms) and cheaper to purchase (by grow-out farmers). This will ensure production in sufficient volume to reduce reliance on wild-caught and potentially cheaper and more environmentally risky imported stock

This assumption partially held true for Vietnam. Price data for hybrid grouper eggs and fingerlings sourced locally or imported was difficult to compare due to a mixture of seasonal price fluctuations and the point of purchase obscuring their origin (whether middlemen buy stock from project-related RIA sources or local Taiwanese sources or import them). It is not therefore clear that project-related fingerlings were in fact cheaper, but they appear to have been at least competitive. In any case, they most certainly contributed to reducing reliance on imported stock during the Vietnamese spawning season from an estimated 50% in 2018 to an estimated 20% in 2023. The inability to close the seasonal production gap domestically means that importation and its associated biosecurity risks will continue.

The local and export markets for grouper in the partner countries and the Southeast Asian region are sufficiently stable and profitable to drive widespread adoption by farmers.

This assumption partially held true in Vietnam. By the time of this evaluation, adoption of hybrid groupers in Vietnam was apparent beyond the initial surveyed provinces most closely adjacent to the RIA. This appeared to be driven by the continuing high prices and demand generated by the local tourist industry. There was little evidence of an international market being serviced by Vietnamese grouper, and with prices of hybrid grouper much lower in Hong Kong, it is questionable that Vietnamese grouper could compete and remain profitable to growers.

Factors that led to or hindered project successes

'It is a challenge with ACIAR-related projects to balance the core research and implementation potential … especially working with academics that are incentivised towards high-end research but you're working in a developmental space, so there's very much 2 different areas here that are under evaluation. This project had some really great high-end research done and separating that from the [gap between] implementation, it's some really amazing outcomes.' (A3)

The factors that either led to or hindered the project achieving its intended outcomes are drawn from the analysis of all evaluation data. While some factors are more specific to this project's particular historical circumstances and subject matter, many are applicable to research-for-development projects generally, and many are already well known. However, the complexities of working across multiple countries in varying development settings will continue to make them worth repeating when reflecting on lessons for future designs. Where relevant, these are specified for the different partner-country settings; however, they are mostly presented around the broader themes evident in the evaluation findings.

Success factors

Highly regarded project team

A highly respected and competent research team managed the project. The female project leader in particular was highly regarded in the field of marine fish reproduction, and the depth of their experience and approach helped overcome any initial gender bias that may have acted as a barrier to knowledge-sharing among partner countries. Trust was also developed by mutual acknowledgement of the diverse skills of the partner-country teams, and a willingness by the Australian team to develop culturally appropriate approaches when responding to setbacks in experiments. This helped foster a more collegial and cohesive learning environment that encouraged innovation.

Supportive learning environment

The availability of high-quality and committed staff and students both in partner countries and in Australia to participate in and benefit from project training ensured maximum effectiveness of the educational opportunities offered. The approach taken to capacity development, which instilled scientific rigour in experiments, led to a legacy of greater attention to following protocols and conducting experiments in a more controlled way. Importantly, it left a cohort of researchers in Vietnam with more refined broodstock reproduction expertise. The exposure to a well-managed international research program also provided younger participants with a greater understanding of the realities and complexities of 'doing research' where industry application is the expected outcome.

In the Philippines especially, the culture of rewarding innovation and learning from setbacks instilled an ongoing pride in small project successes. This assisted in fully engaging individuals from partner organisations who actively sought to adapt and overcome the many challenges the experiments presented. It instilled greater curiosity and a way of moving forward among participants, many of whom went on to explore and adapt the research in their ongoing roles.

Focus on higher-level science and documentation

The deliberate incorporation of cutting-edge science had the effect of attracting high-calibre scientists to work on the project in the first place, enabling them to meet their career scientific publication requirements while working on an ACIAR project. The project's important contributions to advancing understanding on grouper reproduction helped generate a level of interest among the aquaculture research community commensurate with its broader reach objectives. Domestically, it responded to the real desire of partner countries to make progress on effective use of hormones, genetic analysis, molecular work and the diagnostics of diseases. Documentation of project-enhanced protocols and publications provided a good basis for the organisational retention of project-related scientific knowledge and their steps for practical application – much of which is applicable to marine species beyond giant grouper.

High-calibre research papers

High-calibre papers that have had good impact were produced with a genuine engagement and contribution from the partner-country participants, some of whom contributed to the writing as first authors. During project implementation, the growing regional interest in grouper aquaculture among regional producers made them more receptive to the information disseminated by the project. The development and publication of new, high-quality research findings, and growing regional interest, combined to increase the likelihood of the project achieving its broader influence outcomes – especially among the initial and next-user scientific community.

Flexible project design and team

Once the popularity and potential of the GGTG grouper were noticed by key RIA staff mid-project, they expressed a desire to respond to farmer demand for a more fit-for-purpose crop rather than persist with a crop perceived to hold greater production challenges and less economic promise. The project was sufficiently flexible and adaptive to respond to changed priorities in Vietnam, elevating what was initially envisaged as a minor aspect of the project research to the major focus. The project team pivoted application of aspects of their research to further this outcome. The fact that there were giant grouper males available in better condition, and increased capacity to handle them and manipulate their spawning to reliably produce milt, placed the Vietnamese research institutions in a good position to participate in contributing to hybrid grouper industry development.

Although the shift to hybrid production reduced focus on closing the giant grouper breeding cycle, insisting on maintaining this focus would likely not have been sustainable in the changed context. The fact that the project was able to respond may also have lasting impact in Vietnam, where one of the project team members is now head of the government's marine research budget and is involved in decision-making around more farmer-focused research priorities.

Factors that hindered achievement of broader success

COVID-19 disruptions

The effect of COVID-19 disruptions on ongoing research and development following project closure in 2019 is not clear. Although this was raised in only a small number of interviews, the hiatus caused by limited staff access to research facilities, and the lull in the industry in Vietnam in particular, is likely to have disrupted any industry outreach at least temporarily, and may have resulted in a loss of momentum in technology transfer.

Broad design issues

This project was designed at a time when theories of change were not expected to be made explicit in ACIAR proposal formats. While the articulation of expected longer-term social impacts was required, the steps and particular mechanisms through which they would be achieved, and by whom, were not described in detail or resourced. Importantly, proposals were also not required to specify how achievement of impacts would ultimately be measured, or what would constitute success in their achievement.

