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Final report

project

Expansion and Diversification of Production and Management Systems for Sea Cucumbers in the Philippines, Vietnam and northern Australia

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Contents

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Acronyms used:

ACIAR – Australian Centre for International Agricultural Research
BFAR - Bureau of Fisheries and Agricultural Resources, Philippines
Brgy. – Barangay (meaning village in Philippines)
DAC – Darwin Aquaculture Centre, Australia (Project partner)
DO – Dissolved oxygen
DOST – Department of Science and Technology, Philippines
FGD – Focus group discussion
GDFI – Guiuan Development Foundation Incorporated (Project Partner)
GPS – Global Positioning System
JCU – James Cook University, Australia
LGU – Local government unit
MMA - Maliwaliw Multi-purpose Association (People's Organisation, Eastern Visayas)
MOA – Memorandum of Agreement
MOU – Memorandum of Understanding
MSUN - Mindanao State University Naawan (Project partner)
NGO – Non-Governmental Organisation
NISPC - Northern Iloilo Polytechnic State College
NT – Northern Territory, Australia
OM – Organic matter
PNG – Papua New Guinea
PO – People's Organisation
RIA3 – Research Institute for Aquaculture No. 3, Vietnam (Project partner)
SEAFDEC AQD – South East Asian Fisheries Development Corporation, Aquaculture Department
SMMVI - Samahan ng Maliliit na Mangingisda ng Victory, Inc. (Sandfish community group – Mindanao)
TO – Traditional owners
UPMSI – University of the Philippines, Marine Science Institute (Project partner)
USC – University of the Sunshine Coast

2 Executive summary

The harvest of sea cucumbers has, for many years, supported livelihoods in coastal communities throughout the Asia/Pacific region, feeding into high value international markets. Yet the biological vulnerability, increasing demand and high value of sea cucumbers have together resulted in precipitous depletion of wild resources. Ranching and restocking provide plausible mechanisms for sea cucumber stock recovery and livelihood restoration. This project continued long-term support from ACIAR for ranching of the high- value sea cucumber sandfish (*Holothuria scabra*), and supported national initiatives in partner countries. Methodologically, this project used a diversity of engagements across the Philippines, Australia and Vietnam to focus on developing, testing and refining a toolbox of approaches applicable throughout the culture cycle, and across diverse social, bio-physical and institutional contexts.

Hatchery culture methods for sandfish are well established, and a source of live cultured micro-algae has been both a key requirement to success and a bottleneck to scaling production in developing country settings. Growth trials showed that commercially available micro-algae concentrates can replace live micro-algae as a food for sandfish larvae. This greatly simplifies hatchery culture methods and removes what has been a substantial bottleneck to production. Improved knowledge of the nutritional requirements of sandfish larvae provides a basis for further improvement to larval nutrition and hatchery production.

While experimental-scale ranching has been supplied largely with release size (>2 g) juvenile sandfish grown in hatchery raceways, growth is density-dependent and space rapidly becomes limiting in commercial-scale operations. In addition, the cost of this approach is prohibitive. Approaches to engaging communities early in the production cycle, using in- situ nursery systems in coastal embayments, were tested and refined. Floating hapa nets proved successful, and were most productive when densities of post settlement juveniles were kept low (<500 individuals per 2 m^2 hapa net), and juveniles were graded for size part way through the hapa nursery cycle. Growth trials showed that the diet of juveniles shifts from algae to diatoms during 60 days of juvenile growth in hapa nets, and as such, a diversity of fouling on the nets is desirable. Sheltered areas are essential for nursery culture, and under appropriate conditions bottom-set hapa nets with sediment access can provide for on-growing to larger (e.g.10-20 mm) release size, which reduce predation losses on release.

In Vietnam, ranching trials were largely unsuccessful with very high mortality and possibly issues with theft. Given the availability of ponds ideal for sandfish farming, further investment in pond-based polyculture system development is more likely to be beneficial to local livelihoods. Conversely, in the Philippines, field observations and laboratory experiments demonstrated that ponds were not conducive to sandfish growth and survival, and coastal ranching is the best option in these areas. In the Philippines, partnering with multiple communities for ranching trials in diverse setting provided an opportunity to test and document different governance and community engagement processes which will feed into technical manuals and policy advice.

Detailed environmental monitoring of sediment, water and seagrass parameters across ranching sites in Philippines, Australian and PNG showed substantial but idiosyncratic fine-scale spatial and inter-annual variability. Machine learning approaches to analysis across sites and countries showed only weak association between environmental parameters and juvenile sandfish growth. Low levels of silt and high chlorophyll a in sediments were the best, although weak, predictors. Statistically, 'site' remained the best predictor, suggesting variables not accounted for in our environmental monitoring, and perhaps inconsistent among sites, were driving variability. Predation, in particular, is not well understood.

In Australia, the project partnered with the Warruwi Aboriginal community on Goulburn Island, Northern Territory and a fisheries industry partner (Tasmanian Seafoods P/L) to test sandfish ranching as a supplemental livelihood for the community. The industry partner supported hatchery production, was licensed for harvest and export of sandfish, and trained community members in methods processing for high quality product. Unique ranching protocols were developed to account for extreme tidal ranges (8 m +) and safety concerns related to the presence of crocodiles. To assess recovery from hatchery releases, methods of marking sandfish with fluorochrome dyes were used and refined. Approaches to mass-release from a small boat were tested, and a chute-based system found to be effective and highly efficient. Survival and growth rates of released juveniles recovered 12 months from release were high by global standards, suggesting high numbers of released juveniles would have been harvestable size by18 months. Trial harvests (of wild sandfish) as a partnership between the community and industry partner were financially and operationally successful, supporting the potential viability of sea ranching.

The project resulted in substantial diversification, improvement and refinements of culture and ranching technologies, with strong buy-in from communities, industry, and local governing institutions. While the project fell short of developing viable, economically sustainable community enterprises, research outcomes removed substantial bottlenecks to future success and highlighted remaining areas for research engagement.

3 Background

Sea cucumbers are a highly valued commodity consumed mainly as food, but also used in cosmetic or medicinal products in China and elsewhere in Asia. Their harvest has, for many years, supported livelihoods in coastal communities throughout the Asia/Pacific region (Purcell et al., 2013). Yet the sedentary nature, biological vulnerability, expanding market and high value of sea cucumbers have together resulted in their widespread and precipitous depletion. This scenario of resource depletion has frequently been seen as marine resources are overexploited, starting with removal of high value species, and progressively moving to lower value species and undersized individuals (Anderson et al, 2010; Rawson and Hoagland, 2019). These declines have been sorely felt in terms of lost earning capacity in coastal communities. There are social impacts imbedded in this shift also. As a healthy fishery, sea cucumbers are present in the littoral zone, where women and those without access to boats engage in the fishery through gleaning at low tide. As exploitation levels increase and easily accessible stocks are depleted, the fishery becomes a boat-based dive activity, and in many cases ultimately relies on access to underwater breathing apparatus (SCUBA or compressors) – and becomes a male domain (Friedman et al., 2008; Eriksson et al., 2012).

Despite clear signs of sea cucumber stock collapse among many species throughout the tropics (Purcell et al., 2013), high prices paid throughout the value chain drive continued exploitation, and examples of effective governance are rare. Biologically, sea cucumbers are not well adapted to recover from overexploitation. It follows that governance reform alone will be unlikely to reverse wild stock declines, with ranching and restocking providing a plausible mechanism for recovery and livelihood restoration.

Ongoing efforts to develop simple low-technology approaches to culturing sandfish (*Holothuria scabra*), a high-value tropical sea cucumber species, have a broad range of potential benefits in restoring coastal livelihoods and ecological function. This project continued efforts and built directly on outputs and outcomes from the multilateral ACIAR project *Sea ranching and restocking sandfish in Asia-Pacific* (FIS/2003/059), as well as research completed under the *Philippines national program on sea cucumber research and development*, and government investments in Vietnam and Australia. Much of this work is in turn built on advances in husbandry, hatchery technology and grow-out systems achieved through past ACIAR programs (ACIAR projects FIS/1995/703 and FIS/1999/025). These previous programs have highlighted both the potential and limitations of sandfish culture technology and demonstrated that significant impact is likely if systems and technologies applicable across a broad range of social, institutional and bio-physical settings can be developed. Critically, we also need tools to determine where these technologies are unlikely to succeed due to biophysical or social constraints.

Scaling and system diversification were therefore a central focus of this new project. As a tri-lateral engagement, the project provided an opportunity to robustly test systems and approaches to scaling sea cucumber culture and ranching in a diverse range of physical, institutional and social settings. The project provided a timely platform for south-south engagement/learning, with the Vietnamese partners at the forefront of hatchery systems development, and Philippines partners having substantial experience in community-based ranching and governance. In both the Philippines and Vietnam, government agencies have invested in sea cucumber research and development, as they recognise its potential to provide a critical source of income in coastal communities. Both countries have existing, complex, socially integrated, and very much undersupplied market chains developed through a long history of capture fisheries, which will ensure a ready market for quality product.

In the Philippines, the project integrated with the national sea cucumber R&D program, and contributed to the national research priority to promote '*adoption of mariculture-based strategies to provide livelihoods and enhance locally managed fisheries*'. While the long-term emphasis in Philippines has been on the establishment of community-based sea cucumber ranching, exploring options for integration with sea cucumber fishery management through enhancement/restocking remained of interest, as did exploring options for pond-based culture based on the Vietnam model. In Vietnam, past investments by partner institute RIA3 and previous ACIAR and WorldFish projects have built the technical foundations for a pond-based sea cucumber culture industry. Vietnam has been at the forefront of developing robust and simple hatchery systems, and market conditions for shrimp farmers had seen them keen to diversify into other commodities.

In Australia, the extreme level of social and economic disadvantage of Aboriginal people living in remote communities across the Northern Territory is well documented (e.g. Biddle 2019). Across government agencies, policies seek to develop business opportunities, invest in infrastructure to attract businesses and offer training for local people. Sea ranching fits with Aboriginal peoples' cultural practises and customs; the flexibility of work that sea ranching suits their aspirations to blend economic participation with cultural obligations (Fleming, 2012). This, and the relatively low requirement for capital, makes this activity a good candidate to address social and cultural considerations, while providing a supplementary livelihood and capacity to participate in the mainstream economy. The engagement of an industry partner (sea cucumber fisher/harvester) in the project presents a unique context, and the potential for private investment.

Aspirations of the three country programs and their research partners (government, industry and communities) were approached through biophysical experimental research, social research and environmental monitoring and at an expanded diversity of test sites, complemented by development of diverse models for community engagement and enterprise structure.

Key questions the project sought to answer were:

1) What components of the production cycle can be further diversified, simplified and refined to improve output and facilitate uptake in a range of remote or less-developed areas?
2) What are the bio-physical requirements for successful on-growing in ponds and the open ocean?
3) What are the most effective models for capability building, community engagement and extension of technologies?
4) How can the release of cultured sea cucumbers be integrated into, and utilised as a tool to improve, fishery governance systems?

4 Objectives

This project built on efforts by stakeholders across all engaged counties (including PNG, by association through FIS/2010/054 - *Mariculture Development in New Ireland, Papua New Guinea*) to work towards improving livelihoods and sustainable production of sea cucumbers among coastal dwellers throughout Asia/Pacific. The project incorporated technical development of production systems, experimental research on habitat and tolerances, social research on institutional requirements and engagement strategies, and development of models for extension. Specific objectives were:

1. **Improve efficiency and adaptability of sandfish hatchery systems**

    1.1. Improve knowledge of optimal feeding regimes that maximise condition, settlement and survival of larvae under conditions encountered in small-scale hatcheries (JCU and DAC)

    1.2. Facilitate staff and PhD interchange and research collaborations for current and planned research to improve the efficiency and reliability of hatchery production (DAC and JCU)

2. **Improve efficiency and adaptability of sandfish nursery and growout systems**

    2.1. Refine ocean nursery systems to facilitate uptake of sandfish culture across a broader range of locations (Philippines and links to PNG)

    2.2. Assess prototype mass release and sand conditioning methods (Philippines, Australia and links to PNG), and harvest technologies that may facilitate community engagement in harvesting (Australia)

    2.3. Assess opportunities for pond-based sandfish culture through detailed testing of physiological tolerances, field observations of conditions in ponds, and trials with industry (Philippines)

    2.4. Test integrated community enterprise systems (hatchery, nursery, ranching and pond culture) as a model for maximising community benefit (Vietnam).

3. **Develop capacity to identify suitable sites for ranching using bio-physical indicators**

    3.1. Conduct regular fine-scale environmental monitoring at ranching sites to better understand relationships between bio-physical parameters, growth and survival of released sandfish, and the temporal variability in these parameters (Philippines, Vietnam, Australia, links to PNG).

    3.2. Conduct controlled manipulative experiments to understand bio-physical factors affecting growth and survival of released juvenile sandfish (Philippines)

4. **Develop tools, technologies and capacities to engage and train communities in sandfish culture**

    4.1. In partnership with local research and development institutions and local government units, develop and test models for the establishing learning sites for sandfish production as a vehicle for scaling-out technologies and management systems (Philippines)

    4.2. Test and refine models for community engagement and integration of release strategies into improved models for community-based resource management (Philippines)

    4.3. Expand Australian trials to three pilot sites, and facilitate broader community engagement activities targeted at potential enterprise participants, including processing training by our industry partner and activities for women, men and youth.

5 Methodology

Building on a substantial history of research into methods and opportunities for sea cucumber culture, this project leveraged diverse experience and interests across three countries to answer key questions regarding system design and scalability. Methodologically, the project used this diversity of engagement to focus on developing, testing and refining a toolbox of approaches applicable throughout the culture cycle across diverse social, bio-physical and institutional contexts. The diverse and dispersed nature of islands within **the Philippine archipelago** provide a particular challenge for extension. The previous sea cucumber project (FIS/2003/059) conducted research to improve hatchery production and test ranching methods at a limited number of sites. In this project, we engaged diverse institutional partners (research, academic, NGO) in four very different regions of the Philippines to understand scaling processes. **In Vietnam**, pond culture had been established as a small-scale industry in the central regions for a number of year, with good returns to farmers. The project sought to diversify systems for production of release-size juveniles, and test opportunities to diversify commercial production using sea ranching approaches developed in the Philippines. **In Australia**, the engagement of an industry partner, and the interest from Aboriginal communities in ranching provided the impetus to test sea ranching as culturally integrated supplemental livelihood for coastal traditional owners. While this provided another arena to test scaling approaches, the bio-physical and governance contexts of this project node were unique and required additional development.

1. Improve efficiency and adaptability of sandfish hatchery systems

Sandfish hatchery production has been the subject of considerably past research (see synthesis/ in Purcell et al., 2013). The research components of Objective 1 were integrated with the PhD project conducted by John Allwright Fellowship recipient Nguyen Duy from Vietnamese partner institution RIA3, and with research activities within FIS/2010/054 - *Mariculture Development in New Ireland, Papua New Guinea*.

Hatchery culture methods for sandfish are well established (Agudo, 2006; Duy, 2010) and a source of live cultured micro-algae is generally considered to be a key requirement for successful hatchery production. But developing and small-island nations often lack the technical resources and skilled personnel required for successful hatchery operation, including production of appropriate quantities of high quality live micro-algae, and this is a common bottleneck (Southgate et al., 2016). Research prior to this project had shown that commercially available micro-algae concentrates may have potential as replacements for live micro-algae during hatchery culture of sandfish (Hair et al., 2011), and they had been used successfully as a sole larval diet for other invertebrates. Research in Objective 1 therefore focused on assessing the potential of commercially available micro-algae concentrates as a food source for sandfish larvae and a replacement for live micro-algae with a view to developing simpler and more reliable culture protocols that are more appropriate for partner country hatcheries.

A series of hatchery-based growth trials were undertaken to assess the efficacy of the various products available commercially with the Reed Mariculture, Instant Algae® range (https://reedmariculture.com/product_instant_algae.php) **(Activity 1.1)**. Initial screening of products (pure cultures of specific micro-algae species) identified those from genera known to be of acceptable nutritional value for sandfish and sea cucumber larvae based on literature accounts (i.e. primarily golden-brown flagellates and diatoms). Selected products were then assessed for their rates of ingestion and digestion by sandfish larvae using epifluorescence microscopy. Those that were readily ingested and well digested were used in further growth trials with sandfish larvae to assess the nutritional value of each of the products and the efficacy of various combinations of products on the basis that mixed micro-algae diets are known to provide a better ‘balance’ of nutrients. Matching larval performance with nutritional compositions of the tested micro-algae products generated improved knowledge of the nutritional requirements of sandfish larvae.

In line with a key requirement of **Activity 1.1** relating to improved knowledge relating to maximising condition, settlement and survival of sandfish larvae, a follow-up study assessed the influence of diet composition on hyaline sphere development in larvae and the subsequent relationships between the presence and size of hyaline spheres and competency through settlement and early juvenile performance. Hyaline spheres are thought to be indicators of subsequent (post-larval) performance representing a key nutrient source during settlement and metamorphosis. This experiment was the first to assess (and confirm) this relationship and to establish a correlation between diet composition, hyaline sphere development and post-larval performance. In order to assess the potential of commercial micro-algae concentrates for early sandfish juveniles and to deduce new information about their nutritional requirements, a final small-scale culture experiment was performed to assess ingestion, digestion and relative nutritional values of six commercially available micro-algae concentrates compared to commonly used live micro-algae.

The initial concept for this objective was that much of the planned research would occur at the DAC hatchery to support capacity development (i.e. potential for Mr. Nguyen Duy to transfer successful RIA3 knowhow) and interaction with the private sector partner. However, this did not occur, and all research in Objective 1 was completed at the National Fisheries Authority's Nago Island Mariculture Research Facility in Kavieng, Papua New Guinea. This impacted activities that were planned within **Activity 1.2.** Although information relating to preparation and use of commercial micro-algae products for hatchery culture of sandfish were passed on to personnel at the DAC hatchery, hands-on training by Mr. Nguyen Duy within the DAC hatchery facility was unable to be completed. All proximate and nutritional analyses conducted within this research were undertaken using standard methods by Prof. David Francis of Deakin University.

2. Improve efficiency and adaptability of sandfish nursery and growout systems

This objective takes on a contextual form in each focal country, but with a number of commonalities. Across the board, the density dependence of sea cucumber growth and survival at all post-settlement stages has long been a limiting factor for mass culture. While production of stage-1 (immediately post-settlement) juveniles can be achieved at scale in the confines of a small commercial hatchery (e.g. see Duy 2010), experimental scale juvenile grow out to release size (generally 3–20 mm) has been conducted largely in raceway or tank systems producing low numbers adequate only for experimental trails. Importantly, if efficient low-tech ocean-based systems can be developed, this will enable community engagement in ranching or enhancement operations at an earlier stage, increasing livelihood opportunities and income potential for community. Moreover, in Philippines, where coastal ponds are proving unsuitable for nursery culture, there is a strong imperative to develop viable alternatives to expensive processes of mass-rearing of juveniles in hatchery facilities.

Trials in the Philippines and PNG addressed issues of appropriate-technology design of ocean-based nursery systems **(Activity 2.1)**. SEAFDEC in Philippines conducted field-based manipulative experiments at the Igang Marine Station, Guimaras, addressing questions on stocking density, size grading during culture and frequency of net changes to balance water flow and food availability. Additional enhancements to ocean nursery designs were tested in response to local conditions. The UPMSI team conducted manipulative experiments in Northern Luzon relating periphyton (algal and diatom growth) quality, water quality and environmental parameters to growth and survival of 3 mm sandfish juveniles in ocean hapa nursery systems. Trials were repeated seasonally over a two year period in eutrophic coastal waters in northern Luzon, providing a wide variety of environmental parameters for comparison. Establishing a community based sea ranch in PNG (associated with project FIS/2010/054) provided further opportunity for testing and refining ocean hapa systems.