The somewhat simplistic manner in which ACIAR proposal formats and expected input-to-outcome dialogues were formulated led to a tendency towards overly optimistic outcome aspirations being formulated. Key informants described the significant expected industry and regional-level impacts included in this project's proposal as being the result of optimistically assuming breeding objectives would be achieved, with subsequent industry uptake and growth following on with limited project input. This inflation of expected impacts was considered common practice at that time in order to secure funding. In this case a set of specific science objectives and general capacity development at a hatchery level were expected to lead to economic impacts at a countrywide and regional scale. In addition, the proposal and project reporting requirements did not include an evaluation framework where industry engagement and impact were monitored at each outcome level. Assessment of ultimate outcome achievement was therefore largely subjective, where *any* level of contribution was sufficient to constitute 'success'.

Specific design issues

Incomplete analysis of the needs of the whole grouper production chain in which to locate the limits of project input and develop more realistic, measurable outcomes

The goal of establishing a sustainable grouper industry required an articulation of all the needs of the production chain required to make it a 'sustainable' industry – beyond reductions in imports and wild capture. These needs include disease management and biosecurity across the whole production chain, sustainable grow-out feed, diversified product marketing (when live fish market capacity is reached) and the development of industry standards to maintain production quality. The bulk of project research focused on addressing spawning and early larval survival bottlenecks. While this is reasonable and commits the project to a manageable suite of interventions, the project design may have more appropriately articulated outcomes at the hatchery level only, rather than expecting industry-level impact with regional dimensions. These more encompassing aspirations may have been more appropriately taken up by a broader subsequent project, following proof of local breeding capacity.

Analysis of differing partner capacity and interest to participate may have led to separate, more targeted outcome objectives for each country

Expected contribution to industry articulated in the design did not reflect the varying capacity of the 3 partner countries who were at different stages of grouper industry development. Australia had already achieved spawning independent of the project and became more of a provider of knowledge than a recipient. The Philippines had the research capacity but not enough mature broodstock to participate as effectively as Vietnam. Vietnam had sufficient broodstock but needed to improve its broodstock management skills before progress could be made. Partner countries also had different interests, with Vietnam more aligned to production outcomes, while the choice of SEAFDEC as the partner organisation for the Philippines was more aligned to research interests and training. It was not clear what industry outcomes expectations were expected to look like in each country beyond 'initiation', and therefore how to measure success in each.

Articulation and resourcing of domestic extension programs in Vietnam in particular was missing from the design

The 'missing middle' in the project design (intermediate outcomes) largely related to extension work in partner countries. While the choice of SEAFDEC as a partner was largely appropriate for broader, regional and scientific community reach and influence, the way in which information would be packaged and shared for partner-country industry uptake was less well articulated and resourced.

In Vietnam, this fell to the RIA, which did not appear to be resourced to do this beyond low-level and personal interactions among immediate network members. The small scale and fragmented nature of the industry production chain in Vietnam also made the targeting of specific pieces of information more challenging and resource intensive, including specific strategies and products for broodstock managers, live-feed producers, hatcheries to different stages of fingerling production, pond grow-out farmers and sea-cage grow-out farmers.

If industry-wide impact of any significance beyond the RIA networks was expected, this aspect in particular could have been better designed. This might have included resourcing of more formal training, developing a strategy to improve the RIA's industry profile and influence, and the inclusion of specialist extension expertise. These inclusions could more appropriately have been treated as a separate follow-on project once the appropriate packages of technologies leading to production enhancements were developed.

Ineffective involvement of commercial partners in project development and delivery

In Australia, the choice of 'industry' partners was initially limited by the non-existence of commercial operators with an interest in giant groupers. When the government defunded the initial partner, which then became commercialised, the partnership ended and the void was only informally filled. In the Philippines, the informal relationship with a commercial operator may have resulted in some technology transfer, but gains in giant grouper production were not evident. In Vietnam, the hybrid grouper sector appears to have taken off independently and in parallel to project government research centre partners, using skills imported from outside Vietnam. The evaluation noted an entrenched lack of willingness to share information across the sector in Vietnam, combined with a reluctance to change. The potential to optimise the sustainability aspects and enhanced protocols promoting good husbandry and broodstock management techniques may have been hindered by not having more commercial companies involved from the outset to try to bridge this information gap. Whether this would be best addressed through tightened government regulation or improved outreach methods to champion good practice warrants further analysis.

Challenges in achieving an appropriate balance between high-level science and industry implementation in developing-country settings

While the decision to pursue high-level science was a response to partner-country research organisation preference and had some positive outcomes, some of the science was not implementable within a five-year time frame, and required further work to optimise its application. Some of that work was not completed by project end, and the surrogacy work in particular was widely considered to have been too technically challenging, especially as the focus shifted to easier-to-breed hybrids. In resource-strapped production environments, low-tech solutions could have been further explored to complement the more experimental research undertaken. For example, in Vietnam, manipulation of broodstock spawning through temperature regulation may have been able to extend the spawning cycle and close the seasonal gap that still necessitates importation of hybrid grouper – a key requirement to achieve the project's definition of sustainability.

The switch of focus to the hybrid grouper compromised advancements in giant grouper culture

The switch to GGTG hybrids as the main focus of the project was a double-edged sword. On one hand, it allowed for the immediate application of ready-made advances in male giant grouper broodstock and early larval rearing and responded to farmer demand, resulting in real economic gains. On the other, the perception in Vietnam that GGTG hybrids' performance is already adequate and not a high priority for improvement has compromised further advances in giant grouper culture. Interest in developing medium- to longer-term genetic management plans is not evident, while low numbers of giant grouper wild males and potentially tiger grouper females used as parents could create a bottleneck in the future. Evidence suggests that wild capture is continuing to some extent, but is combined with use of captive F1 sourced from local farms and importation of cultured grouper broodstock from Taiwan and Indonesia. Ideally, broodstock genotyping would be used to manage this from a species identification and genetic diversity management perspective. This expertise is available within the research institutes. However, the intention and capacity of the wider commercial sector, where the bulk of the breeding takes place, is less well known. Providing high-quality cultured giant and tiger grouper broodstock could be a significant contribution by the research institutes to the sustainability of the industry, rather than merely contributing hybrid fingerlings.

Partnership issues

The withdrawal of the Australia-based partner hampered progress in many ways, including lack of access to mature giant grouper broodstock for the Australia-based experiments, and more particularly the loss of larval rearing research experience – a major bottleneck to improving survival rates. Overall, it was considered by many to be a blow to the overall scientific expertise of the team.

At the end of the project, many of the Vietnamese partner staff remained in their research organisations and were in a position to continue to use and improve on organisational knowledge and practice. In the Philippines, many of the team at SEAFDEC left when the funding ended. Some went overseas to study, while others went on to new jobs in the Philippines or other countries, resulting in a lack of organisational momentum within SEAFDEC to continue with the giant grouper breeding program in the Philippines. While it is acknowledged that some of these staff may return and continue to make significant contributions, at present, organisational memory of the project and its ongoing achievements were difficult to identify from existing SEAFDEC staff, highlighting the limitations of working with partners who contract in specific research teams.

Conclusion

The project targeted a largely promising species for industry development within the context of substantial partner-country interest in high-level scientific solutions to bottlenecks in the giant grouper breeding cycle. Significant advances were made in breeding technologies and larval culture that have application beyond giant grouper. Researcher capacity was developed in partner organisations, leaving a legacy of improved fundamental knowledge and scientific rigour in ongoing research. These were important project contributions to industry establishment.

The project aimed to initiate a grouper industry by taking a research-to-demonstration approach: sharing knowledge through research papers, training programs and extension activities for adoption and adaptation. The project had 2 main pathways to achieve this:

- sharing knowledge with the broader finfish research community in partner countries and regionally through publications and SEAFDEC's training programs
- sharing knowledge directly through extension mechanisms to grouper industry participants in partner countries.

The first pathway was largely successful in terms of producing highly cited research publications and knowledge dissemination, especially in Southeast Asia, and by incorporating related research findings into SEAFDEC's training programs for regional and international sharing. This pathway also enabled the adaptation of the research to other marine fish and aquatic species.

The second pathway had mixed success. Success in the Philippines was hampered by the lack of early progress in producing giant or hybrid grouper in sufficient numbers to extend supply beyond research needs, and the lack of a formal industry partner. Greater success was achieved in Vietnam, with the serendipitous interest in and pivot to hybrid grouper as the species of interest. RIA partners extended the crop to local hatchery and grow-out farmers through a combination of limited formal training and more informal, targeted and personalised information transfer to operators within their networks, leading to increased uptake of their hybrid fertilised eggs and fingerlings. Due to COVID-19 related interruptions, breeding technology transfer is only just commencing 3 years after project end.

While the project enabled government institution participation in Vietnam, their overall contribution to the industry may have been dwarfed by the parallel production of fertilised eggs by domestic private producers who used their own breeding technologies. The RIA's extension program was less successful in reaching important producers outside its networks. These actors cannot or do not appear to access RIA's project-enhanced knowledge and expertise on sustainable broodstock management techniques. The failure to engage them may result in reduced opportunities to influence improvements to seed quality and the overall sustainability of the industry.

The increased domestic production from both research-partner and private-industry sources has resulted in a reduced reliance on imported hybrid grouper stock since the project commenced – a key pillar of the project's definition of sustainability. It may also have contributed to a reduction in pressure on wild grouper stocks, as more cultured fingerlings are available domestically, although this was difficult to verify. For those that farm them, the hybrids are currently a very profitable crop and have become the crop of choice in both sea cages and earthen pond farms.

Despite the success of the hybrid groupers in Vietnam (which may have occurred within the private sector independently of project intervention), there are lessons for ACIAR in relation to design and partnership choices. The project's ultimate outcomes and goal were overly ambitious relative to its science-based inputs and resourcing, and lacked clear articulation of measures of industry impact.

Although attempting to capitalise on the relative strengths of each partner country, their respective capacity and interests may not have been reflected in the shared outcome of industry initiation. The choice of partner in the Philippines (a regional research organisation) suited the regional knowledge-sharing aspirations of the project, but less so the identification of local industry priorities. By project end, these priorities had shifted to lower-value fish more suited to mass consumption. In Vietnam, the research partners had good influence within their limited industry networks, but were not resourced by the project to have broader industry reach and collaboration. This may ultimately have potential implications for industry sustainability, where disease management, species purity and genetic diversity, and quality of production could be compromised.

A more thorough design process that allowed country partners to articulate their anticipated theory of how change would occur could have helped to better define partner capacity to influence industry, outcome expectations and agreed measures of industry impact success. This in turn would have either tempered expected commercial outcomes to be more aligned with project inputs and country partner capacity and interest, or ensured additional resources were provided to address all value-chain bottlenecks and assist in achieving broader industry sustainability.

KEQs	Focus	Topic areas and themes	Methods/information sources	Outputs
1. How appropriate was the design of the project to the context? *Evaluation criteria: relevance design/strategy*				
1.1 What was the project's theory of change, and how appropriate was it to achieving the expected outcomes?	The initial theory of change (ToC) (implicit) at the **whole-of-program level**, and how it changed over time to reflect the changing context	• What was the implicit ToC in the project design document? • How was it adapted to the changing context? • Was it actively used to guide project implementation and monitoring? • Was it sufficient to guide achievement of research to development outcome?	• Project document review to map a draft implicit ToC • Key informant interviews (ACIAR managers, project team) to discuss and verify • Verification of implicit ToC with key stakeholders • Analysis of project reporting against ToC • Synthesis of data from all KEQs	• Agreed ToC diagram and narrative • Utilisation of the ToC to guide the assessment of intended outcomes and pathways from research to outcomes
1.2 How well did this project align with the priorities and capacity of the Vietnamese and Philippine governments?	At the **whole-of-program level**, appropriateness of the focus on the giant grouper industry in partner countries, the type of research selected to address apparent bottlenecks, and the capacity and needs of partner organisations)	• Was the research focus on giant grouper appropriate to the marine finfish industry priorities in partner countries? • Was the science appropriate to the production constraints experienced by the industry? • Was the science appropriate to the capacity of the partners to utilise/replicate it?	• Project document review to document pre-project assessment of partner-country priorities • Key informant interviews (ACIAR managers, project team, RIA1, RIA3, SEAFDEC/AQD) • Synthesis of data from KEQ 2.1–2.4 relating to science outcomes	• Analysis of project alignment to context for findings report
1.3 How well did this project interact with or complement other ACIAR projects or those of other development partners in the partner countries?	At the **whole-of-program level**, the historical progression of previous ACIAR grouper research to the current project and level of fit with ongoing/planned activities of development partners at the design stage in particular	• Did this project add value by progressing previous ACIAR grouper projects? • Did this project add value by building on the resources and ongoing programs of partner countries? • Was there effective and ongoing collaboration with new/emerging programs?	• Project document review to document the ACIAR value add from previous projects, and leverage of any relevant ongoing programs • Key informant interviews (ACIAR managers, project team, RIA1, RIA3, SEAFDEC/AQD)	• Analysis of the project's value add to ACIAR and partner countries' grouper programs