While not initially planned within the project, discontinued ranching trials in Vietnam saw project resources allocated towards improving pond-based nursery systems – also a production bottleneck in Vietnam. Trials conducted at RIA3 Van Ninh hatchery facility north of Nha Trang assessed effect of stocking density on survival and growth of newly settled and larger juveniles in pond-based (rather than ocean) systems. Density dependence was tested for immediately post-settlement juveniles (ca. 5 mm body length) and for larger pre-release (2 gram) juveniles.

In scaling operations from experimental to commercial, new approaches to juvenile release are required **(Activity 2.2)**. Past research, which used labour-intensive 'hand planting' methods, suggested that the minutes to hours immediately following release are critical for survival (Purcell, 2004; Purcell and Simutoga, 2008). Mass release methods were tested in the Northern Territory in collaboration with industry partner Tasmanian Seafoods Pty Ltd and the Warruwi community. Only boat-based methods were considered due to the practicality for mass releases and safety concerns regarding crocodiles. A temporary cage system (left in place for 24 hrs) was compared to a chute systems of immediate release. Juvenile sea cucumbers were marked with fluorochrome dyes to enable treatments to be differentiated. Warruwi community members trained through project-related initiatives (coxswains certificates, cert two in Aquaculture) participated in conducting replicated comparisons of the two methods.

Further scaling pathways, as well as south/south learning opportunities, existed through diversifying production in Philippines to include pond-based systems (where currently only a small-scale pond-based industry exists) (**Activity 2.3**) and assessing the potential for sea ranching in Vietnam (**Activity 2.4**). In Philippines, the SEAFDEC project team monitored temperature and salinity, and tested sediment type in indicative shrimp farming ponds in four regions on or adjacent to Panay Island. In Vietnam, a series penned ranching trials were conducted by the RIA 3 team in collaboration with a pond farmer in Cam Ranh Bay. Replicate sea pens of 50 m^2 were stocked with 100 x 10 g or 20 g juveniles each. Growth was monitored every 15 days for 6 months by collecting a subsample by hand for measurement.

3. **Develop capacity to identify suitable sites for ranching using bio-physical indicators**

Early in the development of ACIAR and Philippines national research efforts towards sea cucumber ranching, a decision was taken to focus on 'open ranching' approaches. Other high profile efforts, such as NGO Blue Ventures projects in Madagascar (e.g. Robinson and Pascal, 2009) use an extensive system of household-owned pens to demarcate ownership of sea cucumbers. As the emphasis of our research was on community enterprise, but also with an eye to approaches that can work for fishery enhancement, open architecture for ranching sites is more appropriate. Additionally, it allows for multiple uses of the ranching area (e.g. other forms of fishing) and reduces potential for environmental damage from placement and regular servicing of pens. Each ranching node in the current study followed (to the degree possible) the approach developed through the previous project phase (FIS/2003/059) and the national research program in the Philippines.

The total area for each sea ranch was approximately 5-hectares (Figure 1). The configuration of the sea ranch varied depending on the depth and substrate type at each site. The 5 ha sea ranching site was further divided into zones for monitoring purposes: the core juvenile release area (Zone A - 50 m x 50 m) is part of the 1 ha nursery area (Zone B) within a 4 ha buffer zone (Zone C). In negotiating access agreements in the Philippines, participant groups as right holders have the exclusive harvest rights for sea cucumbers in the 5 ha area and exclusive access in the core release and nursery area (Zones A and B). Other members of the community may undertake traditional fishing activities in the reserve area (zone C) with permission from the rights holders.

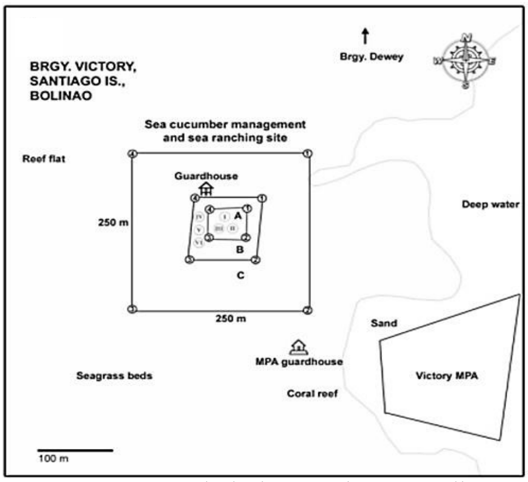


Figure 1. Sea ranch design at Victory, Bolinao - the model for sea ranching areas at all sites in this project (From Juinio- Meñez et al., in prep)

Environmental conditions experienced by sea cucumbers during growth may be at the microhabitat to macro scale. Environmental parameters vary significantly even within these relatively small ranching areas (see outcomes of Activity 3.2). As such, linking growth and survival of released juveniles to environmental parameters requires an understanding of temporal and physical processes within ranching areas at multiple scales. A standard set of environmental protocols was developed to measure parameters understood to have the potential to influence habitat suitability for sea cucumber ranching (e.g. Lavitra et al., 2010; Ceccarelli et al., 2018). These included sediment particle profiles, sediment organic matter (labile and refractory), sediment chlorophyll and phaeopigments, and sediment penetrability (softness). Methods were compiled from soil science, sediment and seagrass monitoring literature (e.g. Kristensen, 1990; McKenzie and Campbell, 2002), and modified to context as appropriate. Sediment cores were taken from sites and returned to team laboratories for sieving for particle sizes, processing and ignition to measure organic matter, and chemical assays for chlorophyll and phaeopigments. Multiple random placings of a 50 cm x 50 cm quadrat were used to assess seagrass cover. A standardised system that facilitated dropping a sharpened steel rod from a height of 10 cm above the sediment provided an estimate of sediment 'compactness' or 'penetrability'.

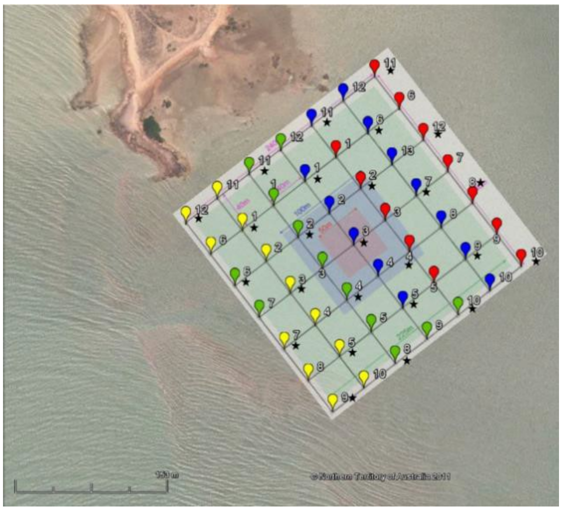


Figure 2. 49 point environmental sampling grid here shown imposed on the Wigu (NT, Australia) ranching site. Colour codes represent teams completing each survey point to enable the survey to be completed within the brief time window available at low tide.

At the ranching sites in Philippines (7 sites) and Australia (1 site) we established broad-scale spatial monitoring to better understand intra- and inter-site variability in key environmental parameters (**Activity 3.2**). At each site a set 7 x 7 grid with points at 40m intervals was established (Figure 2), and GPS positions set as way points or recorded to 6 decimal places to ensure repeatability. At two sites (Victory, Philippines and Wigu, Australia) three repeat samplings over three years were conducted. Three sites in the Philippines (Polopina, Tubajon, Maliwaliw site 1, Maliwaliw site 2) were sampled over two years and a further two sites (Molocaboc, Pandaraonan) sampled only once as they were established late in the project timeline. Environmental parameters were compared as surface plots to understand spatial and temporal dynamics, and possible links to growth and survival.

Growth and environmental parameters were linked through finer scale sampling in pens established within the release zones of ranching sites (**Activity 3.1**). Monitoring growth and survival of released juveniles is difficult in an open sea ranch, as juveniles are free to move across variable habitat, and recovery in numbers can be difficult at any point in time. To counter these issues, for the Philippine and PNG nodes we established three 100 m^2 sea pens within the release zone (Zone A) of each ranching site. Round sea pens were constructed from 'oyster mesh' to a height of 30 cm held in place with steel pegs, with the lower lip buried into the sediment to prevent sea cucumbers burying under the fence. They functioned as a fence to limit sea cucumber movement while not restricting movement of fish predators. Concurrently with ranch releases, pens were stocked with 100 juveniles, and growth was monitored every 3 months over periods of 9 months to 3 years, depending on site.

4. Develop tools, technologies and capacities to engage and train communities in sandfish culture

Philippines:

With a central focus on scaling, the development of *learning sites* for sea cucumber culture was prioritised during project development. **Activity 4.1** focused on processes of scaling existing hatchery, juvenile grow-out and governance systems to new project pilot sites. The experienced UPMSI and SEAFDEC teams provided initial training, orientation and advice in processes of setting up physical environments for culture, selecting sites feasible for culture and developing partnerships and governance arrangements in focal communities. Training included exposure trips to the well-established UPMSI ranching site at Victory, Northern Luzon for all project teams, trainings in hatchery methods, hapa system construction and management, and the establishment of a hatchery production course (commercially available to the public) at the SEAFDEC Aquaculture station in Iloilo. The team learned from, and documented, processes of scaling out to contribute to training materials for industry development.

Early stages of engaging new project partners were greatly complicated by Super Typhoon Yolanda (Typhoon Haiyan elsewhere in SE Asia) directly impacting the Eastern Visayas node, with devastating consequences. As one of the strongest typhoons to ever make landfall globally, with sustained winds of up to 285 km/h[1], destruction was massive, and loss of life unprecedented. The recovery and reactivation of this node required time and the redirection of project resources. While the project hatchery was destroyed, a makeshift hatchery was soon constructed using new and salvaged hardware at a nearby Bureau of Fisheries and Agricultural Resources (BFAR-8) facility.

The more experienced teams from UPMSI and SEAFDEC worked across all Philippines nodes to provide advice and training during the processes of establishing hatchery systems, infrastructure for hatcheries, juvenile culture and ranching, and governance arrangement with local government and People's Organisations (POs). The nature of tenure agreements varied depending on the type of organisation engaged at the local level, and the nature of institutional support for each community. This process of engaging new project partners fed directly into the development of approaches for scaling to industry.

Sea cucumber fishing was traditionally a gleaning activity – it occurred in the littoral zone, and women were often central to its operation. Given the potential of sea ranching to contribute to women's livelihoods, but also the tendency for women's voices to be lost in governance processes, the SEAFDEC team conducted a detailed case study on gender and community engagement. This initiative aimed to examine the gender differences in fishing activities, the involvement of the women and men in sandfish *H. scabra* collection and trade, and to determine how these factors affect the willingness of the community in engaging in the sandfish sea ranching project. A series of focus group discussions (FGDs) and semi-structured interviews were conducted with 60 household involved in the collection and trade of sea cucumbers. Household surveys asked questions about households' socio-demographic characteristics, knowledge of the coastal and marine resources, and awareness of the *H. scabra* sea ranching project.

Australia:

The Northern Territory, Australia has one of the last remaining sustainably fished tropical sea cucumber fisheries in the world which, unlike many of its Indo-Pacific counterparts, is

[1] "Tropical Cyclones in 2013". Retrieved March 5th, 2020

subject to strict fisheries management and is devoid of significant poaching activity (Fleming, 2012). A single commercial operator (Tasmanian Seafoods Pty Ltd) owns all available licences, while Aboriginal peoples own 85% of the Northern Territory coastline including the intertidal zone (Bowman, 2012; Fleming, 2015) – a context which poses a range of atypical environmental challenges for sea cucumber farming. Additional challenges include extreme tidal variations of up to eight meters, strong tidal flows of up to 2.5 m/s, site access difficulties and the presence of abundant saltwater crocodiles (Williams et al., 2006).

The project worked with Tasmanian Seafoods Pty Ltd and the Warruwi community to test the viability of sea cucumber ranching as a supplemental income for the community (**Activity 4.2**). Warruwi is a small remote settlement on South Goulburn Island located about 280 km northeast of Darwin, and 3 km off the West Arnhem Land coast. In 2016, Warrawi was home to 366 Aboriginal people (ABS 2016). The project relationship with the Warruwi community originated from a request from senior Aboriginal Traditional Owners (TOs) to build on a history of sea cucumber harvesting and an early attempt at ranching (Fleming, 2015). In the mid-1700s, the people of Goulburn Island worked and traded goods with the Macassan seafarers from Indonesia who visited the coast seasonally to fish for sea cucumber (Clark & May, 2013). A Methodist mission was established on the island in 1916 and existed until 1974, during which time food and funds were generated through harvests of sea cucumber, oysters, mussels, dugong, turtle, and fish (McKenzie, 1976; Stanley, 1985). In the early 2000s there was an unsuccessful attempt to set up a sea cucumber ranching enterprise (Gould, 2015). By 2005, TOs at Warruwi were searching for ways to generate income for the community and a consultant was engaged to develop business plan based on trepang aquaculture (Realfish, 2005). This did not progress further until the current opportunity was recognised.

An open sea ranch similar in dimensions to those in the Philippines was established at Wigu, an allocated aquaculture trial area on Goulburn Island. Physical challenges associated with the site meant that the Philippines model could not be directly replicated. Despite several trials of different approaches, we were unable to develop a sea cage system that could withstand both the strong tidal flow and possibly the occasional crocodile interaction. Additionally, field methods needed to be carefully orchestrated and adequately resourced to be completed within a 2–4 hr low-tide window, over 3–4 days during spring-tides (lows of >1 m were required).

Environmental mapping (49-point survey) was undertaken over three consecutive years (2015 – 2017) at the Wigu site, using a modified approach to the Philippines methods to allow completion within low, spring-tide windows. As cages could not be constructed at the site, growth was estimated by fluorochrome tagging (see methods by Purcell and Blockmans, 2009) of all batches of juveniles released, enabling recaptures to be allocated to a release batch and differentiated from wild recruits. These methods involve juvenile sandfish being immersed in a dilute bath of fluorochrome dye (e.g. calcein or tetracycline) for approximately 20 hours. The stains are taken up in the calcareous ossicles within the body wall. Skin samples are then taken from recaptures sea cucumbers, and stained ossicles detected within the sample using fluorescence microscopy. Juvenile sandfish were produced as a contribution to the project in a commercial hatchery operated by Tasmanian Seafoods at the Darwin Aquaculture Centre (DAC), and fluorochrome tagged by DAC project staff before being transported by air to Goulburn Island for releases. Juvenile sandfish were released at the Wigu site in August 2012 (1,400 for the release method trials – see below), April 2014 (14,000 juveniles) and February 2016 (4,200 juveniles for survival/growth trials).

The 2012 juvenile sandfish release was structured around a replicated trial of feasible mass release methods. The massive tidal range, the abundance of saltwater crocodiles and cultural norms and traditions regarding the ocean mean that boat based methodologies for release were necessary. However, small juvenile sandfish are generally most vulnerable to predation during the minutes to hours immediately following release due to high visibility, and possibly poorly developed natural behaviours such as burying (Purcell, 2004; Purcell and Simutoga, 2008). The challenging tidal conditions at Goulburn Island also present the risk of newly released sea cucumbers being rapidly swept away from the release site increasing mortality and reducing potential for later harvesting. Two contrasting release methods were investigated– a temporary cage, protecting juveniles for 24 hrs after release, and a quick-release chute method. Recapture surveys were conducted 20 weeks post release, and skin samples taken from all sandfish <250 mm to identify released individuals.

To estimate survival and growth following the February 2016 release, wide area surveys using a structured transect method were conducted at the site in October 2016 and January 2017. The 5ha ranching site was divided into 3 zones, sampled with decreasing intensity with distance from the release site. All sandfish within realistic size categories (given known growth rates) for the released animals (<200mm length) had a skin sample taken for later laboratory analysis to identify hatchery reared individuals, facilitating estimation of growth and apparent survival.

Finally, to test possible modalities for commercial arrangements between community members and Tasmanian Seafoods, two trial harvests were conducted at the ranching site in October 2015 and March 2017. The harvest was limited to 2 hrs per day centred on low tide and community members were paid by the kilo at the same rate commercial divers are paid by the company. Preliminary training in first stage processing was provided by Tasmanian Seafoods onboard their sea cucumber fishing vessel following the harvests.

6 Achievements against activities and outputs/milestones

Objective 1: To improve efficiency and adaptability of sandfish hatchery systems

no.	activity	outputs/ milestones	completion date	comments
1.1	Improve knowledge of optimal feeding regimes for small scale hatcheries (DAC and USC)	2 hatchery runs per year completed (DAC and PNG)		Production at DAC sufficient to supply field trials A minimum of two hatchery runs conducted per year in PNG that were sufficient to supply research need in field trials and for larval nutrition experiments.
		Basic tissue composition of larvae analysed		Larval nutrition research was carried out by JAF PhD project of Nguyen Duy. His research showed that commercially available micro-algae pastes (Reed Mariculture, USA) is ingested and can be digested by sandfish larvae. Duy, N.D.Q., Pirozzi, I. and Southgate, P.C., 2015. Ingestion and digestion of live microalgae and microalgae concentrates by sandfish, *Holothuria scabra*, larvae. *Aquaculture* 448, pp. 256-261. Growth trials showed that micro-algae concentrates can be used to replace live micro-algae as a food for sandfish larvae. This greatly simplifies hatchery culture methods. As a result of this work, live micro-algae are no longer cultured or used for hatchery culture of sandfish in PNG. Duy, N.D.Q., Francis, D.S., Pirozzi, I. and Southgate, P.C., 2016. Use of micro-algae concentrates for hatchery culture of sandfish, *Holothuria scabra*. *Aquaculture*, *464*, pp.145-152. Relative ingestion/digestion rates and nutritional values of individual Reed Mariculture products were compared. This has allowed optimisation of diets used in hatchery culture. Analysis of the nutrient compositions of Reed Mariculture products has allowed key nutrients for sandfish larvae to be identified. Duy, N.D.Q., Francis, D.S. and Southgate, P.C., 2017. The nutritional value of live and concentrated micro-algae for early juveniles of sandfish, *Holothuria scabra*. *Aquaculture*, 473, pp.97-104. Tissue sampling methods for sandfish larvae were developed. Samples of fed and starved larvae through development were analysed. Quality of diet influenced survival, and a method for assessing larval quality and predicting settlement success was developed. Duy, N.D.Q., Francis, D.S. and Southgate, P.C., 2016. Development of hyaline spheres in late auriculariae of sandfish, *Holothuria scabra*: Is it a reliable indicator of subsequent performance? *Aquaculture*, 465, pp.144-151.
		Trials on settlement success and diet vs tissue composition complete and published		

1.2	Facilitate staff and PhD interchanges	Reciprocal visits between facilities by PhD students facilitated		A substantial PhD student exchange occurred through Nguyen Duy spending an extended stay in PNG to assist Cathy Hair (PhD student under FIS/2010/054) with refining hatchery methodologies and conduct feeding experiments with algal pastes. Further exchanges were limited by restrictions on hatchery use/exchanges imposed by the commercial partner.