Sub-question	Focus	Topic areas and themes	Methods/information sources	Outputs
2. What outcomes (intended and unintended) has the project achieved or contributed to? *Evaluation criteria: effectiveness, gender equity, sustainability*				
Science and capacity				
2.1 What were the scientific outputs? Were they of sufficient quality and quantity to achieve project outcomes?	At the **output** level, the extent to which the project contributed to developing effective methods for giant grouper seed production, broodstock management and larval rearing, including hybrids	• What were the major scientific findings/ achievements in giant grouper seed production, broodstock management and larval rearing? • What were the major achievements in hybridisation? • What scientific publications were produced (by end of project/post-project)?	• Project document review – especially final report and evaluation • Key informant interviews (ACIAR managers; project team, RIA1, RIA3, SEAFDEC/AQD) • Literature search, including websites and grey literature, conferences, etc. • Search and review of post-project outputs	• Summary of the major scientific achievements • List of publications/ other activities to disseminate research findings
2.2 To what extent were the partner institutions and relevant individuals able to utilise project-related scientific methods and outputs?	At the **output** to **intermediate outcome** level, appropriateness of the science to the need (to close the giant grouper life cycle/meet industry demand), capacity of partners to replicate/ utilise it and how it was communicated to next/ end users	• To what extent did research partners participate in developing and publishing the scientific output? • Were the research partners able to reproduce/apply the methods in their own facilities (effective translation of scientific methods)? • Was an information package developed and implemented effectively (development of appropriate science outputs that contribute to application including training manuals, handbooks, technologies, extension materials)? • Was there an extension program and materials developed to assist adoption by nurseries and grow-out farmers?	• Project document review (including dissemination material and manuals; training and uptake records etc.) • Key informant interviews (ACIAR managers, project team, RIA1, RIA3, SEAFDEC/AQD) • Synthesis of data from KEQ 2.5–2.6 relating to uptake • Search and review of post-project outputs • Review information and data sharing methods and access • Review ongoing contact and support by overseas project scientists	• Analysis of the appropriateness of the science to the capacity of the partners to utilise it • Summary of extension/ dissemination materials and their appropriateness for knowledge/skills transfer • Summary of uptake post-project and how the methods have been applied • Identify bottlenecks to uptake and actions taken to mitigate them

Sub-question	Focus	Topic areas and themes	Methods/information sources	Outputs
2.3 What individual/ organisational capacity building occurred in partner research organisations to facilitate project outcomes, and were opportunities for male and female research staff to participate equitable?	At the **output** to **intermediate outcome** level, whether the partner institutions were appropriately equipped to apply the captive-breeding protocols to their breeding programs, whether opportunities to participate in capacity development/career opportunities were equitable, and whether career trajectories were enhanced	• Has the project improved partner research organisation's capacity to effectively support the initiation of a sustainable grouper industry in partner countries (technical capability, equipment, enabling environment)? • Do the partner research agencies have gender equity policies in place, and to what extent did the project influence the equitable selection of research team participants/selection of learning opportunity recipients? • Did individual research team members gain further educational opportunities as a result of participating in project-related research? • Did individual research team members improve their careers as a result of participating in project-related research?	• Project document review • Key informant interviews (project team, RIA1, RIA3, SEAFDEC/AQD) • Analysis of data collected under KEQ 2.1 and 2.2 • Assess related post-project activities and the individuals involved • Details of infrastructure and equipment and ongoing access • Assess number and gender of individuals actively engaged in developing the grouper industry post-project	• Analysis of the capacity-building component of the project • Collated study opportunities and career movement data, including summary of project team achievements and career development post-project, and summary of new developments post project
2.4 How influential has the research produced been in the relevant field, including for other large finfish/in other countries?	At the **intermediate** to **ultimate outcome** levels, the means by which new knowledge was made available (brokered) to a wider audience, evidence of access to and utilisation of project-related research and what influence it had within the broader research community	• Were the relevant publications research outputs sufficiently disseminated for wider utilisation (peer-reviewed journals, local language publications, training extended to others)? • Has the project research been widely accessed? • Has the project research been further developed, applied to other grouper species, or other finfish in partner countries? • Has the project research been further developed, applied to other grouper species, or applied to other finfish in non-partner countries?	• Project document review • Key informant interviews (ACIAR managers, project team, RIA1, RIA3, SEAFDEC/AQD, international researchers) • Citation analysis and impact assessment, including what has been cited and why • Summarise post-project outputs, dissemination materials, project communication methods and outcomes	• Citation analysis and impact of publications • Annex materials on publications and educational opportunities • Analysis of evidence of broader application to other grouper/large finfish/other species in partner and other countries • Summary of feedback by the wider research community

Sub-question	Focus	Topic areas and themes	Methods/information sources	Outputs
Sustainability, welfare and inclusion				
2.5 How has the project contributed to its stated longer-term outcomes, and did the underlying assumptions hold true?	At the **ultimate outcome** level, whether the grouper industry in the partner countries has been initiated, and particularly in Vietnam, the extent to which it is being sustained since project end, and whether underlying project assumptions about the industry's potential were reasonable and held true	• Has the availability of good quality fertilised eggs of preferred grouper species been sufficient to meet current demand? • Has the availability of good quality fingerlings become reliable, in sufficient quantity to meet demand, and more affordable? • What is the overall trend in grouper aquaculture popularity and profitability, and is there evidence of expansion to aquaculture industry participants (including the private sector)? • Did the assumptions in the initial project design hold true, and how did this influence progress?	• Project document review • Key informant interviews (ACIAR managers, project team, RIA1, RIA3, SEAFDEC/AQD, fisheries departments in Vietnam) • Data collection on production and distribution trends for project-related seedlings • Semi-structured interviews with nursery operators in Vietnam	• Analysis of the impact on the grouper industry in Vietnam in particular
2.6 What has been the impact of improved grouper aquaculture on household income and other gendered measures of welfare? Have they been enduring?	At the **intermediate and ultimate outcome** levels for Vietnam only, whether the availability of project-related grouper species have enabled nursery and grow-out farms to maintain or increase grouper production, any gendered barriers to participation or capacity improvement opportunities At the **broader impact level**, whether profitability and ease of production is encouraging expansion, contribution to household nutrition, other benefits	• What changes have occurred to production methods as a result of adopting project-related grouper species? • Did participating nursery/grow-out farmers receive new knowledge or information about the new/improved crops, and was it sufficient to support successful/continued adoption? • Are project-related grouper species a profitable crop for nurseries/grow-out farmers? • What are the perceived advantages of grouper as a crop for male and female farmers? • What are the perceived disadvantages of grouper as a crop for male or female farmers? • What are the perceived constraints to continuation/expansion of grouper production for male and female farmers?	• Document review, especially socioeconomic study (Dennis et al. 2020) and photovoice study (Pierce unpublished) • Semi-structured qualitative interviews with nursery operators and grow-out farmers in Vietnam • Analysis of data collected under KEQ 2.5	• Analysis of trends in grouper production from end of project (2019 – pre-COVID-19) to now (post-COVID-19) and the perceived benefits and future trends for demand for the species