Objective 2: Improve efficiency and adaptability of sandfish nursery and growout systems

no.	activity	outputs/ milestones	completion date	comments
2.1	Refine and test ocean nursery systems	Ocean nursery established and monitoring protocols with communities instituted		Ocean nursery systems established in 4 nodes in Philippines. Models for community involvement in nursery systems tested and refined. A diverse toolkit of methods is necessary for a range of physical, climatic and governance contexts. Trials aimed at improving ocean hapa management conducted at the SEAFDEC Igang Marine Station showed that a) initial stocking densities of <500 individuals per (2m^2) hapa were optimal; b) size grading positively influenced growth and survival, but did not mitigate growth heterogeneity, and c) under conditions present frequent net replacement did not influence survival and growth. In Northern Luzon, trials in organic enrichment of sediment using *Sargassum* sp. for advanced nursery grow-out in Silaqui Island resulted in significantly higher biomass and overall survival after 30 and 60 days or rearing. Sinsona, M.J. and Juinio-Meñez, M.A., 2018. Effects of sediment enrichment with macroalgae, Sargassum spp., on the behavior, growth, and survival of juvenile sandfish, *Holothuria scabra*. *Aquaculture Reports*, 12, pp.56-63.
		Manipulative experiments to optimize growth, survival, and density in ocean nursery systems commenced (UPMSI and PNG)		**Northern Luzon:** Experiments in NL investigated the effects of periphyton quality, water quality and environmental parameters on growth and survival of juveniles. Periphyton with high chlorophyll-a and lower autotrophic index (AI - relates to colonization stage and trophic state) was favourable in the first 30 days of growth, while low ch-a and high AI produced higher growth rates in the subsequent 30 days. Results clearly show a feeding shift that must be considered in nursery systems Sinsona, M.J. and Juinio-Meñez, M.A., 2019. Periphyton characteristics influence the growth and survival of *Holothuria scabra* early juveniles in an ocean nursery system. *Aquaculture Research*, 50(9), pp.2655-2665. **Western Visayas:** Comparative trials in a replicated experimental system at the SEAFDEC aquaculture station (Iloilo) showed that low densities of juveniles of < 500 post settlement individuals in a 2m^2 hapa improved growth and survival compared to higher densities. Size grading was effective at improving survival, while hapa net changes to reduce fouling were of limited value given the slow fouling rates at the experimental site. **Eastern Visayas:** Completed 3 floating hapa trials between Dec 2014 and May 2016 at Bagonbanua Island, Eastern Samar. Early survival was low, at about 12%. It was speculated that rough sea conditions, particularly from December to April, had a substantial impact. A number of nets were overturned by sea conditions, resulting in zero survival. Design modifications with heavier weights

				attached to the four bottom corners did not fix this issue, with all remaining cages overturned in the next monitoring period. The small amount of growth data obtained, as well as the issues with mechanical disturbance suggest more sheltered waters should be sought, and best survival and growth will be achieved in the months of April to June. **PNG:** trials were successful in growing early juveniles transferred directly from larval rearing tanks to fine mesh suspended hapa nets in seawater (sensu Vietnamese grow-out system). This has reduced tank-culture duration and provided additional area for production of release-size juveniles. A replicated experiment has helped determine optimum stocking density and the requirement for artificial substrate in the hapas
		Different hapa design (e.g., floating hapa, bottom-set hapa cages) field tested and evaluated (UPMSI and PNG)		**Northern Luzon:** Juveniles were successfully reared in floating hapas managed by community partners belonging to people's organizations in 3 communities (Brgy. Victory in Bolinao, and Brgy. Imbo and Cabungan in Anda, Pangasinan). With this, the community partners also earned supplemental income from the juveniles reared. Bag nets, which are completely enclosed rectangular coarse meshed nets held together by bamboo frames and anchored to the sediment (10 x 10 m and 1.25 x 3.2 m), were tested as an intermediate nursery system for release-size juveniles (>3 g) in the Imbo restocking site. Results showed low growth and high mortality due to high fouling rates.
		Pilot-test community-based nursery rearing of sandfish juveniles to release size near sea ranching sites in northwestern Luzon		**Eastern Visayas:** A community-based approach of rearing sandfish juveniles to increase release size (from 5 g to >10 g) was tested by setting up bottom-set sand-conditioning hapas. Sandfish juveniles (>3 g) grew to an average of 6.1 grams with 91% survival rate over a month and an average of 10.1 g with 93% survival rate (when they were graded by size) after two months. Cleaning the nets every 15 days facilitated the natural exchange of water. Sand conditioning of juveniles improved outcomes and survival rate when released to the sea ranch. However, rearing sandfish juveniles for three months (or more) inside the bottom-set sand-conditioning hapas reduced both size and survival as sandfish density became a limiting factor **PNG:** Hatchery-produced juveniles were grown out in floating, fine-mesh bag nets deployed in protected channels. Local village labour was used to clean and maintain nets, with supervision by project staff. Growth in bag nets was slow compared to other methods but did relieve major issues with space in the hatchery. Grading bag net juveniles led to minor improvements in growth. Cleaning and regular exchange of fouled nets improved outcomes
		Protocols and training manuals for community nurseries produced		Community-based pilot trials of adoptability of floating hapas as nursery systems were conducted through the DOST project in partnership with Palawan Aquaculture Corporation in Coron Palwan and Alson's Aquaculture Corp in Saranggani Bay (Juinio-Meñez et al. 2017). Training of research and academic institutions and BFAR on ocean nursery rearing was conducted at the Bolinao Marine Laboratory with the assistance and support of ACIAR funded research personnel and the ACIAR project ocean nursery for demonstration.

				Experience from training was utilised in the drafting of protocols for collation into a manual, however this remains in draft form
2.2	Assess mass release, sand conditioning and harvest methods (DAC)	Develop and construct release and harvest prototypes in partnership with industry. (DAC)	2013	Two boat-based release techniques were trialed: temporary, floorless cages; and a chute. Sea cucumber recovery rates, dispersal distance and direction were compared to assess the relative merit of each. The proportion of sea cucumbers recovered from the chute release treatment (18.9%) was significantly higher than those from the cage release treatment (10.6%). given the significantly higher recovery rates, lower cost, ease of construction and efficiency, the chute release method proved superior. Taylor, A.L., Nowland, S.J., Hearnden, M.N., Hair, C.A. and Fleming, A.E., 2016. Sea ranching release techniques for cultured sea cucumber *Holothuria scabra* (Echinodermata: Holothuroidea) juveniles within the high-energy marine environments of northern Australia. *Aquaculture*, 465, pp.109-116.
		Prototypes tested in partnership with Goulburn Island community, Assess efficiency, environmental impact and practicality of use. (DAC)		
		Assess community acceptance of release and harvest prototypes methods		At the completion of the project, community members were actively using the release method On Goulburn Island the Yagbani Aboriginal Corporation were considering options to invest in a processing facility to value add to the harvest and sell first stage (as opposed to green) product to the industry partner. (Post project: This investment into a processing facility did not eventuate as the commercial company TSF did not continue to release trepang at Wigu. They have been focusing on developing their hatchery and nursery systems in Darwin and have not had ongoing contact with the community. The community has decided to focus on growing tropical oysters which does not involve a commercial partner.)
2.3	Assess opportunities for pond culture in Philippines (SEAFDEC AQD)	Establish ongoing monitoring of conditions in selected marine ponds (minimum 5)		Extensive monitoring of test ponds in 4 areas (Capiz, Antique, Iloilo and Guimaras) showed no ponds to be suitable for culture due to 1) regular low salinity events due to rain and lack of regular tidal flushing 2) substrate too silty as ponds are almost invariably in converted mangrove areas and 3) ponds were too shallow (typically 0.5m) leading to thermal instability.
		Identify commercial hatchery partner commence modification to sandfish hatchery		As ponds in Philippines were shown to be unsuitable for sandfish culture, and a regular market for juvenile sandfish had not been established, it was not plausible to engage a commercial hatchery prepared to invest time into sandfish hatchery development. However the benefits and learning from 'scaling out' developed systems were still judged to be worthwhile, as was adding to the production capacities of this node. A local academic institution, Northern Iloilo Polytechnic State College (NIPSC) in Concepcion, Iloilo partnered with the project to diversify hatchery production, and was able to produce large numbers of larvae.

		Assist commercial hatchery to produce 10,000+ sandfish juveniles per year		The NIPSC hatchery in Concepcion, Iloilo demonstrated good spawning runs, producing as much as 23M larvae in a run, although optimal capacity for larval rearing is currently only at 0.5 M. 5,864 early juveniles produced. Problems with power interruptions causing high mortality were a persistent issue.
		Laboratory experiments on survival in Philippine ponds completed		Laboratory trials completed at SEAFDEC showed typical pond conditions in Philippines are not suitable for sandfish culture, and that continued investment in diversified approaches to sea ranching and stock enhancement were more likely to be productive. Altamirano, J.P., Recente, C.P. and Rodriguez Jr, J.C., 2017. Substrate preference for burying and feeding of sandfish *Holothuria scabra* juveniles. Fisheries research, 186, pp.514-523.
		Pond trials with industry partner completed		Pond trials not undertaken due to experimental findings (see above) – typical Philippine ponds are only good for nursery stage, over 3-4 months in the dry season when temperature fluctuations and inundation by seawater are at a minimum.
2.4	Test integrated community enterprise systems in Vietnam (RIA3)	Partnerships with shrimp farmers in Cam Ranh established, and information session held		Changed market conditions made establishing industry partnerships difficult. An unexplained low price, and a reluctance of buyers to buy cultured sea cucumbers, combined with high price for shrimp (due to disease issues elsewhere) and new market interest in Babylon snail, meant that farmers generally did not want to spend the time and commit the pond area to grow sea cucumbers at this time. The risk/return ratio had 'flipped' to squarely favour shrimp over sea cucumber. We conducted a survey engaging 20 out of the 30 former sea cucumber farmers to understand their decision making processes. Of the 20, only 4 were still farming sea cucumbers, and then only in small quantities. Most had switched to focus on other species (white leg shrimp, Babylon snail). Most farmers were not keen to move back to farming sea cucumber in the near future, and for many the price would have to double or triple over current levels for them to consider it. Eventually, a partner was identified and trials commenced some months late.
		Nursery ponds seeded and ranching areas established		Two nursery trials with different juvenile densities in hapa nets (from 5mm to 2g with 400, 800, 1200, 1600/ m^2) and in advanced nursery pond (from 2g to 20g with 2, 4, 8, 12/ m^2) under Project's support. Highest survival rate for 400/m^2 was 80.5% in average after 6 weeks and growth from 2g to 20g took 5 weeks with 2 sandfish/m^2.
		Small-scale ranching releases completed		Size-at-release trial established in 6 seapens at one site in Cam Ranh Bay. The survival for sandfish released at 10g body weight was zero after one month, and for 20g survival was 30% on average (highest was 61%) with sandfish reaching 230g after 5,5 months. The cause of mortality was mainly predation by blue swimming crab (*Portunus pelagicus*)
		2 large-scale ranching areas established		Large scale ranching trials did not proceed, as mortality rates from cage experiments were many times higher than seen in ponds, and the use of limited project resources to continue testing ranching was not seen as productive.

		Plausible enterprise structures established and documented in information sheets and scientific publications		Clear outcomes from project activities in Vietnam were: 1) In central Vietnam, ranching is unlikely to be viable due to issues with predators (most notably crabs) and possible theft of stock 2) In a context where pond farming has been, and can, in the right market conditions, continue to be productive and profitable, investing in diversifying production systems into sea ranching is unwise. Instead, further efforts to develop co-culture systems for pond farming are warranted and may be a pathway to improved livelihoods for pond farmers, and improved environmental and economic resilience of farming systems. 3) Global markets for cultured invertebrates are fickle. Resilient livelihood among small-scale pond farmers can best be developed through processes that a) provide current market data and forecasts to farmers, b) enable proactive responses from farmers in switching species in response to market conditions. This in turn can best be supported through infrastructure such as hatcheries that are adaptable to market demand.

PC = partner country, A = Australia

Objective 3: Develop capacity to identify suitable sites for ranching using bio-physical indicators

no.	activity	outputs/ milestones	completion date	comments
3.1	Conduct experiments to understand bio-physical determinants of growth and survival (Australia and Philippines)	Establish cage experiments at one site in Philippines and one site in Australia		For sites in Philippines and PNG, regular monitoring, coincident with measurements of growth and recapture rates was conducted in pens at a total of 10 release sites over durations of up to 24 months. Analysis shows that while organic matter and seagrass density have some influence, local and idiosyncratic drivers appear to dominate, making predictive modelling difficult at this broad scale. Conditions at Goulburn Island proved too extreme (strong tidal flows) for cages to be maintained for any useful experiments to take place Effect of sea cucumbers on sediment composition in sea ranch areas were tested in Maliwaliw Is., Eastern Visayas by monitoring environmental indicators over 1 year in stocked sea pens. Results showed no differences between control and stocked pens with densities of up to 2 sandfish/m2 with weights averaging ca. 350g at the end of the trial. de la Torre-de la Cruz, M., Villamor, J., Diodoco, R.J. (2018). Effect of *Holothuria scabra* (Jaeger) on Particle Size Composition and Components of Sediments. *Environment Asia* 11(3): 148-160.
3.2	Conduct regular fine-scale environmental	Review current knowledge and develop protocols for bio-physical	Dec 2013 (with modifications	A set of field and laboratory methods was developed by Cathy Hair in collaboration with the Philippines project team following team inputs at the first annual meeting. This included methods for repeated fine-scale monitoring of temperature, percent cover of sea-grass (shoot density and species cover), number

	monitoring at ranching sites to better understand relationships between bio-physical parameters, growth and survival	indicator assessment work.	following later experience)	of sea-grass species, canopy height, percent cover of other macrophytes, sediment penetrability, biofilm index, sediment (LOI and grain size), chlorophyll assay and anoxic layer depth. A modified methods manual was developed for the unique conditions in NT (notably extreme tides and crocodiles).
		Implement monitoring protocols across all sites in Philippines, Australia, Vietnam and Philippines		Regular monitoring of high resolution grid (up to 49 points per site) conducted at 7 sites in Philippines and Wigu, NT. Sites are samples in one (2 sites), two (3 sites) or three (2 sites) years. Analysis shows substantial variability between and within sites, and that year-to-year variability of important parameters such as organic content is of similar magnitude to differences between sites exhibiting high and low growth rates. Eastern Visayas: Factors affecting the distribution of sandfish of various sizes in relation to the biophysical characteristics in the natural environment were studied at the Maliwaliw Is. ranching site, Salcedo, Eastern Samar. Results suggest the importance of having various sediment particle size and composition to support the ontogenetic shifts in habitat preference by different life stages of growth and development of the sandfish in sea ranch sites. (**STATUS:** *READY FOR PUBLICATION*) Villamor, J., de la Torre-de la Cruz, M., Diodoco, R.J. Movement of Sandfish (*H. scabra*) Juveniles Released on Sea Ranch in Maliwaliw Island, Salcedo, Eastern Samar, Philippines

Objective 4: Develop tools, technologies and capacities to engage and train communities in sandfish culture

no.	activity	outputs/ milestones	completion date	comments
4.1	Develop and test models for establishing learning sties as a vehicle for scaling out (Philippines)	Training of partner institutions by UPMSI or SEAFDEC on hatchery and nursery production of sandfish larvae and juveniles commenced		First training on sea ranch and exposure trip to pilot sandfish sea ranch site in northwestern Luzon for MSUN, GDFI, and SEAFDEC in UPMSI (Dec 2011) MSI training on hatchery and ocean nursery systems for MSUN (Oct 2011, April 2012) and SEAFDEC (2012) MSI trained all partners on floating hapas and ranching (Jan 2013) SEAFDEC provided hatchery training and nursery training for GDFI, BFAR and MSUN (Oct 2013) SEAFDEC provided in-house and on-site training and assistance to partner institutions and local collaborating communities Training in hatchery techniques was established as a regular course at SEAFDEC Aquaculture Department, with students from around the world attending – while not directly financially supported by the project, the course was a development from project (and related) activities.
		MSUN sandfish hatchery construction completed	January 2014	Hatchery facility completed with an estimated rearing capacity of 3 million fertilized eggs per spawning induction

		Culture sandfish for ranching at learning sites		Northern Luzon and Western Visayas nodes were generally able to produce adequate juveniles for releases although did not consistently hit (but sometimes also exceeded) project targets for releases at individual sites. Following the impact of Super Typhoon Yolanda, the Eastern Visayas node in particular struggled, releasing some 8000+ juveniles in total over the project duration (target 10,000 in year 1, then increasing). The Mindanao node struggled in year 1, but production steadily improved ultimately resulting in the release 23,000 juveniles in the final year. Most commonly, while production of stage 1 juveniles was adequate (once early hatchery issues were sorted out), bottlenecks existed post settlement, and thus numbers available for release were at times limiting.
		Collaborators assisted in site selection and initial bio-physical monitoring (UP-MSI)		All sites selected as per project design and on time. Bio-physical monitoring training was the major focus of the first annual project meeting, and ongoing mentoring was provided in Philippines by UPMSI and externally by Cathy Hair (through interactions with project FIS/2010/054).
		Serial establishment of governance arrangement across all Philippine nodes		**Northern Luzon:** March 2015: Executive order signed by Local Government Unit in Anda protecting the restocking site, and implementing size limits. March 2016: Expansion sites in Barangay Cabungan, Anda, and Bintuan, Coron initiated through community-based floating hapa trials and consultations with municipal and village officials, the latter in conjunction with DOST project. (note main site at Victory has long been established, and no further developments required here) **Western Visayas:** 2014: Executive order with Local Government Unit (LGU) in **Conception**, Iloilo signed for 5 Ha ranching site. Technical working group headed by the Mayor established to assist with management of ranching site an unrelated MPAs. 2015: MOAs signed for sea ranch site at Pandaraonan, Guimaras; LGU and governance arrangements completed at Sagay site. **Eastern Visayas:** March - August 2013: A MOU and municipal ordinance were developed through a consultative process with local CSOs, stakeholders and government, and the resolution passed by local government declaring 20 hectares of identified sites in Maliwaliw Is. for the exclusive use of the project and partners. The Bureau of Fisheries and Aquatic Resources (BFAR) agreed to provide 20,000 sea cucumber juveniles per year for the project. **Mindanao:** Dec 2014: MOA was signed for sea ranch site at Tubajon, together with MSUN Chancellor, Mayor of Laguindingan and community association President.

				June – Aug 2015: Entry protocols developed with Barangay Mood, Laguindingan (for hapa nursery experiment), and Kauswagan Lanao del Notre. Dec 2015: Barangay Resolution approved declaring a 5 Ha sea ranching site in Barangay Poblacion, Kauswagan.
		Baseline socio-economic profiles of partner communities completed	2015	**Northern Luzon** - Socio-economic profiles completed in 3 ranching communities, and 3 communities adjacent to the restocking site (Anda). **Western Visaya**s – SE profiles completed at 2 ranching sites. Coastal resource mapping also completed with 2 communities. Relatively low numbers of households were traditionally involved in sea cucumber harvest (8%, 23% for the two communities) although > 90% of family income came from fisheries. **Eastern Visayas** – Barangay profile completed for 1 site, and socio-economic profiles obtained for 60 households. In contrast to Western Visayas, 74% of households were traditionally involved in sea cucumber fishing. **Mindanao** – Socioeconomic profiles completed at 3 sites.
		Training manual on sea ranching prepared Coordinate training-workshop for local partners to improve quality of beche-de-mer (UPMSI) Perception surveys of impacts of ranching conducted	June 2014	Community training approaches have been tested across all nodes and lessons shared via a) involvement of research staff in site establishment across nodes, and b) sessions on community engagement at project meetings. While a manual remains in draft form, components are regularly being utilised and refined through increasing engagements in related projects. Training conducted at BML with PO partner (SMMVI) in collaboration with a DOST Funded Project. Western Visayas: A stakeholder feedback workshop was held in 2017 with participants from the project community, government officers and members of local academe. Recommendations included: 1) to strengthen law enforcement and support from government, 2) to increase communication and information provision to all stakeholders, 3) to increase and enhance capacity of NIPSC hatchery, and 4) to consider other sites for expansion of sea ranching activities. Perception surveys were not conducted at other sites, but are a component of the social research initiated under continuation project FIS/2016/122.
		Information materials for dissemination to LGUs and community prepared Comparative analysis of different		Experience with engagements with diverse communities in the four Philippines project regions will be incorporated into a manual produced in continuation project FIS/2016/122.

		institutional and management arrangements		A paper on governance approaches is in draft form.
4.2	Test and refine models for integration of release strategies into improved models for community-based resource management (Philippines)	Sustainability plans for sea ranch site implementation and integration of sea ranch as part of sea cucumber fishery management developed Assessment of attitudes, uptake and compliance to sustainability plans		The Northern Luzon node has progressed a draft executive order covering the sustainability of sea cucumber fisheries and local environment, however this was ultimately derailed towards the end of the project by local government elections. The project did not have the capacity to re-engage with new leaders to redevelop momentum for the sustainability plan. The importance of gendered perspectives in governance arrangements was emphasised, as invertebrate fishing has traditionally been a highly gendered activity generating income for women through fishing, processing and marketing. The Western Visayas project node conducted a pilot study on women's engagement in fishing in a ranching site. Suyo, J.G.B. and Altamirano, J.P., 2018. Mapping gendered spaces for sandfish resource management in Guimaras, Philippines. *Fish for the People* 16(2), pp 20-25.
4.3	Expand Australian trials to 3 sites and facilitate broader community engagement and test broader applicability (Australia)	Conduct pre-surveys on sites (one new, two on recently harvested grounds from previous releases), construct 4 experimental pens on new site, and harvest marketable stocks off sites.		Large scale biophysical survey grid completed at Wigu site. Additional sites identified and community negotiations commenced. Due to historical relationships a lot of mistrust exists between communities and the industry partner (Tasmanian Seafoods) (on both sides). The industry partner developed an MOU with the key community organisation (Yagbani Aboriginal Corporation on South Goulburn Island). Although interest has been expressed by two additional communities (Groote and Maningrida) the Industry partner was not on board, preferring to see more success (in the form of more harvests and the MOU agreement) on Goulburn before committing to other communities. They would like Goulburn to be the "spearhead" of this area of their development. Numerous efforts with different approaches and designs demonstrated that using pens was not possible with the extreme tidal currents at this site (in excess of 8m tidal range), with trial pens likely also being damaged by crocodiles. Large-scale biophysical sampling was conducted, however cage experiments were abandoned at this site.
		Produce 30,000 juveniles in hatchery, stain them and fly 10,000 to each site. Facilitate community releases. Community releases		• 22,000 juveniles released in multiple batches at the Wigu site, with batches used for release method and size/growth trials • Staining techniques for assessing survival modified, streamlined and tested. Taylor, A., 2016. A modified method for processing fluorescently marked sea cucumber ossicles. SPC Beche-de-mer Bulletin, p.54. • Community members trained (including Cert 2 in Aquaculture) and engaged in releases at Goulburn Wigu site.

		completed at 3 sites		• Monitoring and reporting of growth and survival (including stain assessment) occurred in October 2016 and January 2017.
		Seek community advice on preferred engagement activities for different sectors of future enterprise participants (women, men, and youths).		Early focus was on laying the foundations for healthy partnerships between communities and the industry partner, as a relationship and degree of trust between partners was recognised as an important precondition for success. Social engagement research with communities was expanded beyond the limited scope of the project, and was funded separately. The contracted partner (externally funded) produced a report titled "Yagbani Aboriginal Corporations Trepang (sea cucumber) Enterprise on Goulburn Island Prospectus". The report was, unfortunately, overly simplistic and disappointing in quality. Economic assessments included in this contract were overly simplistic, and ultimately not useful. Women and youth were a strong focus of extension activities with 2 community women enrolling in a Cert 2 in Aquaculture, and further project planned to build this engagement. Five women were actively involved in ranch releases, and the 2016 release on Goulburn was conducted (as boat skippers) by women who had recently gained their restricted coxswains tickets.
		Conduct harvest of released stocks at 3 sites. Collect data for economic analysis		An agreement was finalised between Tasmanian Seafoods (industry partner) and Yagbani Aboriginal Corporation (the local community governance organisation on Goulburn Island) for a joint community harvest (including training in processing) in Oct 2015. This went well with 548.6kg harvested over two days (two low tides= ~4 hours) by eight community members (from the Yagbani Aquaculture traineeship team). Community members were paid $10/kg for green sandfish and were also trained on board TSF vessels in first stage processing. Catch per unit effort: 8.3kg/person/hour (on average). A second harvest conducted in March 2017 yielded similar numbers. Growth and survival results: Total average growth was: ~195.3g at 8 months post release and ~349.3g at 12 months post release, with a release weight of 2.7 g. Approximate harvest weight is >350g and minimum length of 16 cm. Therefore most animals would be of a harvestable size 12 months post release at Wigu. Harvest training videos were developed (in local language with English subtitles).
		Assessment of economic viability made, economic and biological assessment of repeat releases made, identification of key criteria for optimal site made.		This milestone was not met. As mentioned above a consultant report from 2014 included an economic assessment, however this report did not include relevant data that was generated in the project and data post 2014 (notably the harvest data). Enough data now exists from this work to put biological viability and site selection assessments together.

PC = partner country, A = Australia

7 Key results and discussion

7.1 Improve efficiency and adaptability of sandfish hatchery systems

Although reliable hatchery methods for sandfish were well established before this project (Agudo, 2006; Duy, 2010) hatchery production relied on simultaneous culture of live micro-algae as a larval food source. Furthermore, very limited knowledge of the nutritional requirements of sandfish larvae prevented development of improved larval nutrition supporting enhanced hatchery production. Culture of live micro-algae is technically demanding and often beyond the capacity of developing country facilities, and so a key component of this project objective was to assess the nutritional value of 'off-the-shelf' commercially available micro-algae concentrates as potential replacements for live micro-algae in sandfish hatchery culture. Key results were:

Ingestion and digestion of micro-algae concentrates: Ingestion and digestion of two live (TISO and *Chaetoceros muelleri*) and six concentrated microalgae (Instant Algae®, Reed Mariculture Inc.) by sandfish (*Holothuria scabra*) auricularia larvae of different ages were assessed using epifluorescence microscopy for the first time with larval echinoderms. Experiments were conducted using 2, 6 and 10 day-old auricularia larvae. Seven of the eight microalgae tested were ingested and digested by the larvae with digestion occurring more rapidly in older larvae. *C. muelleri* was rapidly digested by 6-day and 10-day old larvae but our results indicate that *C. muelleri* is unsuitable as a food for 2-day old sandfish larvae. TISO was well ingested by sandfish larvae in both live and concentrated forms and live TISO was the most suitable of the microalgae tested in terms of ingestion and digestibility. All commercially available microalgae concentrates tested were readily ingested and digested by *H. scabra* larvae with the exception of *Thalassiosira pseudonana* (3H 1800®) which was not ingested by larvae of any of the three ages tested. Results show potential for using microalgae concentrates as alternatives to live microalgae in hatchery culture of sandfish. However, further research was required to assess the relative nutritional values of digestible microalgae as a basis for optimising a diet for hatchery culture of sandfish, and to provide further information on the nutritional requirements of sandfish larvae.

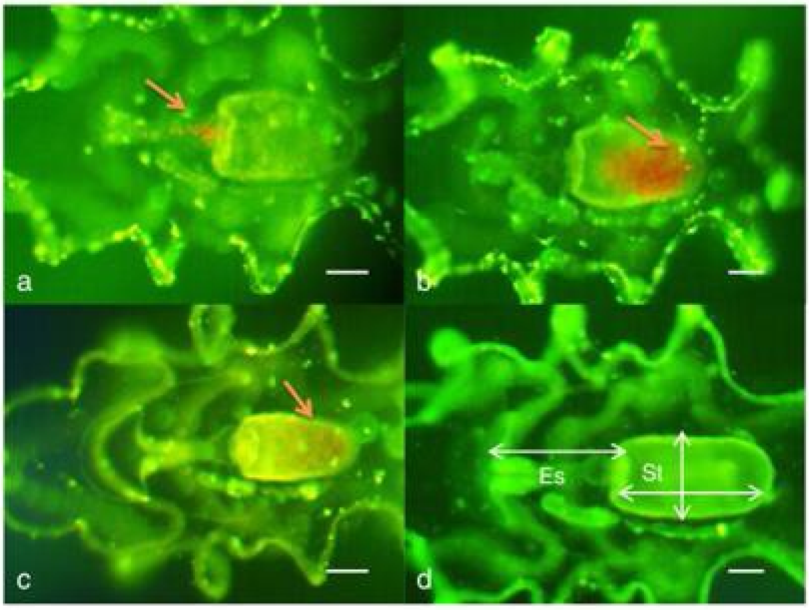


Figure 3. Photosynthesising pigments of micro-algae cells in the stomach of sandfish auriculariae fluorescing under blue-light illumination representing different stages of ingestion and digestion: (a) red fluorescence of

whole micro-algae cells in the oesophagus but not in the stomach (arrow); (b) red fluorescence of ingested by undigested micro-algae cells in the stomach; (c) pink and orange fluorescence of digested micro-algae cells in the stomach; and (d) empty stomach without fluorescence. St, stomach; Es, oesophagus; Scale bar = 100 µm.

Use of micro-algae concentrates as larval diets: Three Instant Algae® (Reed Mariculture Inc., Campbell, CA, USA, 95008) products: (1) mono-cultured *Isochrysis* sp. (Haptophyceae) (Isochrysis 1800®); (2) mono-cultured Pavlova sp. (Haptophyceae) (Pavlova 1800®); and (3) mono-cultured *Thalassiosira* weissflogii (Bacillariophyceae) (TW 1200®) were used to feed sandfish (*Holothuria scabra*) larvae both singly and in ternary combination to assess their nutritional efficacy. Auricularia larvae were held at an initial density of 0.3 mL^{-1} and received an initially daily ration equivalent to the dry weight of 10,000 cells mL^{-1} of Isochrysis 1800®, increased by the dry weight equivalent of 1000 cells mL^{-1} of Isochrysis 1800® per day as larval development proceeded. Post-settled larvae fed TW 1200® were significantly larger than those fed the ternary diet, Isochrysis 1800® or Pavlova 1800®. There were significant differences in the mean (± SE) survival of auriculariae and post-settled larvae between treatments and survival to settlement was significantly higher ($P < 0.05$) for larvae fed TW 1200® (13.7 ± 0.7%) alone. Laval development, competency and survival were significantly correlated with dietary levels of total protein, lipid and nitrogen-free extract (NFE), and with total polyunsaturated fatty acid (PUFA) content of the diets, and the levels of some specific fatty acids (FA). The proportion of late auriculariae with hyaline spheres (day 13), numbers of competent doliolariae (day 15) and the total length of post-settled larvae (day 21) were all positively correlated with dietary NFE and palmitic acid (16:0) contents, as well as dietary EPA: DHA ratio. This study was the first comprehensive assessment of the nutritional value of micro-algae concentrates for sandfish larvae based on their nutrient compositions. Results confirmed the feasibility of using commercially available microalgae concentrates as a sole food source for hatchery culture of sandfish, and were the first to report successful hatchery culture of *H. scabra* without using live micro-algae. All micro-algae concentrates used in this study proved nutritious for *H. scabra* larvae and supported normal growth and development and relatively high survival, through settlement. Use of commercially available micro-algae concentrates as a replacement for live micro-algae in sandfish hatcheries supports development of cheaper, simpler larval rearing protocols for this species.

Influence of diet composition on hyaline sphere development: This study assessed the influence of diet composition on hyaline sphere (HS) development in auricularia larvae of the sandfish, *Holothuria scabra*, and the subsequent relationships between the presence and size of hyaline spheres and competency through settlement and early juvenile performance. Two-day old larvae were fed one of three commercially available micro-algae diets that varied in their nutrient compositions: (1) *Isochrysis* sp. (Haptophyceae); (2) *Pavlova* sp. (Haptophyceae); and (3) *Thalassiosira* weissflogii (Bacillariophyceae) or a ternary combination of the three. There were positive significant correlations between HS development in late auriculariae on days 10, 11, 12 and 13 post-fertilisation, and the proportion of competent doliolariae on day 15, post-settlement size (day 21) and post-settlement survival (day 25). The dietary components that most strongly influenced these relationships were carbohydrates and the *n*-3 polyunsaturated fatty acids arachidonic acid (ARA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Result confirmed the strong relationship between HS formation in late auriculariae of sandfish and subsequent larval competency through settlement. As such, the presence and size of HS is a reliable indicator of subsequent performance for sandfish. Given that HS development was influenced by the nutrients available to sandfish auriculariae, results indicate that there is clear opportunity for development of more appropriate diets for hatchery culture of this species that will improve HS formation and larval performance supporting improved hatchery production.

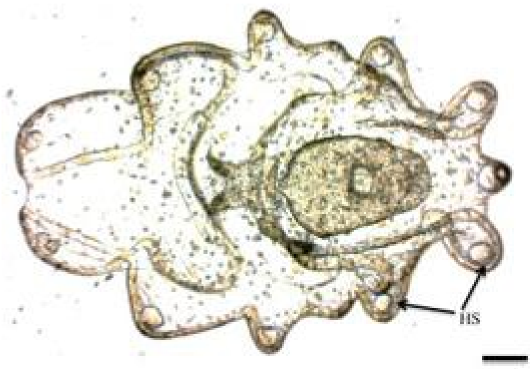


Figure 4. Late sandfish auricularia with hyaline spheres (HS), Scale bar 100 µm.

Use of micro-algae concentrates as juvenile diet: Ingestion, cell wall digestion and relative nutritional values of two live micro-algae (*Isochrysis* aff. *galbana* (TISO) and *Chaetoceros muelleri*) and six concentrated micro-algae products (Instant Algae®, Reed Mariculture Inc.) were assessed for early juveniles of sandfish. Seven of the eight micro-algae tested were ingested by juveniles with the exception of live TISO. Faeces excretion times varied between ingested diets that passed through the juvenile gut in less than 1 h. The cell walls of five of the eight micro-algae tested were partially or mostly digested (*Chaetoceros muelleri*, TW1200®, Palova 1800®, Isochrysis 1800® and Shellfish 1800®), while the cell walls of Tetraselmis 3600® and 3H 1800® remained intact. Juvenile growth rates were significantly different between diet treatments over the duration of a 14-day growth trial. Mean (± SE) length of early juveniles at the end of the growth trial was highest for those fed live *C. muelleri* (4.10 ± 0.03 mm) followed by TW 1200® (3.49 ± 0.05 mm). Juvenile survival did not differ significantly between diet treatments and was highest for those fed *C. muelleri* (79.33 ± 6.11%) followed by TW1200® (78.33 ± 1.20%). Pearson's correlation tests were used to identify key correlations between the levels of specific nutrients and juvenile performance (growth and survival). A significant positive correlation between growth and dietary protein content ($P < 0.05$), and a highly significant positive correlation between growth and dietary EPA:DHA ratio ($P < 0.01$) provide new information to inform diet selection for juvenile sandfish that will help improve juvenile performance and support improved hatchery production. Use of commercially available micro-algae concentrates as a replacement for live micro-algae in sandfish hatcheries supports development of cheaper, simpler post settlement rearing protocols for this species.

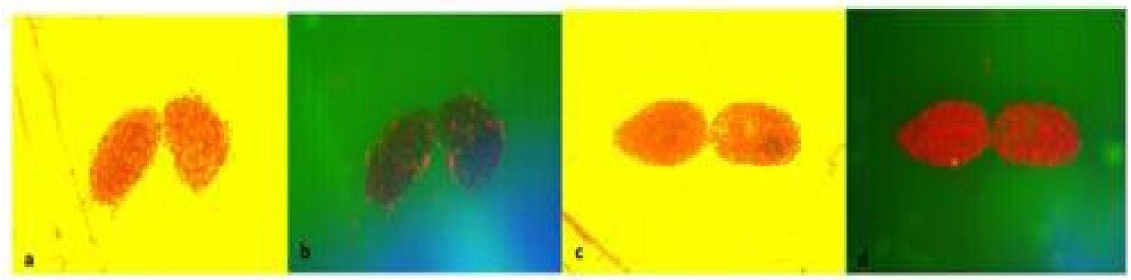


Figure 5. Photographs of faeces from sandfish early juveniles after feeding on TW 1200® (a,b) and Tetraselmis 3600® (c,d) when observed using both compound (yellow background) and epifluorescence (green background) microscopy. Photosynthesising pigments of intact micro-algae cells in the faces fluoresce under blue-light illumination; (b) shows high cell wall digestion with few intact cells in the faeces and (d) shows low cell wall digestibility with mainly intact micro-algae cells in the faeces.

Improved knowledge of feeding options and the nutritional requirements of sandfish larvae lay a foundation for further improvement of larval nutrition and for development of simplified, cheaper and more reliable hatchery culture methods for sandfish, that support regional expansion of sandfish hatchery production. Subsequent research has shown that large scale hatchery production of sandfish can be achieved using micro-algae concentrates as the sole food source (Militz et al., 2018), further illustrating this potential.

7.2 Improve efficiency and adaptability of sandfish nursery and growout systems

Production of release-sized juveniles (2^{nd}-stage nursery) remains a bottleneck at all production nodes. The inherent density dependence of growth and survival of sandfish (Battaglene et al. 1999; Lavitra et al. 2010) prescribes that developing a cost-efficient way of providing growth habitat for juveniles is a priority technology for scaling. Floating hapa nets (Figure 6) are an attractive solution that are cheaper, more adaptable and more practical to operate than hatchery tanks or marine ponds (Gorospe et al. 2017; Juinio-Meñez et al. 2012; Juinio-Meñez et al. 2017). Importantly, the floating hapa nursery system provides an opportunity for coastal communities to become engaged in culture systems earlier in the lifecycle, boosting livelihood opportunities and income. To optimise hapa nursery systems, we conducted a series of trials across geographies and technologies needed on design, operation, and maintenance procedures that optimise growth and survival of sandfish juveniles.

Figure 6. Experimental floating hapa setup at the Igang Marine Station

Trial 1 – density, size grading and net changes for optimal management of ocean hapas (SEAFDEC AQD, Philippines)

Field experiments were conducted at the SEAFDEC Igang Marine Station at Guimaras, central Philippines. The station is protected from strong waves and winds by the surrounding coves and rocky islets. Between these islets are deep (6-12 m) lagoons where aquaculture studies are conducted. The sandfish nursery study site is within one of the inner lagoonal coves which is 2–3 m deep. The floating nursery hapa nets were placed inside a netted bamboo pen enclosure that protects the delicate hapas from debris, while providing a platform for monitoring (Figure 6).