Sub-question	Focus	Topic areas and themes	Methods/information sources	Outputs
2.7 What environmental outcomes have occurred as a result of project activities?	At the **ultimate outcome/ broader impact** levels, whether there have been any positive or negative environmental impacts	• Has there been a decrease in reliance on wild-caught grouper? • Has the change to grouper as a crop negatively impacted the environment (increase in trash fish use, other environmental impacts from changed/ increased/expanded aquaculture)? • Has the change to grouper as a crop positively impacted the environment (less pressure on wild populations/ increased protection of wild populations in Vietnam in particular)?	• Document review, especially socioeconomic study (Dennis et al. 2020) and photovoice study (Pierce unpublished) • Key informant interviews with project team, RIA1, RIA3 staff, government fishery departments • Semi-structured qualitative interviews with nursery operators and grow-out farmers in Vietnam	• Analysis of environmental outcomes attributed to the changes in grouper species production
3. What can ACIAR learn from the design and implementation of this research-for-development project? *Evaluation criteria: Learning*				
3.1 What were the most effective pathways and mechanisms of change?	At the **whole-of-program** level, whether the activity to impact trajectory envisaged was effective, or other more effective pathways emerged/ achieved different outcomes in different partner countries	• What effective pathways to achievement were evident in each partner-country context • Did the project effectively adapt its intended change pathways to the changed context?	• Collation and analysis of data from KEQ 1 and KEQ 2 • Analysis of possible pathways	• Revised ToC documenting actual pathways that led to ultimate outcomes and how they may have differed in the partner countries
3.2 What were the factors that hindered effective achievement of outcomes?	At the **whole-of-program** level, whether any of the initial design features (context, ToC) or implementation features (partnership relations/collaborations/ documentation/ monitoring and evaluation etc.) hindered outcome achievement	• How could the project design have been more effective? • How could project implementation have been made more effective? • What areas of grouper production have not yet been adequately addressed by the project?	• Collation and analysis of data from KEQ 1 and KEQ 2 • Analysis of possible pathways	• Collated factors that supported or hindered achievement of outcomes

Appendix 2: Publications produced by each project

FIS/2012/101

Scientific journals	Lead author	
	Gender	Nationality
Anderson K, Knuckey R, Canepa M and Elizur A (2018a) 'A transcriptomic investigation of appetite regulation and digestive processes in giant grouper, *Epinephelus lanceolatus*, during early larval development', *Journal of Fish Biology* 93(4):694–710.	Female	Australian
Anderson K, Kuo CY, Lu MW and Elizur A (2018b) 'A transcriptomic investigation of digestive processes in orange-spotted grouper, *Epinephelus coioides*, before, during, and after metamorphic development', *Gene* 661:95–108.	Female	Australian
Bright D, Reynolds A, Nguyen NH, Knuckey R, Knibb W and Elizur A (2016) 'A study into parental assignment of the communal spawning protogynous hermaphrodite, giant grouper (*Epinephelus lanceolatus*)', *Aquaculture* 459:19–25.	Male	Australian
Carnevali O, Maradonna F, Sagrati A, Candelma M, Lombardo F, Pignalosa P, Bonfanti E, Nocillado J, Palma P, Gioacchini G and Elizur A (2019) 'Insights on the seasonal variations of reproductive features in the Eastern Atlantic Bluefin Tuna', *General and Comparative Endocrinology* 282:113216.	Female	Italian
Chieu HD, Turner L, Smith MK, Wang T, Nocillado J, Palma P, Suwansa-ard S, Elizur A and Cummins SF (2019) 'Aquaculture breeding enhancement: maturation and spawning in sea cucumbers using a recombinant relaxin-like gonad-stimulating peptide', *Frontiers in Genetics* 10:77.	Male	Vietnamese
Dennis LP, Ashford G, Thai TQ, Vu VI, Ninh NH and Elizur A (2020) 'Hybrid grouper in Vietnamese aquaculture: production approaches and profitability of a promising new crop', *Aquaculture* 522:735108.	Male	Australian
Dennis LP, Nocillado J, Palma P, Takafumi A, Soyano K and Elizur A (2020) 'Development of a giant grouper luteinizing hormone (LH) enzyme-linked immunosorbent assay (ELISA) and its use towards understanding sexual development in grouper', *General and Comparative Endocrinology* 296:1–12.	Male	Australian
Dennis LP, Anderson K, Wylie M, In VV, Nocillado J and Elizur A (2021) 'NextGen molecular barcoding of larval grouper diet in an extensive green-water pond system', *Aquaculture* 531:735971.	Male	Australian
Knibb W, Luu G, Premachandra HKA, Lu MW and Nguyen HN (2017) 'Regional genetic diversity for NNV grouper virus across the Indo-Asian region – implications for selecting virus resistance in farmed groupers', *Scientific Reports* 7:10658.	Male	Australian