Each floating hapa bag net was made of white fine mesh poly-ethylene net (~1 mm mesh size), fabricated into a 2 m^3 bag measuring 2 × 1 × 1 m. Bags were supported by a rectangular PVC pipe (~8 cm diameter) frame which doubled as a float. Weights made of re-used PET bottles filled with sand were attached to the four corners of the bottom of the hapa net, while a perforated PVC pipe frame (2 cm diameter) was placed inside the hapa to maintain its rectangular-shaped floor as a substrate for sea cucumbers. The nets were deployed two days prior to stocking to promote the growth of natural periphyton biofilm which served as food for the grazing sandfish. No supplemental feeding was provided throughout experiments. Water parameters (DO, temperature, salinity and pH) were monitored daily. Growth was estimated using photographic and digital measurement methods, and weight calculated from a known length-weight relationship. This approach minimises disturbance of juveniles. To determine survival, all juveniles from each hapa were harvested and counted after 30 then 60 days.

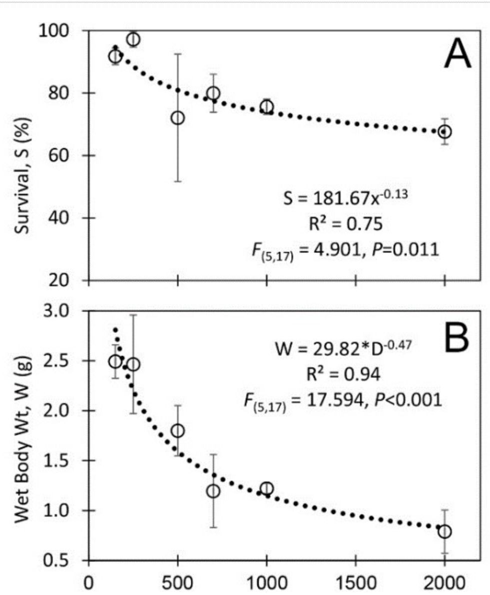


Figure 7. Relationship between initial stocking density (x axis) survival (graph A) and body weight (graph B) after 30 days (plot of means and standard deviations).

Stocking density - Six stocking densities (150, 250, 500, 700, 1000, and 2000 sandfish juveniles per hapa) of early settlement juveniles (4-10mm) were compared over 60 days of growth from April to June 2015.

After 30 days a clear trend was apparent in both growth and survival (Figure 7). Growth rates from 30-60 days were not significantly different among treatments. The net effect of this is that lower initial stocking densities (≤500 hapa^{-1}) promoted faster growth, whereby 2 g fingerlings were attained in shorter culture durations (34–48 d), as compared in higher densities of (≥700 hapa^{-1}) that required longer (60–85 d). Throughout the trial, lower densities promoted higher survival.

Size grading **–** Juvenile sandfish tend to grow unevenly, with individuals termed "shooters" as fast growing outliers, while others become stunted in the presence of larger conspecifics. In many cultured species, size grading during culture pays overall dividends in terms of population growth rate. Early juvenile sandfish of the same batch from the hatchery were stocked in 12 hapas at 500 individuals per hapa, and initially reared for one month. After 30 d, all animals were harvested and measured. Sandfish from three of the 12 hapas were randomly selected and re-stocked into new pre-conditioned hapas without size grading. The rest of the juveniles from the remaining nine hapas were pooled and then graded into small (0.05–0.99 g), medium (1–1.99 g) and large (2–3 g) size groups. Two hundred and fifty sandfish from each size group were stocked into new pre-conditioned hapas, with three replicate hapas for each size group. Nursery rearing continued for 45 more days. Monitoring for growth parameters and survival was conducted every 15 d using the methods described earlier.

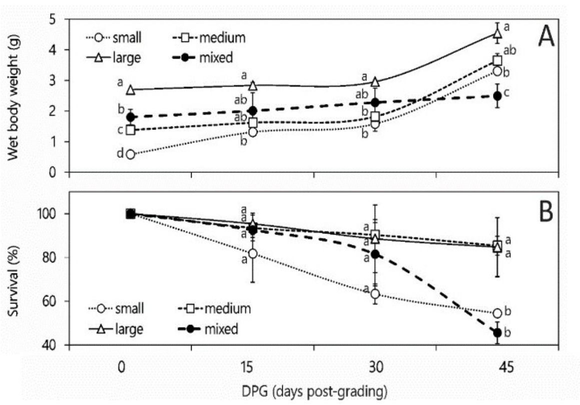


Figure 8. Change in body weight (graph A) and survival (graph B) of size graded juveniles over 45 days post-grading

Size grading was clearly beneficial (Figure 8). After 45 days, all graded groups had grown significantly faster than the ungraded controls, and had assumed very similar growth rates. Survival (graph B) was high amongst large and intermediate graded groups, but low amongst small and ungraded groups. It appears likely that the small/stunted group were small because they were compromised. It is plausible, then, that the presence of these smaller individuals in the ungraded group lead to the whole group being compromised. Further experiments are needed to confirm this, and if correct, perhaps the most beneficial grading activity would be to simply remove all stunted individuals from all hapas.

Net change trial - A challenge in nursery rearing of sandfish in sea-based floating hapas is excessive fouling caused by growth of epiphytic biofilm on the nets. Excessive fouling hampers water movement and makes it difficult to observe and maintain juvenile sandfish in the hapas, and in some locations has been implicated in mass-mortality in hapas. Cleaning of nets can be laborious and the action of cleaning can stress or damage sea cucumbers, so understanding the benefits from cleaning nets is important. We tested three net replacement frequencies, each with three replicates: replacement (1) every 15 days, (2) every 30 days, and (3) every 45 days. Using the floating hapa design described above, a comparatively low density of 135 sandfish juveniles were stocked in each hapa and reared for 12 weeks. Monitoring for growth was conducted every 15 days, following the same methods described in previous sections.

Production performance indicators (weight, growth rates, survival and size variability) were not significantly different among treatments of varying frequencies of net replacement. Although nets the were changed 3 times over 45 d (i.e. every 15 d replacement) can provide incrementally better production performance for sandfish juveniles (i.e. attaining 3.44 g at 83.7% survival), changing of nets only once (i.e. every 30 days) is very much comparable (3.11 g at 72.7% survival) with the added benefit of substantially reduced labour and less wear on hapas. From these results we recommend net replacement of every 30 days is the optimal. It is also expected that at 30 days most animals will be ready for harvesting, provided that initial stocking density was <500 $hapa^{-1}$.

Trial 2 – Effects of periphyton quality and sediment enrichment on growth, survival and behaviour (UPMSI – project publications # 9 - Sinsona and Juinio-Meñez 2018 and #10 - Sinsona and Juinio-Meñez 2019**)**

Periphyton and environmental parameters **-** This study investigated the effects of periphyton quality (i.e. chlorophyll-a, phaeopigment, total biomass, autotrophic index or AI), water quality (nutrients, chlorophyll-a) and environmental parameters (temperature, rainfall) on the temporal variation in the growth and survival of early juvenile (~3 mm) *H. scabra* reared in floating hapas. The study site near Barangay Victory in Santiago Island, Bolinao features a water nutrient gradient along the eastern coastline of Santiago Island, resulting from the dominant current system that brings chlorophyll-a and nutrients outward from the extensive mariculture activities for milkfish (*Chanos chanos*; Fortes et al., 2012). The study took advantage of this gradient within a eutrophic environment to test the impacts of enrichment on hapa nursery outcomes. Five trials with a duration of 60 days were carried out from November 2013 to June 2015 in an experimental hapa nursery established in the bay. In each trial, strips of hapa cloth were sewn into hapas to allow periphyton to be sampled, and compared to growth rate of juvenile sandfish held in the hapas.

Significant differences in the growth and survival of juveniles among trials were found. Trials with high growth rates of juveniles (0.07–0.09 g/day) during the first 30 days of rearing had significantly higher chlorophyll-a (chl-a) in biofilm loads (15.9–27.5 mg/m2) and lower autotropic index (AI, a measure of diatom abundance). Conversely, during the subsequent 30 days, trials with high growth rates of juveniles (0.06–0.11 g/day) had significantly lower chl-a and higher AI. Multivariate analyses showed that chl-a in biofilm, AI and nutrients in the water column are good indicators of periphyton quality and juvenile growth rates in floating hapas. Further, this study validates the expansion of the feeding mode of juveniles from primarily grazing on microalgae, to feeding on detritus and heterotrophs as they grow. These results are important in optimizing ocean nursery systems.

Sediment enrichment: Early post-release juvenile sandfish are particularly vulnerable to predation and mortality generally. In some instances, a 'size refugia' of 10 to 20 mm will see a considerable decline in mortality. This and the variable and unpredictable quality of coastal habitat for early post-release growth suggest it may be worth investing further in these early stages to minimise mortality and optimise growth. This trial tested the ability of dried *Sargassum* spp. enrichment to increase growth through improved food availability (directly, or indirectly through boosting microalgae and bacterial growth), and investigated behavioural changes associated with enriched sediment.

The effects of sediment enriched with dried *Sargassum* spp. on the diel burying behavior, growth, and survival of juvenile (> 3 g) sandfish were investigated in the field for 60 days using sea pens ($2.25m^2$) with a stocking biomass of 66 g m^{-2}, and in glass tanks ($0.045m^2$) with the same stocking biomass (~3 g individual $tank^{-1}$) in the laboratory for 30 days. Enrichment with Sargassum markedly changed sediment characteristics. Although diurnal burying behavior did not vary significantly between treatments, a greater percentage of juveniles in enriched pens and tanks remained buried during the daytime compared to unenriched pens. Without protection from predators in the wild, all juveniles from enriched pens survived, bettering those from unenriched pens (85 ± 10%) after 7 days. After 30 days, absolute growth rates (AGR) of juveniles in enriched pens (0.51 ± 0.06 g day^{-1}) and tanks (0.82 ± 0.27 g day^{-1}) were significantly higher compared to unenriched pens (0.13 ± 0.04 g day^{-1}) and tanks (0.49 ± 0.19 g day^{-1}). Growth correlated with higher chlorophyll a concentrations in sediments, which was enhanced by addition of dried *Sargassum*. This study demonstrated that the organic enrichment of sediment is a viable option to optimize the growth of sandfish in an advanced ocean nursery system that may significantly improve survival prior to release for grow-out.

Mass release of Juvenile Sandfish (Darwin Aquaculture Centre – Project publication #12 – Taylor et al., 2016)

In much of the science behind sandfish ranching to-date, seeding of juveniles has been done by hand, by divers or wading at low tide (e.g. Battaglene, 1999; Purcell, 2004). The massive tidal range, the abundance of saltwater crocodiles, and cultural considerations among community partners mean that a boat-based mass release system for juvenile sandfish is a prerequisite for a productive industry. More broadly, for large-scale ranching, diving methods are too labour intensive, and as such this research has broader applicability.

Two release methods were tested: temporary cages and chute release (Figure 9). Temporary cages consisted of a PVC frame enclosed with 1mm shade mesh. Sea cucumbers were suspended from the centre in a torn paper bag, and the frame lowered into the water from a boat. As the bag rapidly perished, the sea cucumbers were released into the cage, which was left in place for 24 hours. Chute releases involved a 2m PVC pipe that was held in place from the boat deck with the exit approx. 10cm from the sea floor. Sea cucumbers were poured down the chute with excess water to limit abrasion while the vessel moved at slow speed (Figure 10).

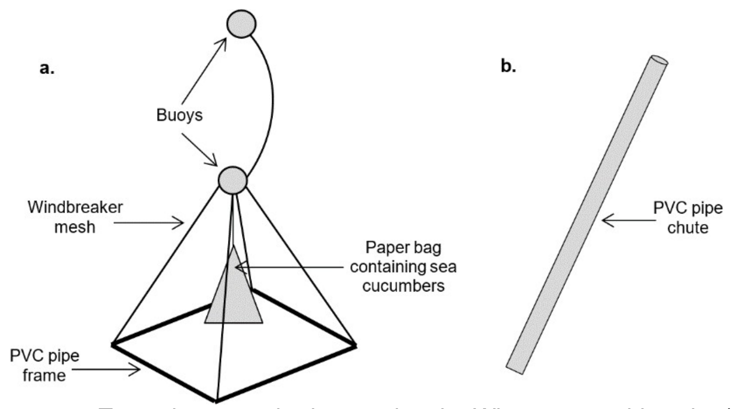


Figure 9. Two release methods tested at the Wigu sea ranching site (from Taylor et al., 2016)

Juvenile sea cucumbers (3-15g) were marked using fluorochome dyes following the methods of Purcell and Blockmans (2009). Juveniles were marked with either calcein (cage release) or tetracycline (chute release) to allow juveniles from the different release treatments to be identified and differentiated from wild recruits.

Trials were conducted at the Wigu sea-ranching area. Four zones 50m apart were selected within the site, and within each zone two release points (10m apart) allocated for the two methods. Four replicate releases for each treatment (n=175 juveniles per treatment) were conducted over a 3 hr period cantered around the slack of a low neap tide.

Figure 10. Warruwi community member helping with test releases using the chute method

Sites were surveyed intensively on foot at low spring tides on 3 consecutive days, 20 weeks after the release. Initially a 25m zone around each release site was searched intensively, followed by a grid pattern search of the remaining area of the Wigu sea ranching zone. Only sandfish up to 250mm were sampled due to projected growth rates of released individuals (Juinio-Meñez et al., 2014; Pitt and Duy, 2004). Location of each sampled sea cucumber was recorded (GPS), and skin samples taken to check for fluorochrome stained ossicles (Taylor, 2016 – project publication #13).

The survey yielded 394 sea cucumbers, among which 206 (52%) were marked (hatchery produced). Ossicle processing showed that 132 of recaptured individuals were chute released (18.9% recovery) and 74 were cage released (10.6% recovery). The proportion of sea cucumbers recovered from the chute release treatment was significantly higher than from the cage release treatment (χ^2=8.77, df=1, $p<0.001$). Dispersal distances from the release site were similar for the treatments.

Acclimation of sea cucumber juveniles on release has typically been considered important for optimising survival (Dance et al., 2003; Purcell, 2004). Interestingly these results suggest that immediate protection of juveniles after release (i.e. within a cage) may not be a critical factor in their subsequent recovery and survival when deployed in the conditions present at the Wigu site. Given the relative ease of the chute deployment method, this was clearly the preferred approach, and was adopted for the remainder of the project

Opportunities for pond culture in Philippines (including project publication #1 – Altamirano et al., 2017)

Pond culture of sandfish has shown good potential in Vietnam, and is important to the livelihoods of a small group of pond farmers in the central coast area. Identifying opportunities for pond culture in Philippines may assist with nursery rearing in a relatively predator free environment, or may be viable as an alternative production modality. SEAFDEC AQD monitored ponds across four districts (Capiz, Antique, Iloilo and Guimaras) revealing no ponds to be suitable for culture due to 1) regular low salinity events due to rain and lack of regular tidal flushing 2) substrate too silty as ponds are almost invariably in converted mangrove areas, and 3) ponds were too shallow (typically 0.5m) leading to an unacceptable level of thermal instability. Monitoring raised a number of questions about suitable pond environments. Central Vietnam, where pond culture has been successful, is characterised by low-lying coastal plains with sandy substrates. Ponds in this area are not dug in mangrove forests. To resolve questions regarding substrate suitability in the Philippines setting, controlled field and tank experiments were conducted at SEAFDEC AQD.

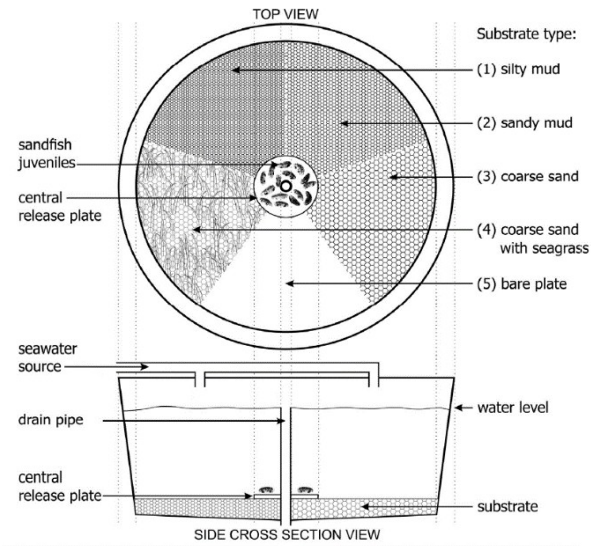


Figure 11. Tanks system with multiple sediment types to test sediment preferences of juvenile sandfish (from Altamirano et al., 2017)

Using a purpose designed tank system (Figure 11) we first conducted experiments to test substrate preferences for small juvenile sandfish, comparing typical coastal substrate types - silty mud, sandy mud, and coarse sand. During the peak hours of burying (03:00–09:00 h) and feeding (15:00–03:00 h) times, a significantly greater number of sandfish juveniles preferred to bury in (28.3%) and feed on (21.5%) sandy mud, typical of intertidal coastal sand flats. Silty mud was the least preferred substrate for feeding (13.5%) and burying (13.8%). Burying and feeding preferences of sandfish juveniles were not significantly influenced by the presence of seagrass (*Thalassia hemprichii*) on coarse sand. Growth of sandfish juveniles in the first two weeks of rearing in tanks was significantly greater on coarse sand (growth rate: 0.59 g d^{-1} or 7.0% d^{-1}), followed by sandy mud (0.34 g d^{-1} or 4.72% d^{-1}) while OM content of these sediments remain almost unchanged. On silty mud, sandfish juveniles constantly shrunk (−0.02 g d^{-1} or −0.63% d^{-1}) for 8 weeks while sediment OM content increased.

In field experiments using the same substrates, silty mud substrate of a mangrove pond caused total mortality of sandfish within two weeks, while sandy mud substrate of a sand flat provided significantly higher growth than the control (no sediment), but not significantly different than coarse sand of a seagrass bed. Sandy mud to coarse sand substrates of intertidal sand flats were most preferred by sandfish juveniles while silty mud associated with muddy mangroves and culture ponds seems to be unsuitable that sandfish would opt to avoid.

Results confirmed that sediments found in shrimp ponds dug in mangrove areas, as is the case throughout the Philippines, are not suitable for sandfish culture. The trials reinforce the notion that research endeavours in the Philippines are better directed to focus on sea ranching, and that alternatives to ponds (as used in Vietnam) for nursery production will be required in the Philippines.

Sea cucumber enterprise in Vietnam

The project objective to "*test integrated community enterprise systems in Vietnam*" (Activity 2.4) focused on improving efficiency of all stages of culture beyond hatchery systems – as hatcheries have developed to a point in Vietnam where surplus juveniles can be produced. Again, due to functioning enterprise systems around pond farming of sea cucumbers, the project focussed initially on the potential to diversify production by adopting sea ranching systems developed in the Philippines. However, between project design phase and implementation, market conditions in Vietnam and globally shifted considerably. Where 30 pond farmers in the central region (districts adjacent to Nha Trang where RIA3 is based) had been enthusiastically farming sea cucumbers during the design phase, by implementation most had switched to other species. As such, it was initially not possible to find an industry partner willing to commit valuable time to research on sea cucumbers. We therefore launched this activity with a survey of farmers to understand their current situation, and approaches to decision making around species to grow in their ponds. The RIA3 team surveyed 20 farmers, finding that:

1. Almost all farmers stopped or reduced production of sea cucumbers (16 stopped; three reduced; one continued) during 2013 (range Dec 2012 to March 2014)

2. Of those still farming sea cucumbers in 2014, the majority only maintained one pond for sea cucumber among several owned.
3. Of those who reduced or stopped production, the majority did so to farm Babylon snail - *Babylonia areolata* (14 produced snails, three produced white leg shrimp, two produced both)
4. Of those who reduced or stopped production, eight did so due to discount in sea cucumber prices, three did so due to increasing prices for other species, and eight did so as a response to both price shifts.
5. When they stopped farming sea cucumbers, farmers were receiving 40,000 VND (whole) to 60,000 VND (gutted) per kg, while four said they could not find a market for their product.
6. When asked what the price would have to be for them to start production again, the majority of answers were VND 100,000/kg or more – effectively a doubling of the price available when they stopped farming.