Scientific journals	Lead author	
	Gender	Nationality
Nocillado J, Palma P, Fielder S, Zanardini M, Dennis L and Elizur A (2019) 'Development of specific enzyme-linked immunosorbent assay for yellowtail kingfish (*Seriola lalandi*) follicle stimulating hormone using recombinant gonadotropins', *General and Comparative Endocrinology* 282:113208.	Female	Australian
Nocillado J, Palma P, Wang T, Ayson EG, Levavi-Sivan B and Elizur A (2022) 'Intracellular production of recombinant GnRH1 in yeast, *Pichia pastoris*, and its potential as oral treatment to advance gonadal development in juvenile orange-spotted grouper, *Epinephelus coioides*', *Aquaculture* 554:738115.	Female	Australian
Palma P, Nocillado J, Superio J, Ayson EG, Ayson F, Bar I and Elizur A (2019) 'Gonadal response of sexually immature protogynous grouper (*Epinephelus fuscoguttatus*) to long-term recombinant follicle-stimulating hormone administration', *Biology of Reproduction* 100(3):798–809.	Male	Filipino
Palma P, Nocillado J, Superio J, Ayson EG, Ayson F, Lu MW and Elizur A (2019) 'Induction of gonadal development in protogynous grouper with orally delivered FSH DNA', *Marine Biotechnology* 21:697–706.	Male	Filipino
Palma P, Takemura A, Libunao GZ, Superio J, Ayson, EG, Ayson F, Nocillado J, Dennis L, Chan J, Thai TQ, Ninh NH and Elizur A (2019) 'Reproductive development of the threatened giant grouper *Epinephelus lanceolatus*', *Aquaculture* 509:1–7.	Male	Filipino

Appendix 2: Publications produced by each project (*cont.*)

Other papers and conference proceedings	Lead author	
	Gender	Nationality
Bright D, Nocillado J, Canepa M, Reynolds A, Knuckey R and Elizur A (28 June – 2 July 2016) 'Social structure affects reproductive development and sex change in giant grouper (*Epinephelus lanceolatus*)' [conference poster], *8th International Symposium on Fish Endocrinology*, Gothenburg, Sweden.	Male	Australian
Nguyen Duc Tuan, Tran The Muu, Vu Thi Thanh Nga and Pham Quoc Hung (2015a) 'Effects of temperature and salinity on embryonic development and hatching rate of hybrid grouper (♂ grouper *E. lanceolatus* × ♀ tiger grouper *E. fuscoguttatus*)', *Journal of Agriculture and Rural Development* 7:102–107.	Male	Vietnamese
Nguyen Duc Tuan, Vu Thi Thanh Nga, Tran The Muu and Pham Quoc Hung (2015b) 'Effect of live feeds on survival rate and growth performance of hybrid grouper (♂ Giant grouper *Epinephelus lanceolatus* × ♀ tiger grouper *Epinephelus fuscoguttatus*) from larva to fingerling', *Journal of Agriculture and Rural Development.*	Male	Vietnamese
Nocillado J, Palma P, Bright D and Elizur A (28 June – 2 July 2016) 'Application of recombinant follicle stimulating hormone to manipulate reproduction in giant grouper, *Epinephelus lanceolatus*' [conference poster], *8th International Symposium on Fish Endocrinology*, Gothenburg, Sweden.	Female	Australian
Palma P, Chan J, Superio J, Libunao GX, Ayson EG and Ayson F (27–30 May 2019) Preservation of economically important grouper (*Epinephelus* spp.) spermatozoa at low and ultra-low temperatures' [conference presentation], *International Science, Technology and Engineering Conference*, Bohol, Philippines.	Male	Filipino
Palma P, Nocillado J, Superio J, Ayson EG, Ayson F, Bar I and Elizur A (8–12 April 2019) 'Studies towards advancing reproductive development in giant grouper (*Epinephelus lanceolatus*) using recombinant hormone manipulation' [conference presentation], *12th Asian Fisheries and Aquaculture Forum*, Iloilo, Philippines.	Male	Filipino
Palma P, Nocillado J, Superio J, Ayson EG, Ayson F, Bright D, Bar I and Elizur A (4–9 June 2017) 'Recombinant follicle stimulating hormone-induced testicular development in immature protogynous grouper (*Epinephelus* sp.)' [conference poster], *18th International Congress on Comparative Endocrinology*, Banff, Canada.	Male	Filipino
Palma P, Nocillado J, Superio J, Ayson EG, Ayson F, Bright D, Bar I and Elizur A (November 2017) 'Smaller and younger broodstock' [poster], *UniSC Research Showcase*, Sunshine Coast, Australia.	Male	Filipino
Palma P, Takemura A, Libunao GX, Superio J, de Jesus-Ayson EG, Ayson F, Nocillado J, Dennis L, Chan J, Thai TQ, Ninh NH and Elizur A (8–12 April 2019) 'Reproductive development of the threatened giant grouper *Epinephelus lanceolatus*' [conference presentation],*12th Asian Fisheries and Aquaculture Forum*, Iloilo, Philippines.	Male	Filipino
Tran TM, Vu VS and Vu VI (2014) 'Effect of density on growth rate and survival rate of tiger grouper (*Epinephelus fuscoguttatus*) from fry to fry', *Journal of Fisheries Science and Technology*, 3:43–47.	Male	Vietnamese
Truong QT, Nguyen VD, Nguyen KD and Nguyen TTH (2021) 'Effects of food and rearing density of hybrid grouper (♂ *E. lanceolatus*× ♀ *E. fuscoguttatus*) from fry stage to fingerling', *Vietnam Journal of Marine Science and Technology* 21(2):149–159.	Male	Vietnamese
Vu VS, Vu VI and Dang TV (2016) 'Effect of stocking density on growth, early survival rate of grouper hybrids between grouper and grouper', *Journal of Fisheries Science and Technology* 4:107–112.	Male	Vietnamese

Appendix 3: Outcome summaries

Outcomes	Evidence found	Supporting reference
Scientific		
Advancement of science through the production of highly credible quality science research indicated by: (i) the project published in peer-reviewed journals (ii) 26% of outputs are articles published in peer-reviewed local language (where English is not the academic language of the context).	Yes Yes	Appendix 2: Publications produced by each project. Five papers published in Vietnamese journals, in Appendix 2
Development of knowledge unique for application in context, which includes: (i) development of appropriate science outputs that contribute to application including training manuals, handbooks, technologies (ii) translation of the above science outputs for use by a clearly identified next user.	Yes	Appendix 2: Publications produced by each project, RIA3 Training manual produced. Other forms of research dissemination (p. 24)
Socioeconomic		
Improved access to social-economic institutions and organisations (e.g. markets, social organisations, producer groups, cooperatives, unions, etc.), which includes: (i) a reduction in barriers to access (i.e. regulatory, logistic, informational) OR (ii) the enhanced capacity to meet requirements for participation (i.e. quality and food safety standards in markets).	N/A	
Expanded range of social-economic opportunities that are realistic and appropriate in the context and includes: (i) expanded range of employment opportunities OR (ii) expanded range of agricultural production options OR (iii) expanded range of post-harvest value-add options OR (iv) expanded range of options to extract/harvest natural resources (i.e. forests, fisheries).	(ii) Addition of giant grouper fertilised eggs available for order, and GGTG hybrid grouper fertilised eggs and fingerlings for sale by government research institutes.	Table 6: Hybrid grouper fingerling production (p. 28)
Reduced barriers to switching between alternative social-economic activities, which includes: (i) reduction in social barriers (e.g. gender norms, stigmas, status) OR (ii) improved knowledge which facilitates switching (i.e. from cropping to livestock raising) OR (iii) decreased financial barriers to switching (i.e. better access to micro-credit or improved application of government subsidies) OR (iv) reduced regulatory/legal barriers to switching.	(ii) Knowledge on hatching, husbandry and feeding requirements of GGTG hybrids shared with hatcheries, and cage cleaning and parasite management knowledge shared with grow-out farmers.	Sources of knowledge and immediate impacts on productivity (p. 29)

Appendix 3: Outcome summaries (*cont.*)

Outcomes	Evidence found	Supporting reference
Reduced exposure to risk (e.g. human health risk, production risk, social risk), which includes: (i) improved risk management/response OR (ii) increased avoidance of risks OR (iii) improved opportunities to mitigate risk through community, government or financial arrangements (i.e. crop insurance).	(ii) GGTG hybrids are considered a less risky crop to farm than some other alternatives.	Household wellbeing (p. 38)
Increased social-economic returns (e.g. wellbeing, profits), which for the systems households engage with includes: (i) increased benefit flows for same cost outlay ('more with same' – increased availability of food or resources to the household from the same outlay of effort) OR (ii) sustainment of benefit flows with decreased cost outlays ('same with less' – labour-saving techniques allow same income to be achieved with less time) OR (iii) increased benefit flows and decreased cost outlays ('more with less' – new crop variety generates higher incomes with less labour time and land).	(i) In general, 'more with same' was achieved for both hatchery operators and grow-out farmers. While seed and fingerling costs may have been slightly higher for GGTG hybrids, comparisons were dependent on which crop was being replaced by individual producers.	Sources of knowledge and immediate impacts on productivity (p. 29)
Gender		
Increased inclusion and opportunity for women and/ or diverse sexual orientation and gender identity/ expression (SOGIE) researchers within the project, in both the Australian and partner-country teams, specifically:		
(i) project team composed of a minimum of 40% women or men	No	Initial proposal listed 12 men and 6 women (this may have fluctuated over the life of the project)
(ii) women and/or diverse SOGIE researchers held position of project leadership	Yes	Project lead and SEAFDEC lead were women
(iii) women and/or diverse SOGIE researchers appeared as first author on at least one of the peer-reviewed or conference publications/presentations produced in a relevant and high-ranking journal	Yes	Appendix 2: Publications produced by each project
(iv) women and/or diverse SOGIE researchers were given scholarships and/or training opportunities.	Yes	Gender equity of research opportunities (p. 17)
Partners identify the project as influencing organisational decisions to adopt gender-inclusive policies and procedures, including: (i) a clear gender strategy (ii) human resource policies are gender-sensitive (iii) representation of women and/or SOGIE researchers has increased in the higher-level functions within an organisation.	N/A	

Outcomes	Evidence found	Supporting reference
The generation of gender-sensitive knowledge, which includes gender-specific publications and/or publications that include gender-disaggregated data, and there is evidence that the research has been translated for use at: (i) the project level (ii) the organisational level (iii) the community level.	N/A	
Positive socioeconomic outcomes women and/or diverse SOGIE community members, which includes: (i) improved access to social-economic institutions and organisations, (e.g. markets, social organisations, producer groups, cooperatives, unions) (ii) expanded range of social-economic opportunities, which are realistic and appropriate in the context (iii) reduced barriers to switching between alternative social-economic activities (iv) reduced exposure to risk, (e.g. human health risk, production risk, social risk) (v) increased social-economic agency (vi) improved social-economic equity (i.e. an improvement in an individual's equity share in their outputs).	(ii) Women as household members were involved in deciding on adopting GGTG hybrids as a crop; a slight increase in women's employment in hatchery operations for weaning fingerlings and grading (grading GGTG fingerlings is unique as they are prone to cannibalism)	Gender aspects (p. 38)
Policy		
Implementation of a policy that informed stakeholders acknowledge draws on ACIAR-supported research, which is evident: (i) in such a way that observable changes in state can be determined to be positive (ii) through qualitative evaluations with a deliberate sample that demonstrate an acknowledged contribution to the policy process of a piece of research and analysis of the impact of these policies.	N/A	
Direct referencing of research in publicly available policy documents, which include: (i) reference to technical manuscripts OR (ii) sections of ACIAR support research text directly incorporated into policy OR (iii) footnoting of research documents in formal policy papers OR (iv) reference to ACIAR-supported research in ministerial statements and/or speeches.	N/A	

Appendix 3: Outcome summaries (*cont.*)

Outcomes	Evidence found	Supporting reference
Policy actors acknowledge that there was a contribution to the policy formation process from the research outputs, which includes an acknowledgement by policymakers in: (i) impact evaluation interviews that the research was 'one of many influences' (ii) emails and other written communication received by researchers from individual policy actors demonstrating engagement with research.	N/A	
The research team self-reports that policy-relevant findings were produced and communicated to known actors within the policy-making realm, which includes the following activities being undertaken during the life of the project: (i) policy dialogues convened (ii) policy briefs produced and distributed (iii) high-level stakeholder meetings held to discuss policy-relevant findings.	N/A	
Improved natural resource management		
Reduced production and/or better management of pollutants, which includes: (i) reduction in the use of harmful chemicals (e.g. herbicides, pesticides) OR (ii) reduction in the overuse/run-off of nutrients OR (iii) reduced discharge and/or better management of wastewater.	N/A	
More efficient and sustainable use of available water resources, which includes: (i) growing more food using less water (reducing agricultural water demand) OR (ii) reducing groundwater depletion.	N/A	
Increased natural resource stocks, which includes: (i) improved soil health (i.e. improved soil structure, pH level, nutrient levels) OR (ii) increased forest/vegetation cover OR (iii) increased wild aquatic species stocks.	(iii) The increase in availability of cultured GGTG hybrids may have led to a reduction in the capture of other wild grouper species among the immediate research institute producer networks	Environmental outcomes (p. 39)
Increased ecological resilience, which includes: (i) increased or restored ecosystem biodiversity (including increased soil carbon) OR (ii) rehabilitated ecosystems (i.e. coral reef systems/ wetlands).	N/A	