Survey data are included as Appendix A, as they will form a useful baseline for future industry development initiatives.

Reasons for the substantial and sustained drop in sea cucumber prices are not clear – the market chain is highly opaque and uses largely informal pathways into China. Notably, concurrent with this drop in sea cucumber prices, shrimp prices were exceptionally high globally due to disease issues in most countries with high shrimp production. Similarly, the expanding market for Babylon snail was very attractive.

Production system trials –trials were established to address three stages of production: First stage nursery (hapa culture immediately post-hatchery), second stage nursery (to release size) and ranching.

Nursery density trials - While hatchery protocols have steadily improved, and with them the reliability of producing stage 1 juveniles, nursery stages remain a bottleneck in many contexts. In Vietnam, the team took advantage of the large experimental pond setup at the RIA 3 hatchery facility to assess optimal densities for nursery stages. These systems are appropriate for either pond-based culture to market size, or sea ranching.

Trial 1: Four densities (400, 800, 1200 and 1600 ind/m2) of ca. 5mm post-larvae from the hatchery were seeded into hapa nets established with three replicates of each density, in a randomised grid within a pond (Figure 12a). The trial continued for 6 weeks

Trial 2: Larger individuals of ca. 2g each (equivalent to 20mm) were reared in 1m x 2m pens with a sandy bottom (5cm thick) substrate at 4 densities (2, 4, 8 and 12 ind/m2) for 4 weeks in a similar random grid to trail 1 (Figure 12b)

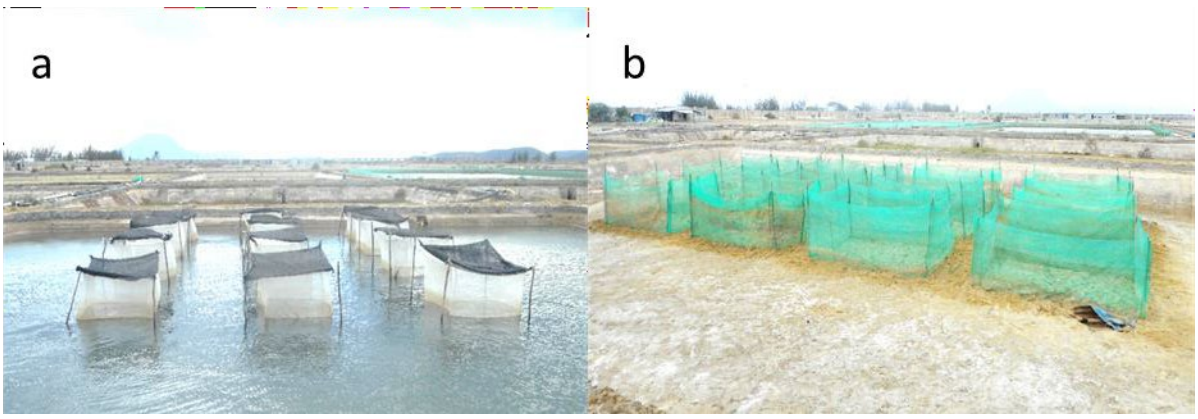


Figure 12. Experimental setup for a) hapa trial for early juveniles, and b) mesh pen trial for larger juveniles (2-20mm) with 5cm deep fresh sand substrate in place.

Trial ponds were drained and treated with industrial lime at a rate of 10kg/100 m2 to balance sediment pH and ensure potential predators (notably crabs) were killed. The pond was left for five days before refilling. Pond environmental parameters were monitored twice per day (06:00 and 14:00) throughout the trails (Table 1). Parameters were generally stable, and well within ranges accepted as appropriate for sandfish culture, although temperatures for trial 2 were on the high side. For hapa trails, post-larvae were fed commercial CP4000 feed at 1g/ m2 on the first day.

Table 1. Average pond environmental parameters for the duration of trials 1 and 2

	Trial 1 (± SE)	Trial 2 (± SE)
Temperature (^{0}C)	30.81 ± 2.62	34.4 ± 2.27
pH	7.93 ± 0.12	7.78 ± 0.21
DO (mg / l)	7.18 ± 0.22	6.9 ± 0.43
Salinity (‰)	33.71 ± 0.0	33.87 ± 0.0

Results clearly indicate a high degree of density dependent growth for both recently settled (trial 1; Figure 13) and larger juveniles (trail 2; Figure 14). In the hapas (trial 1) both growth and survival of recently settled post-larvae vary significantly between treatment. Variability in growth over the 6-week trial was a maximum of about 20%, and on this basis ultimately decisions on whether density in hapas should be lower than 1600 individuals per m^2 would likely depend on hatchery conditions, production rates and space available for hapas. However, survival results for trial 1 (Figure 13B) suggest that lower densities are definitely preferable. If hapas are available to maintain the lowest densities tested in this trial (400 post-larvae per m^2), then this is clearly preferable, with significant substantial reductions in survival between each density treatment.

For nursery rearing of larger juveniles, density dependence is clear for growth, but less so for survival (Figure 14). For project nodes in Philippines and PNG, space for this later nursery stage was a limiting factor in producing juveniles for release trials. These results suggest that where space is limiting, higher densities can be considered. While a consistent trend was apparent, there were no statistically significant differences in survival between the density treatments.

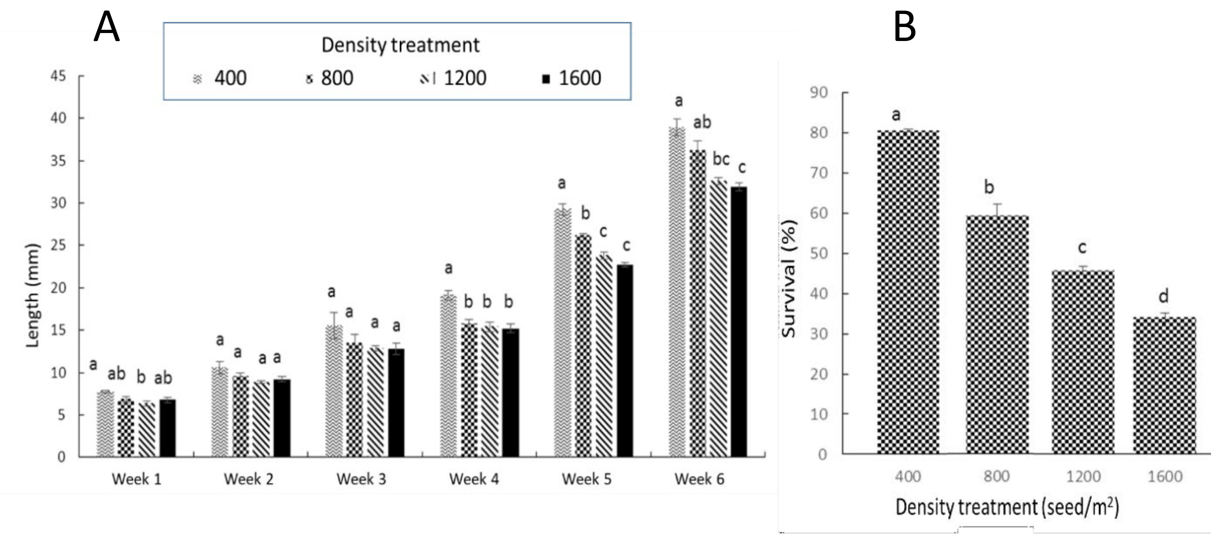


Figure 13. Results from trial 1 showing A) growth over 6 weeks for post-larvae seeded at about 5mm length into replicate hapa nets at 4 density treatments, and B) survival rates for the 4 treatments. Superscript letters show statistical significance of treatment differences (ANOVA, P<0.05)

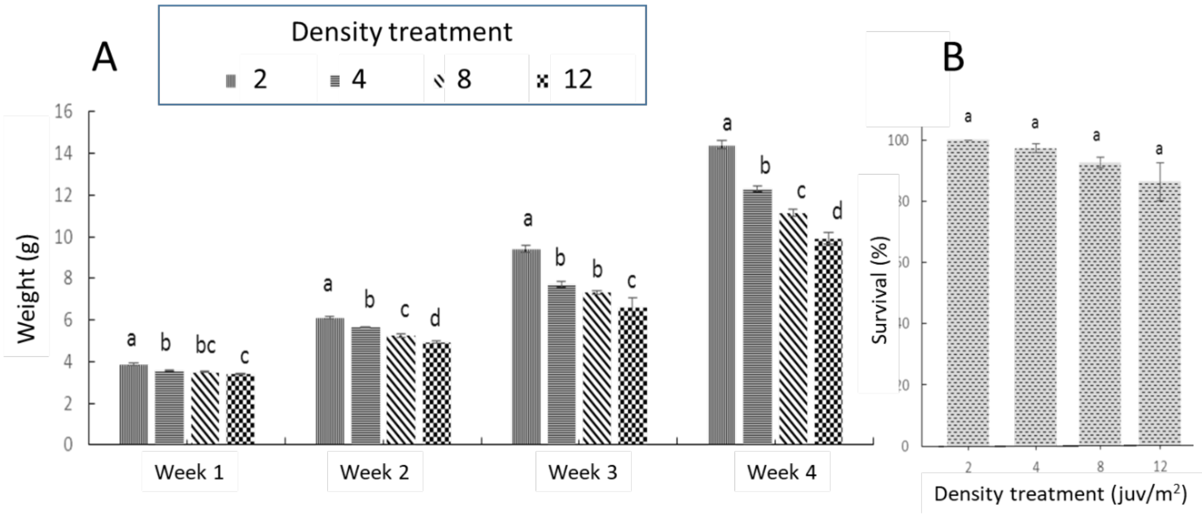
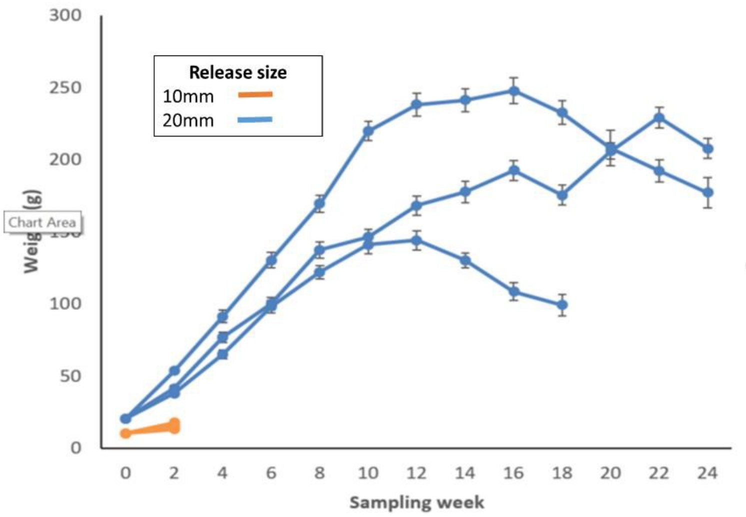


Figure 14. Results from trial 2 showing A) growth over 4 weeks for juvenile sandfish released into cages at 4 density treatments, and B) survival rates for the 4 treatments. Superscript letters show statistical significance of treatment differences (ANOVA, P<0.05)

Sea ranching growout trails in Vietnam – Once an industry partner with an appropriate lease including an open marine area was identified, the project team established six identical experimental sea pens of 50 m2. Each was stocked with 100 juveniles of weight either ca. 10g (3 pens) or ca. 20g (3 pens). Objectives were to assess growth rates, and any differences in survival based on release size. Every fortnight a subsample of 30 juveniles was measured and returned to their cage of origin.



Survival among juveniles released at 10g was very low. After two weeks, only six juveniles were found in two of the cages, while two were found in the remaining cage. None were found in the following sampling period. A number of juveniles were recorded as 'bitten in half' and swimmer crabs were abundant in the area. It appears that the smaller release group were immediately compromised, as growth rates were low among those which survived for two weeks.

While it is apparent that release at 20g + provides a degree of protection form predation, only one cage of these larger sandfish had more than 30 juveniles remaining at the end of the trail. For the other two, mortalities were >80%. Rapid growth rates for at least the first 10 weeks suggest sediment was of a good quality, and it is highly likely that predation was the cause of mortality. Given very high growth and survival rates for sea cucumbers in coastal ponds in central Vietnam, and the significant issues with apparent predation from these trials, research in Vietnam should focus on pond-based production systems.

The species-switching by farmers, highlighted through the survey, suggest that production systems that enable pond-farmers to react to the market and switch species provide a high level of livelihood resilience. This is important for commodified species that feed into international value-chains where markets are volatile and farmers are price-takers. Research that develops parallel and co-cultured systems for producing multiple species should be prioritised above research into diversifying sea cucumber production systems in the Vietnamese context. Importantly, the ability to switch species has to penetrate the value chain, in such a way that all nodes in the chain (including, for example, hatcheries) are able to adapt to changes in market demand.

7.3 Develop capacity to identify suitable sites for ranching using bio-physical indicators

We leveraged the opportunity created by similar experiments across multiple sites in Philippines, Australia and PNG to investigate whether there were common cues from measurable environmental parameters that proved to be good indicators of sites suitability for ranching. Pens set up in the core zone of ranching sites provided the experimental unit for the broadest comparison of growth and environmental parameters. Broader scale environmental monitoring was conducted at most sites to assess intra-site variability in environmental parameters and stochastic processes in key environmental parameters. Past experience shows that while a site may be judged suitable initially, environmental conditions can shift rapidly.

Pen experiments:

A substantial challenge with pen experiment data was ensuring adequate comparable data across sites. A number of sites were ultimately dropped from the analysis due to gaps in datasets that turned out to be critical for the analysis. For example, we were ultimately constrained to analysing comparative data for the first quarter (3 months) of pen experiments only due to considerable mortalities and very patchy data beyond this timeline, particularly among Philippines sites (Figure 15). The exceptions to this were Polopinya and Tubajon which both showed exceptional survival – similar to that seen at the PNG sites.

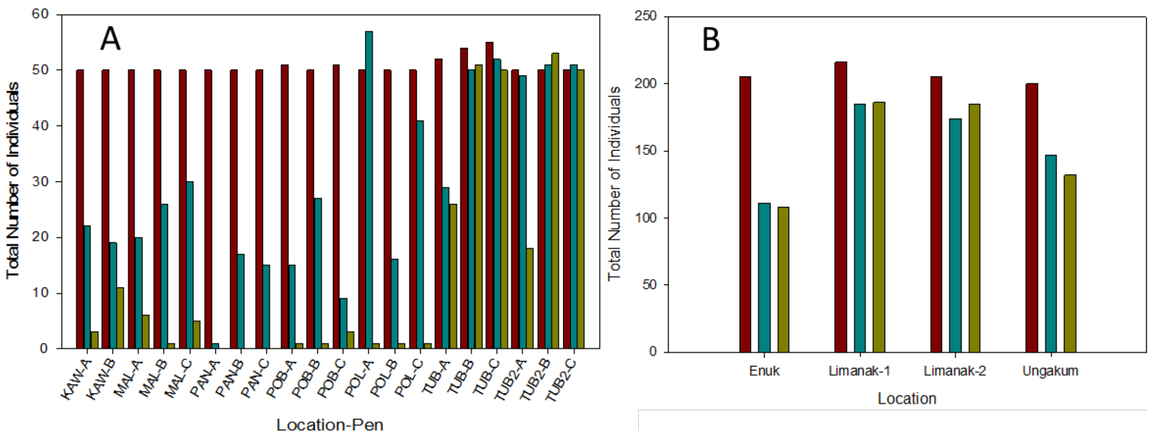


Figure 15. Total number of sea cucumber recaptured after the initial release (Red= initial release; Blue = 3 months; Yellow= 6 months) at the different sites and pens in the Philippines (A) (KAW = Kawit, MAL = Maliwaliw, PAN = Pandaraonan, POB= Poblacion, POL, Polopinya, TUB = Tubajon) and 4 sites in PNG (B)

Comparison of growth rates among sites (Figure 16), and cross-reference to survival data (Figure 15) provides clues about the drivers of mortality. Among Philippines sites, Kuwit and Maliwaliw show exceptional growth rates, however recovery of juveniles at 3 months, and particularly 6 months, is exceptionally low. Clearly, sediments and the habitat were suitable for juvenile sandfish growth – mortality was not due to environmental conditions. This contrasts with Pandaraonan and Poblacion where growth rates were low. Survival may have been low due to poor habitat or other drivers. Possible drivers in the high growth sites are theft of stock (unlikely given guarding arrangements) or predation. Additionally, at Polopinya survival was excellent for the first sampling period, then crashed to near zero. This suggests either poaching or an influx of predators. Further research on predation is urgently needed, as this looms as a bottleneck that may be critical in determining the viability of sea ranching.

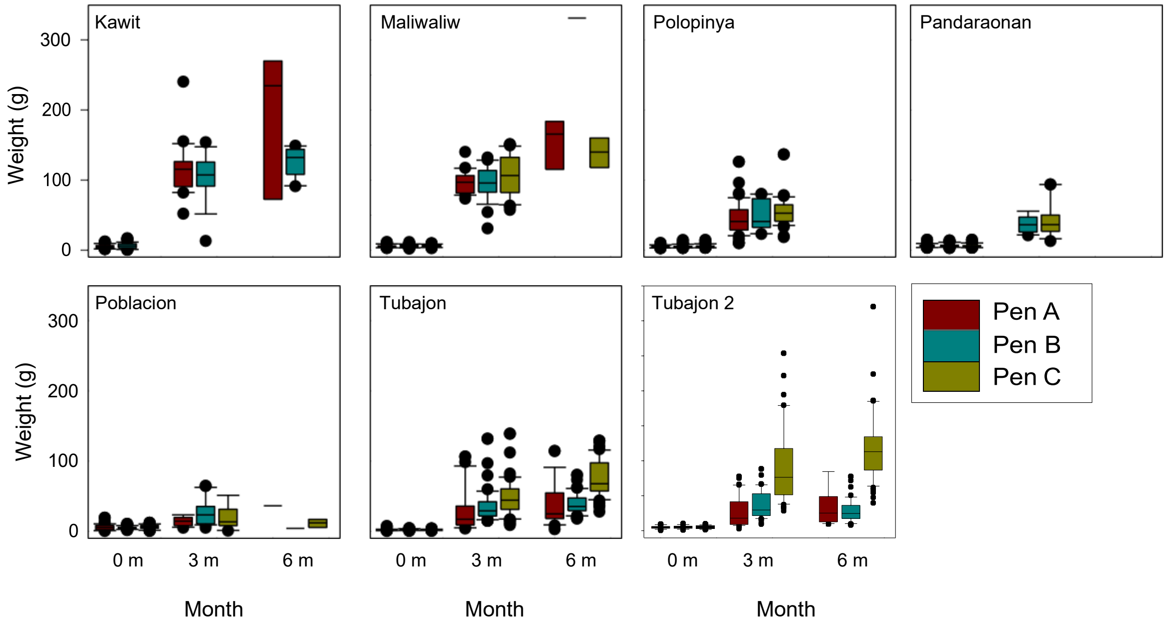


Figure.16 Boxplots of the size distribution in the Philippines sites and across pens and sampling events (release, 3 months, 6 month)

In contrast, growth rates at PNG sites were more consistent, although notably the site with lowest survival over 6 months (Enuk) also showed the slowest growth, This could suggest juveniles were not healthy, but could also be indicative of theft (largest individuals removed from pens). Almost invariably, juveniles grew faster in PNG sites than in the Philippines sites.