Outcomes	Evidence found	Supporting reference
Improved biosecurity, which includes better management of pests and diseases (animal, plant and human).	The reduction in importation of GGTG fingerlings has reduced the biosecurity risk from imports. Greater attention to identifying and mitigating against viral nervous necrosis, and testing fingerlings prior to their sale, has increased industry awareness of biosecurity risks.	Tools with more immediate application (p. 21)
Improved climate change mitigation, which includes: (i) an observed improvement of natural resources (i.e. increased forest cover, improved soil carbon) OR (ii) a reduced energy consumption (e.g. solar water pumps) OR (iii) establishment of new climate mitigation incentive schemes, support mechanisms, extensions at an institutional level.	N/A	
Establishment of a sustainable natural resource management system, which includes the institutionalising and implementation of sustainable practices and management of natural resources (i.e. groundwater systems, salinity management, forest resources, waterways, biodiversity).	Increased availability of a cultured marine crop, and the ability to close the breeding cycle for giant grouper in Vietnam, may have lasting impact on reducing the reliance on wild grouper stock	Environmental outcomes (p. 39)
Innovation system		
Enhanced individual capacity achieved for the project team members, which includes: (i) improved skills development of the individual OR (ii) career progression for an individual (i.e. a promotion) OR (iii) an individual on the project team was awarded an ACIAR fellowship including a John Allwright Fellowship, Pacific Scholarship or John Dillon Fellowship OR (iv) an individual gains an external grant for professional development OR (v) an individual is formally part of a mentor program with senior academics in Australia OR (vi) ACIAR-funded individuals are contributing in the international research-for-development space.	(i) Many members of the team learned new methods, experimental design, analytical skills and English proficiency. (ii) Individuals were promoted after training. Others also went on to new positions in other organisations or additional postgraduate study. (iii) Multiple fellowships were awarded. (iv) Many team members received training from the UniSC team. (v) The team from all 3 partner organisations worked together and jointly published a paper.	Individual capacity building (p. 16)

Appendix 3: Outcome summaries (*cont.*)

Outcomes	Evidence found	Supporting reference
Improved capacity of implementing partners at an organisational level, which includes: (i) improved processes and procedures OR (ii) improved human resources procedures OR (iii) the organisation has developed a clear strategy OR (iv) the team has the appropriate skill set for the work OR (v) stronger organisational leadership is demonstrated OR (vi) strengthened culture of research innovation and collaboration is demonstrated.	(i) New and improved protocols and methods were developed (e.g., broodstock husbandry, live feed and larval production). (iii) Organisation has the skills to successfully produce hybrid grouper for sale to farmers. (iv) Science rigour has improved.	Organisational capacity (p. 18)
Improved capacity of groups and/or individuals in the local community who were members of the project team (i.e. directly engaged people within the target community), which includes: (i) improved skills development within the engagement target area of the project OR (ii) completion of training programs (including work placements) as part of the project that are relevant to their employment/daily activities OR (iii) completion of a formal qualification relevant to their employment/daily activities.	N/A	
Improved capacity of groups and/or individuals in the local community who were not directly engaged with the project, including: (i) the community has increased knowledge and resources relevant to the environment OR (ii) the community has improved skills to continue the project.	(ii) Hatchery and grow-out farmers are largely confident in their knowledge and skills for producing GGTG hybrids. Additional knowledge in improving survival rates from hatching to fingerling stage is still required.	Sources of knowledge and immediate impacts on productivity (p. 29)

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ACIAR Outcome Evaluation series

No	Author(s) and year of publication	Title	ACIAR project numbers
1	Davis P (2022)	*An evaluation of the ACIAR Agriculture Sector Linkages Program*	ADP/2010/091, HORT/2005/153, HORT/2005/157, HORT/2005/160, HORT/2010/001, HORT/2010/006, HORT/2012/002, LPS/2005/132, LPS/2010/007
2	Hanley C and Passfield L (2022)	*An evaluation of the ACIAR Transformative Agriculture and Enterprise Development Program*	ASEM/2014/095, FST/2014/099, HORT/2014/094, HORT/2014/096, HORT/2014/097
3	Davis P and Hanley C (2023)	*A programmatic evaluation of the TADEP and ASLP programs*	ADP/2010/091, ASEM/2014/095, FST/2014/099, HORT/2005/153, HORT/2005/157, HORT/2005/160, HORT/2010/001, HORT/2010/006, HORT/2012/002, HORT/2014/094, HORT/2014/096, HORT/2014/097, LPS/2005/132, LPS/2010/007
4	Campbell J, Gimelli F, Chamberland G, Strempel A and Breen J (2022)	*An evaluation of fruit and vegetable market development research in north-western Vietnam*	AGB/2006/112, AGB/2008/002, AGB/2012/059, AGB/2012/060
5	Myers R and Cininta P (2023)	*Improving the sustainability of cocoa production in eastern Indonesia*	HORT/2010/011
6	Gimelli F, Campbell J, Chamberland G, Strempel A, Mienmany S and Zalcman E (2023)	*Evaluation of village-based livestock biosecurity in Laos and Cambodia*	AH/2012/067, AH/2012/068, AH/2011/014, AH/2010/046, AH/2006/159, AH/2005/086
7	Piper E and Sirajulmunir N (2023)	*Illegal, unregulated and unreported fishing in Indonesia*	FIS/2006/142
8	Meaney-Davis J, Winterford K, Mienmany S, Douangsavanh S and Willetts J (2023)	*Assessing the research to policy interface in Lao PDR*	ADP/2014/047, FIS/2006/183, FIS/2009/041, FIS/2014/041, FIS/2017/016, FIS/2017/017, FIS/2018/153, FIS/2015/006, FST/2012/041, FST/2012/091, FST/2016/151, FST/2019/121, LWR/2010/081
9	Moriarty H, Symonds JE and Thai VN (2024)	*Developing technologies for giant grouper aquaculture in Vietnam, the Philippines and Australia*	FIS/2012/037, FIS/2012/101


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