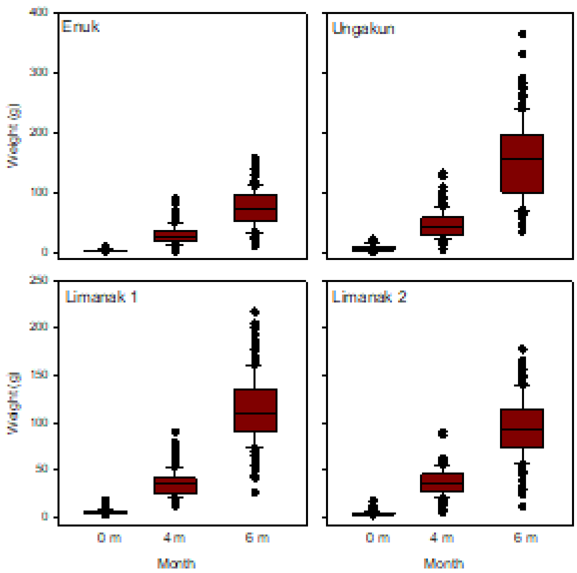


Figure 17. Boxplots of size distribution over 6 months at the 4 PNG sites

Principal components analysis (see Appendix B – Figure 5) of the sediment characteristics across sites and the three sampling dates showed very strong groupings of samples within sites, with the first two principal components explaining 50.3% of the observed variation. Consistency between the sampling months shows relative stability of sediment characteristics over this time period, and given the samples are random, suggests that the sampling method is appropriate to the level of variability seen within sites. The first principal component was weighted most heavily for seagrass cover and fine sediment, showing these to be the best differentiator of site characteristics. A univariate regression tree (mCart) verified these outcomes (Appendix B - Figure 6), grouping PNG sites together, along with Polopinya and Maliwaliw based on higher levels of fine sediment (but low levels of the finer 'silt' fraction) and low seagrass cover. Again, sampling period was not a driver, revealing high site stability across time.

To test environmental drivers of growth, we constructed a univariate regression tree (see Appendix B - Figure 7) on sea cucumber weights after the first sampling period, with site characteristics as predictor variables. The major split based on growth separated most PNG sites (Enuk, Limanak 1 and Limanak 2), Malawani (MAL) and Kawit (KAW), which have the larger overall growth for that period, with the remaining splits based on organic matter (refractory > labile) and chlorophyll a content of sediments. A random forest model constructed to predict weight based on sediment characteristics and sites managed to explain about half of the total variance (44%). Similarly to the univariate CART, the most important variable when constructing the model was sites (Figure 18), followed by refractory organic matter. The majority of the variability in results is likely due to intrinsic site characteristics that were not captured by the environmental variables.

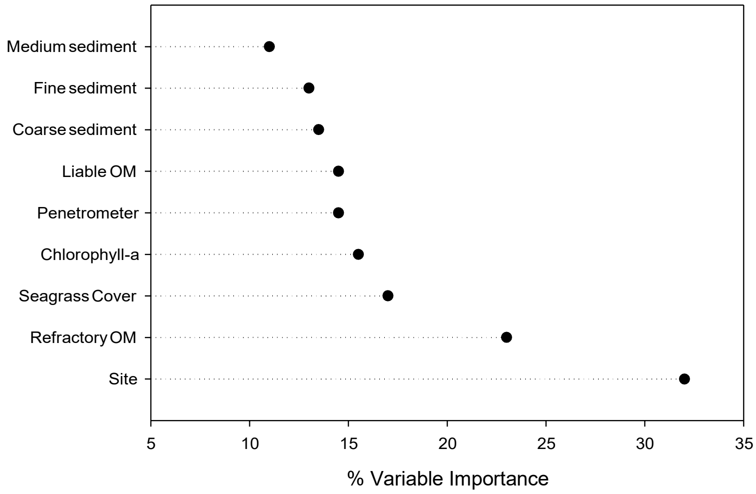


Figure 18. Random Forest importance variable plot describing the importance of each variable within the predicting model.

It is clear from this exercise that there are drivers that were not measured, which effectively become pooled in the 'site' variable, which are contributing substantially to differences in growth among sites. Coupled with the limited growth data, due to either rapid early mortality or theft, the models have not been able to conclusively attribute differences in growth rates to the measured environmental variables. While the broad diversity of sites available for this analysis provided the opportunity to key into universal drivers of site suitability, the lesson from this analysis is perhaps that local drivers are important, and environmental variables interact differently among sites. Local context will remain key in the selection of sites for ranching.

Stochastic processes in seagrass beds

The 49-point environmental parameter sampling process shone further light on plausible reasons for the lack of simple relationships between environmental variables and growth rates. Within site variability year on year is often of similar magnitude to inter-site variability. This is noticeable for the parameters that the random forest analysis reported above suggests are most strongly linked to growth. Examples are given below, while full data are presented in Appendix C. Organic matter profiles (e.g. Figure 19) are the most dynamic, showing considerable changes in both labile and refractory organic matter at a number of sites. Pigment profiles (chlorophyll a and pheaophytin) are similarly dynamic. At a number of sites, seagrass cover seems particularly stable, although there are exceptions here also. As perhaps the highest energy site in the study, the Wigu (NT, Australia) site seems particularly stable across time (Figure 20). While the spatial distribution of seagrass varies among years, the overall coverage remains similar.

While a lack of longer-term growth data precluded complex comparisons the diversity of plots reinforce that within a 5 Ha sea ranch, both inter-annual and spatial patchiness can be very high. Monitoring must be structured to reflect this patchiness.

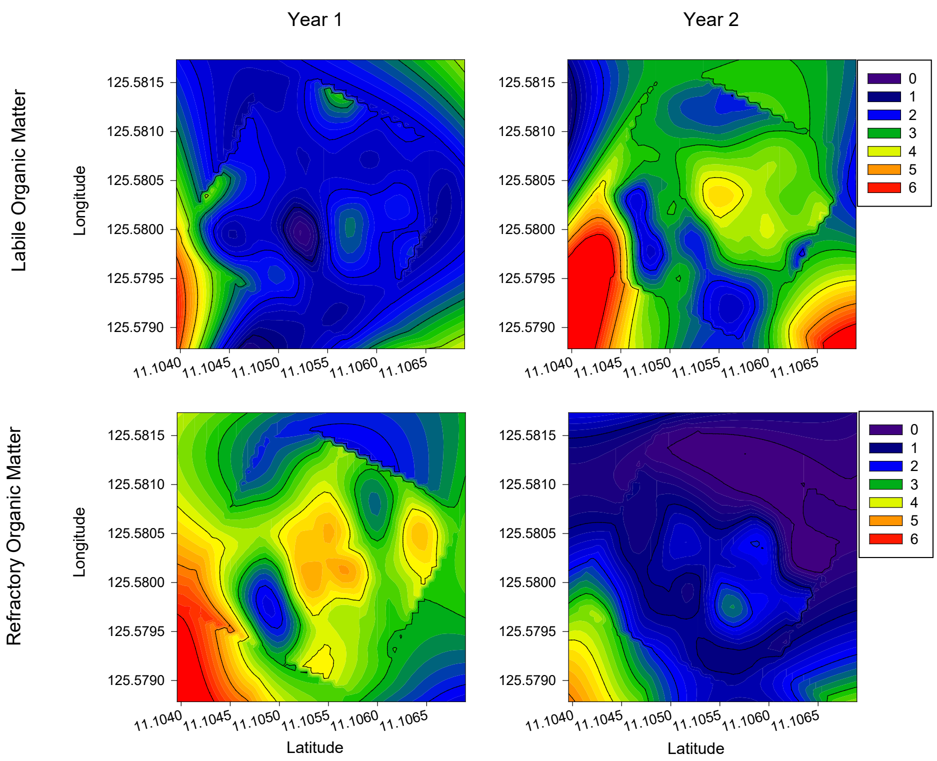


Figure 1. Organic matter profiles across 2 years at the Maliwaliw site, Eastern Visayas, showing substantial changes between years. Refractory organic matter was identified as the environmental variable most strongly linked to sea cucumber growth.

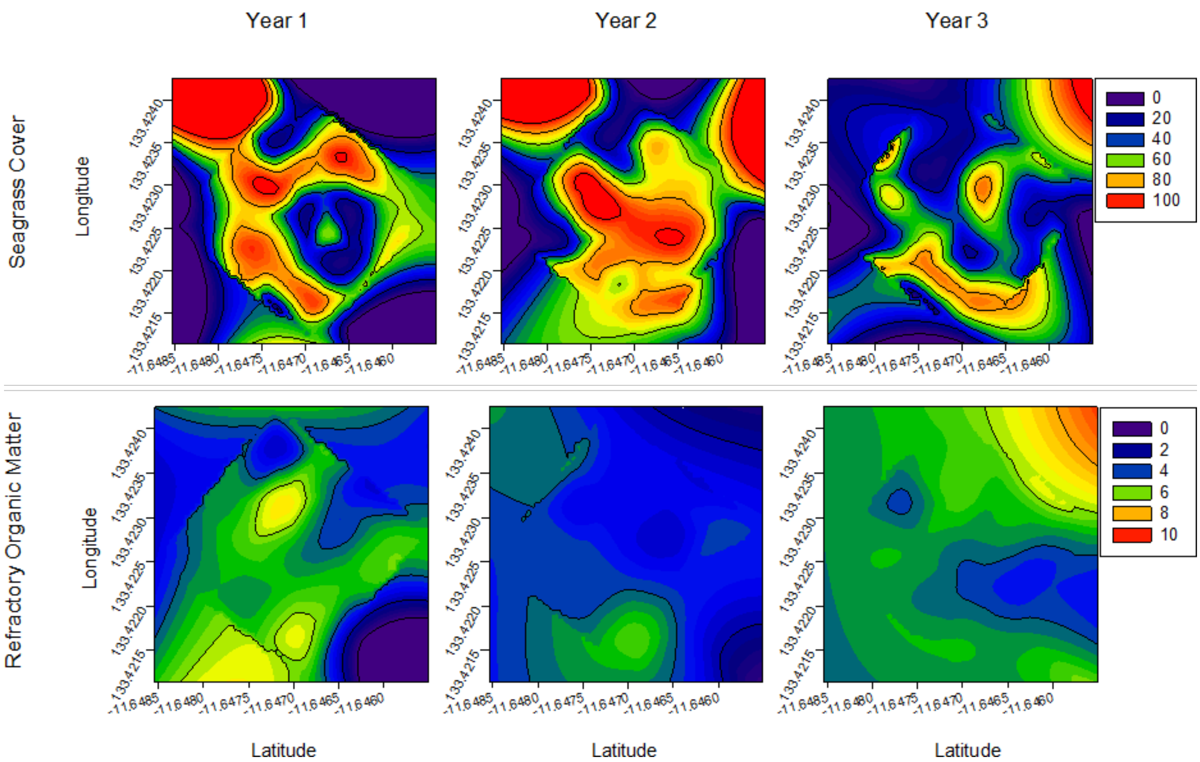


Figure 20. Contour maps showing refractory organic matter and seagrass cover variability over 3 consecutive years (2015-2017) at the Wigu ranching site, Northern Territory, Australia

7.4 Develop tools, technologies and capacities to engage and train communities in sandfish culture

Ranching trials at Goulburn Island, Northern Territory, Australia - Stratified transect sampling of the three zones within the 5 Ha ranch area enabled an estimate of the total recoverable numbers of sandfish and number of hatchery reared sandfish at the site. These estimates suggest that of a site population of 2186 recoverable individuals, 260 would be hatchery-reared sandfish (Table 2). This represents a recovery rate of 6.2% of released juveniles after 12 months. While this figure may seem low, whether or not this is viable as a return rate in a ranching operation is dependent on costs of the enterprise, including the cost of producing release-sized juveniles, and the cost of fishing. While the recovery rates are far less than seen in ponds or caged ranching areas in Madagascar (see Robinson and Pascal, 2012 and synthesis by Purcell et al., 2013), our ranch has had no post-release running or maintenance costs.

Table 2. Calculations for estimated 'recoverable' sea cucumbers at the Wigu site. [1] Estimated population is derived from all recaptures x area multipliers; [2] Tagged population is derived from tagged captures x area multipliers

	Transect Area	Zone Area	Area Multiplier	All captures	Tagged captures	Estimated population[1]	Tagged population[2]
Zone C	1600	40625	25.39	66	5	1676	127
Zone B	1600	7500	4.69	66	15	309	70
Zone A	360	2500	6.94	29	9	201	63
Total				**161**	**29**	**2186**	**260**

The density of hatchery-released juveniles in zone A from the January 2017 sampling (0.025/m^2) remained 2.5 times higher than that in zone B (0.01/m^2) and eight times higher than in zone C (0.003/m^2). This contrasts to the results for wild sandfish, which showed a relatively even distribution among the zones, varying only by a factor of <2 (A – 0.038/m^2; B – 0.032/m^2; C – 0.056/m^2) and being highest for zone C rather than zone A. This suggests a very limited dispersal from the release point over 12 months, perhaps because the habitat is eminently suitable for sandfish. This was corroborated by the exceptional growth rates observed at the site (see below). Interestingly, capture rates of both tagged and untagged juveniles was substantially higher in the January 2017 sample than in the October 2016 sample. Field notes show that conditions for the October sample were windy, with low visibility. This may account for the low numbers of both tagged and untagged sandfish recovered. It also suggests a degree of uncertainty around the percentage of released juveniles recovered even in the January sample. As such, the percentage of released juveniles recovered represents the minimal estimate for survival, and actual survival is likely higher. Also notable is that the recovery of sandfish was low in the areas with the highest density of seagrass. This conforms with past findings that seagrass is an important habitat for settlement, but becomes less important as sandfish grow and favour habitats clear of seagrass rhyzomes to facilitate burying. It is also plausible that sandfish are more cryptic in these denser areas of seagrass, and were present but not recovered.

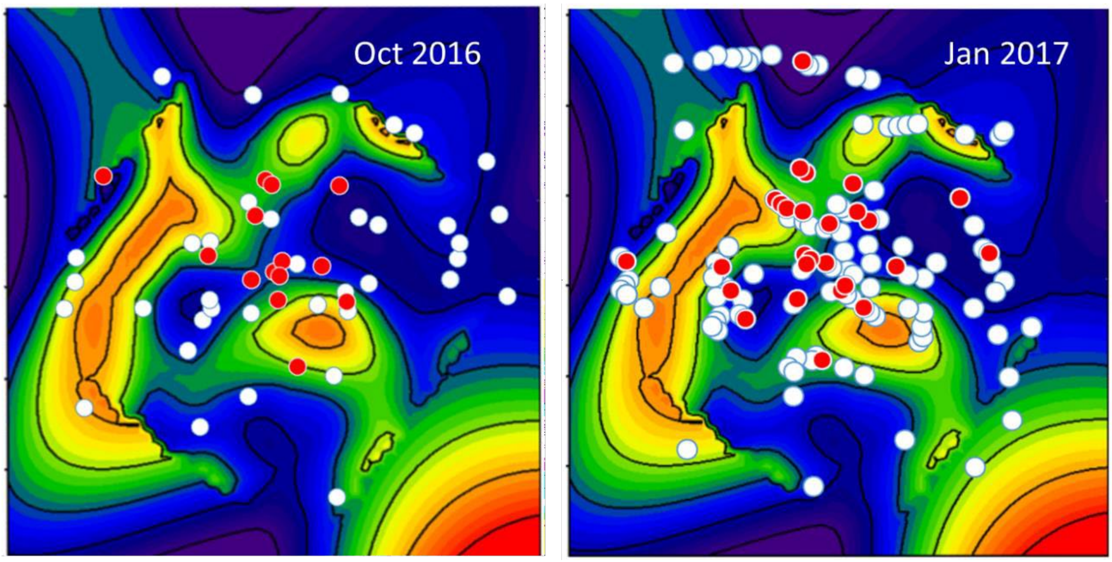


Figure 21. Distribution of surveyed sea cucumbers at Wigu from the two sampling occasions imposed on a seagrass density contour plot as assessed in Dec 2016. Red circles represent hatchery-grown sea cucumbers as confirmed by spicule marking.

Growth rates of released sandfish were in line with the best seen in previous studies using sea pens and in line with those seen in high quality ponds (see synthesis by Purcell et al., 2013). Sandfish larger than about 160mm are considered harvestable in the Australian context, and most of released sandfish had reached this size 12 months after release. The growth trajectory suggests harvesting after 18 months would likely see all released sandfish at harvestable size.

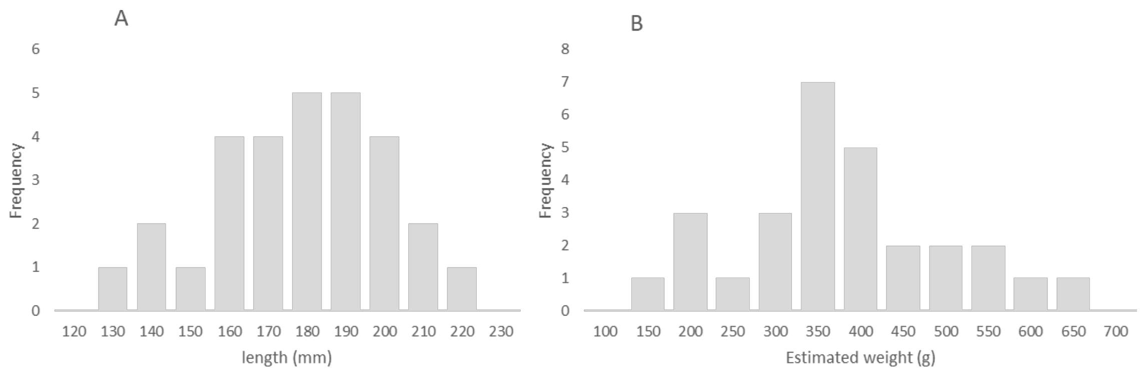


Figure 22. Measured length frequency (A) and estimated weight (B) of sandfish released as juveniles (av. 2.7g) and recaptured 12 months later

Further economic analysis will be required to understand if these survival and growth parameters point to a profitable ranching operation. The substantial and healthy existing populations of sandfish at Wigu may suggest that ranching is not required at this particular site. However the site has been invaluable for research, and in the context of regular harvesting, wild populations would decrease rapidly. In this context, ranching could substantially supplement reduced wild numbers, ensuring a regular supply of recruits to the fishery and a consistent supplemental livelihood for the Warruwi community.

Figure 23. Community member showing her yield from collaborative harvest with Tasmanian Seafoods

Joint community/Industry harvests

The industry partner Tasmanian Seafoods holds all available licences to catch trepang throughout the Northern Territory (Fleming, 2012). It also owns and runs the only sea cucumber hatchery in the NT. The Warruwi Aboriginal community hold sea right over its marine resources within the intertidal zone (Altman, 2008). Thus establishing a collaborative partnership between these two key stakeholders was essential, both for the project as well as establishing a viable industry model for sea cucumber ranching in the NT. The NT project node relied on Tasmanian Seafoods to provide all experimental juveniles for project activities. As they wished to maintain ownership of juveniles, they were provided at no cost.

As a test of potential modalities for future industry operation and stakeholder cooperation, two collaborative harvest were undertaken between Tasmanian Seafoods (Industry partner and fishery license holder) and Warruwi community members. On 1st and 2nd October 2015 and 27th-29th March, 2017 community members collected sandfish >15cm in length while wading in the shallows. Fishing time was limited to 2 hours per day centred on the low tide. Fishers collected sea cucumbers by hand and placed them in bags with a rope and float attached. The Tasmanian Seafoods vessel moved in at high tide to pick up the bags, and the sea cucumbers underwent 'first processing' on board the vessel. Total numbers of sea cucumbers collected was 2858 and 2550, respectively.

Collectors were paid by weight collected at AU$10 per wet kilogram. Catch per unit effort (Kg/hr) for the first sampling period averaged 8.3 kg across all participants, representing $83/hr. Viability calculations for joint harvests must consider related costs of transport and time spent beyond harvesting. Among community members involved in the harvest the highest 3-day return from this harvest for any individual was 150.5kg, earning $1505.00.

Following each harvest, the community participants were invited onto the boat to watch and be trained in the first stage of processing (gutting, boiling and freezing). In association with these opportunities, training videos on ranching and processing were produced in local language, with English subtitles. These trial harvests have shown conclusively collaborative sea cucumber harvesting arrangements between industry and the community can provide the basis of a culturally integrated sustainable livelihood for the Warrawi community. Ranching may form an integral part of this arrangement, ensuring a consistent supply of sea cucumbers in a relatively limited area suitable for harvesting by gleaning.

Figure 24. Focus group discussions and household interviews with community members

Gendered spaces for sandfish resource management in the Philippines

(SEAFDEC - project publications # 11 - Suyo and Altamirano, 2018)

The use of space is influenced by the relations between women and men, and the cultural expectations of femininity and masculinity (Knox and Marston, 1998). Space can be absolute - measured in units of area - and conceptual - measured in terms of the values and perceptions attached to a location - in the sense that the physical components of an area are highly interconnected with the non-tangible elements that operates therein. Women in the Philippines account for 10% of the fishing population (Philippine Statistics Authority, 2016); likely a substantial underestimate as the figure did not take into account the informal roles women play in capture and post-harvest activities

Focus group discussions and household interviews (Figure 24) in coastal communities revealed women and men have differential access to the fishery resources and their governance because of cultural factors that assign limits to each gender. A gendered spatial analysis formed part of the governance component of the project at Pandaraonan, Nueva Valencia, Guimaras, Philippines. The results of the mapping workshops (Figure 25) highlighted that the community utilized a significant portion of the intertidal area for fishing and gleaning during low tide. Most of the stationary gears, e.g. fish corral, operate in this site. Although, during lean season where seas are rough, men also fished in the same

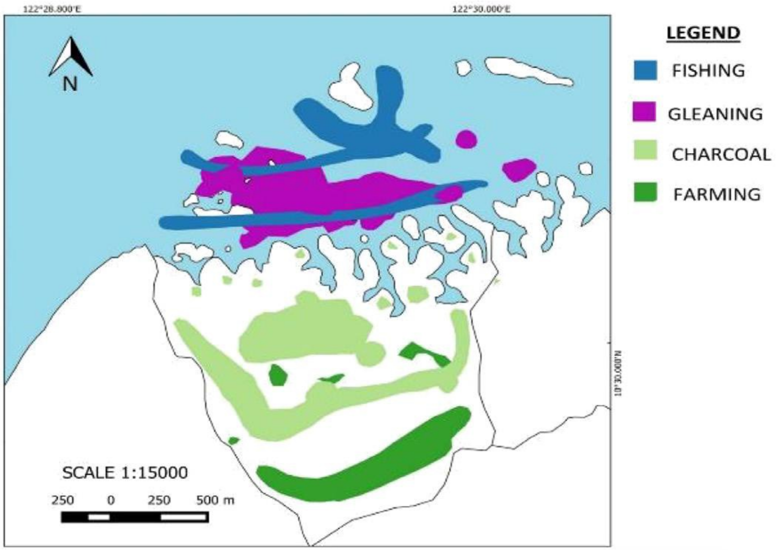


Figure 25. Resource map highlighting the areas utilized by women and men for coastal and upland livelihoods in Pandaraonan, Nueva Valencia in Guimaras, Philippines (from Suyo and Altamirano, 2018)

area using passive gears (e.g. gillnet, hook and line). Women, however, mostly utilised the shallow intertidal zone during low tide to collect shellfish and crustaceans for trade or consumption. Gleaning was most profitable during spring tides especially during the months from November to February. When asked about their perceptions of the use the coastal zone, women said it was not customary for them to engage in fishing in deeper waters. Gender based spatial separation can be summarised in the response from one woman respondent; “Ang hunasan para sa mga babayi. Ang madalum nga parte sang dagat, para sa mga lalaki.” (The intertidal zone is for the women. The deeper portions of the sea are for the men).

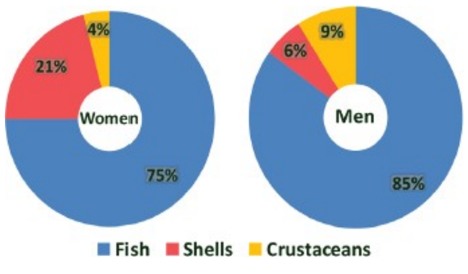


Figure 26. Fishery resources accessed by men and women fishers (Suyo and Altamirano, 2018)

Women and men access similar fishery resources (Figure 26) – the main difference being that due to women’s additional involvement in gleaning, shellfish are of greater importance. All of the men respondents identified fishing as their main source of income whereas 27% of the women said that they were earning from non-fishing activities. Most of both genders have secondary sources of income ranging from casual labor, operation of small business, and fishing-related activities such as gleaning.

The income between women and men were significantly different, with men earning 36% higher than the women. Of note, when asked about income, women did not consider earnings from the sale of their husband’s catch as part of *their* fishing income, but rather ascribed the entire value of sales to their husband.

The importance of fisheries to women’s livelihoods clearly highlights the cultural imperative for their engagement in governance of sandfish sea ranching. The reliance of women's fishing activities on the intertidal zone made them more knowledgeable about *H. scabra* as a resource. When asked about their interest of participating in the sandfish sea ranching project, women were as interested as men, particularly in attending meetings and volunteering their time to test if sea ranching would work for their community. However, they were less keen in assuming tasks that may require too much time or increased physical activity due to time required for household responsibilities. We noted that the attendance of women at project meetings increased over the course of the project, which showed their growing interest in the project. As the primary user of the intertidal zone, the women's ecological knowledge is invaluable to governance processes. Moreover, knowledge sharing can help in increasing the capacities of the community in managing their resources in line with the technological advances introduced by the project. These results show that priority should be given to formalizing women's membership and engagement in fishers' organization to improve outcomes and facilitate balanced representation in policies and decision-making.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Major scientific impacts relate to developments of diversified technologies for sandfish production that will enable production in a range of contexts. Early work on nutrition and condition of sandfish larvae conducted as part of the JAF scholarship to Nguyen Duy was instrumental in demonstrating the efficacy of algae pastes as a replacement for live feeds in sandfish larval culture. Despite commencing this project with the notion that sandfish hatchery systems were essentially a developed, scalable technology, contaminant-free algal culture has continued as a bottleneck for production in most nodes. Water quality, salinity fluctuations and copepod incursions have created issues that have at times required expensive interventions (e.g. UV filtration systems) or lead to production well below targets. The move to algal pastes will remove these risks from the production system.

Similarly, the development of floating hapa ocean and pond nursery systems, applicable in diverse settings, substantially improves the viability of sandfish culture. The nursery stages of sandfish production are space-intensive due to density-limited growth processes. Hapas provide 'cheap space' and allow post-settlement juveniles to be quickly removed from expensive space within hatchery facilities. Importantly, as a simple technology they enable communities and farmers to become involved in the culture process earlier, adding to potential returns from pond culture and ranching.

Approaches to juvenile release at ranching sites have been substantially diversified, and optimal approaches appear to vary based on site characteristics. The rapid chute system developed for the Wigu site in Australia contrasts with the far more nuanced sand conditioning processes that have improved survival at Philippines sites. Again, this diversity of methods adds to the toolbox of approaches, broadening the applicability of sandfish culture and ranching to diverse contexts.

While the project was unable to develop a broadly applicable model linking site environmental characteristics of sites to ranching success (growth and survival), an increased understanding of stochastic processes in sandfish habitats will be important for refining approaches to selecting sites, and cautions that longer term data and local knowledge will be key in selection processes.

Finally, the diverse approaches to community engagement, and the diverse settings for engagement have provided new insights into building inclusive governance systems for sea ranching, including the importance of women's engagement. A clear future research direction is to consolidate these lessons into inclusive and equitable governance models for future communities and stakeholders.

In 5 years' time, this improved toolbox of approaches and technologies spanning the sandfish production cycle should become an integral part in seeing an increasing number of coastal communities benefiting from sandfish pond farming and ranching. The project serves as a solid platform for a final research push that can remove bottlenecks relating to, among others, post release survival, site selection and inclusive governance.

8.2 Capacity impacts – now and in 5 years

Capacity impacts have been diverse across the three project countries. The expansion of the project in the Philippines to a number of new nodes has seen an influx of academic, NGO and government partners, many of whom are new to sandfish ranching and the science involved in monitoring. Early in the program, the scale-out of technologies in the Philippines archipelago, a key point of departure for this project when compared to the previous phase, required substantial capacity building from vastly different starting points. As part of this scale-out SEAFDEC AQD developed a sandfish hatchery training course, which was ultimately undertaken by 55 participants from 18 countries over the course of the project. Beyond direct field activities, the project was instrumental in supporting the

Philippines national program of sea cucumber research in the Philippines, and provided some key collaborations that contributed to objectives of this group. In Coron, Northern Palawan, a collaboration with a USAID-ECOFISH funded BFAR through Palawan Aquaculture Corporation, community grow-out trials were initiated and the grow- out of cultured sea cucumbers attracted greater interest through this partnership.

At project nodes in the Philippines, community members assisted with sandfish grow-out activities from post-settlement stages onwards. Engagement were with existing groups with an interest in conservation or fishing, or alternatively new groups were formed to lead community engagement – often dominated by women. These groups have become ambassadors for the project, and have gained skills in juvenile grow-out in hapas, as well as ranching and the monitoring of hapa and ranch environments.

In Australia, the project became an integral field and training activity in a program led by CDU to improve capacity of local Aboriginal workers on Goulburn Island to engage in income-earning aquaculture activities. A number of men and women community members undertook a Certificate II in aquaculture, obtained coxswain's certificates and were trained in seafood handling. Skills learned were directly applied through involvement in science components of the project and the harvest days.

Vietnam has long excelled in the highly technical processes of developing hatchery technology for a broad range of species. While effective, there has been a tendency to focus on the end point, and lessons have been lost as the skills or motivation for publication have not been present. Through the JAF scholarship awarded to Nguyen Duy, the capacity of project partner RIA 3 to publish quality science has substantially increased. This capacity will be leveraged extensively in the next phase of this project. In addition two masters project in the Philippines were completed through the project (see publications section 10.2) and a further 2 staff from the project have since taken up PhD scholarships in Australia.

Formal training completed during the project includes:

Topic	Trainer	Date	Where	Participants
Training on site survey, sea cucumber resource assessment, and hatchery protocols.	UPMSI, UP Tacloban	April 2012	Guiuan and Salcedo, Eastern Samar	GDFI Staff, BFAR-GMFDC staff, Selected members from Maliwaliw Multi-purpose Association (MMA)
Sandfish seed production, nursery and management	SEAFDEC/AQD sea cucumber and phycology team	10 courses – October 2013 April 2014 October 2014 April 2015 November 2015 April 2016 November 2016 April 2017 October 2017 April 2018	SEAFDEC, Tigbauan, Iloilo	Over 55 participants from 18 countries
Juvenile rearing of Sandfish in ocean nursery systems	GDFI, BFAR VIII-GMFDC	July 2013	Brgy. Maliwaliw, Salcedo, Eastern Samar	Members of Maliwaliw Multi-purpose Association

Juvenile rearing of sandfish in ocean nursery systems	UPMSI project staff	November – December 2013	Anda, Pangasinan	People's Organization from barangay Imbo and Sablig in Anda, Pangasinan
Techno-demo & processing workshop	UPLB (DOST)	3-5 June 2014	BML	PO from Brgy. Victory; UPMSI sea cucumber project staff
Orientation with Sea Cucumber Traders and Processors on Restocking and Existing Laws	UPMSI (ACIAR & DOST)	6 March 2015	Anda, Pangasinan	Anda Brgy. Captains or Kagawad; MAO-Anda; sea cucumber traders and processors; Bantaydagat
Sea Cucumber Fisheries Management Planning for Anda, Pangasinan	UPMSI (ACIAR & DOST)	11 March 2015; 13 May 2015	BML	MAO Anda, BantayDagat;
First stage processing of sea cucumbers (gutting, boiling and freezing)	Tasmanian Seafoods Pty Ltd	1-2 Oct 2015 &27-29 Mar 2017	Tasmanian Seafoods Fishing vessel anchored near South Goulburn Island	Yagbani Aboriginal Corporation aquaculture team and other Warruwi community members
The status and development of sandfish culture in the Philippines	UPMSI (DOST)	September 28- October 2, 2015	BML	DOST partners, ACIAR node representatives, and representatives from other institutions undertaking sandfish culture and grow-out trials
Preparation and use of commercially available microalgae concentrates in the hatchery culture of sandfish	Dr Duy Nguyen	23-30 October 2017	SEAFDEC, Tigbauan, Iloilo	14 participants from project partner and related institutions
Sandfish seed production, nursery and management	SEAFDEC	April 5-20, 2018	Tigbauan, Iloilo	GDFI project staff

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The potential for sea ranching as a supplemental income in Philippines and Australia, and pond farming as a component of a diversified production system in Vietnam is high where appropriate, scalable and economic technologies are available. The market for sandfish as a commodity is strong, and supply from the wild decreasing. This project has made considerable progress in a number of areas towards providing a *toolbox* of technologies that increase productivity and returns in a range of environments.

First, fundamental research on larval nutrition has provided the impetus for developing feeding systems based only on commercially available algal pastes. This obviates the need for feed production (algal culture) as a module of sea cucumber hatcheries, reducing cost and risk. Water quality (pathogen contamination, salinity fluctuations) continued to compromise hatchery production for a number of production nodes throughout the current project. For Vietnam, it also improves adaptability of hatcheries, allowing for diversified production and for hatcheries to respond to market changes by switching species.

The development and refining of protocols for hapa-based nursery systems in ponds and sheltered embayments removes the need for expensive hatchery space for these post-settlement phases. The ability of communities to take on the role of nurseries provides an additional livelihood opportunity, and puts more of the production cycle in the hands of communities. This has already paid dividends in Mindanao and Northern Luzon, where project partners were trained in ocean nursery methods and took on the role of supplying the project with juvenile sandfish for trails. For the next phase of the ACIAR project the project partner in Maliwaliw Island will supply 40-100g juveniles to expansion sites in the area, selling at Php 10.00 per juvenile.

In the Philippines, project outcomes show clearly that investing in pond culture is unlikely to be viable, and likewise in Vietnam, sea ranching is not an option and efforts should be focused on diversifying pond farming livelihoods to cope with market fluctuations. In Vietnam, while farmers had moved away from producing sea cucumbers due to low market prices, recently prices have increased again to a point where pond farming of sea cucumbers is again a viable option. Project research on environmental parameters for optimal growth and survival were perhaps not as conclusive as the project team had hoped, but add weight to other research in highlighting parameters that will help to select viable ranching sites and ponds. Post release mortality remains a clear issue in a number of project sites. Future research will be required that focuses on predation and other drivers of mortality. Over the next 5 year, the extension project will further develop and refine production systems, specifically addressing bottlenecks identified in the current project. Concurrently, research must look to governance and social integration of ranching and pond farming into livelihood, considering equity, gender and likely impact of climate change.

In Australia, indications from project outcomes are that an Aboriginal sea cucumber fishing enterprise, setup as a component of diverse livelihoods, could be productive. Further research focused on operating costs would be required to confirm this. Returns from trial fishing were good, with individual fishers earning up to $1500 for 3 x 4 hour days of fishing. Growth rates of ranched juveniles were exceptionally good, while the balance between the cost of juvenile production and survival to harvest size would need further research to assess economic viability. Under current regulative conditions, the future of Aboriginal sea ranching and harvesting enterprises will continue, for the foreseeable future, to be dependent on the Industry partner for both the provision of juveniles and for processing and export.

8.3.2 Social impacts

At every ranching site, the primary enabling connection for the project was with the community, often with the addition of local government. This relationship was built either by linking with existing interest groups or forming new groups. Invariably through these links, all parties (project, community and local government) gained a deeper understanding of the ecological, socio-cultural aspects of nearshore resource use and conservation, and the feasibility of the sea ranching and restocking. In a number of instances, the social capital built through these interactions has had demonstrable flow-on effects. In Victory, Northern Luzon, the ranching site serves as a demonstration and learning site for many visitors from different regions of the Philippines, and even internationally. The sea ranching group has developed an excellent presentation on the ranch, and takes great pride in the presentation of outcomes and aspirations to outside groups. The local government unit in Bolinao has recognised the importance of this initiative and provided support to the community in terms of maintaining guarding and supplies needed in the sea ranch. In nearby Anda, engagement with local government has increased through joint development of a management plan for a sandfish restocking site, and an existing yet inactive marine protected area has been reactivated through this initiative. In Eastern Visayas, the ranching groups are engaged with a multi-institutional secretariat focusing on coastal zone management. In the follow-on from the project, sea ranching has gained significant profile with this group as ranching areas expand. The group is now starting to implement the unified municipal fishery ordinance in each municipality which incorporates conservation and sustainable and equitable utilization of coastal areas and resources.

In the Australian context, the social impact is perhaps best summed up through an external appraisal of this and associated projects. Gould (2015) summaries the social outcomes of the project as follows:

> *" What stands out .....is that what started as a project investigating the technical aspects of trepang aquaculture and ranching has since expanded into a wider body of work which draws of local assets whilst addressing a range of local capacity issues……*
> *Although the project has not reached a commercial stage, important benefits have been realised. Long-term partnerships between the community and research organisations have brought resources into the community. Immediate and tangible short-term employment, training and capacity development outcomes have been generated whilst providing pathways to long-term enterprise developments based on the sustainable use of marine resources. Training has been provided in a way which allows people to work on the job, simultaneously addressing socio-economic and educational disadvantage."*

8.3.3 Environmental impacts

Sea ranching and pond farming of sea cucumber have excellent potential to provide a substantial environmental impact. These include:

a. Sea cucumbers in a ranch can serve as a seed population for wild stocks
b. Increased sea cucumber populations will restore the ecosystem function (sediment cleaning/turnover) lost due to overfishing sea cucumber populations
c. Increased engagement with sea cucumber production engenders a sense of ownership and responsibility for sustainable governance (as modelled at the Victory site in Northern Luzon, established prior to this project) that can lead to more effective management
d. Collective action towards building this new livelihood builds social capital and capacities that can be leveraged for improved
e. Sea cucumbers in shrimp ponds can reduce sediment fouling from shrimp production, increasing the service life of ponds

The project continues to work towards the realisation of these objective, but does not, at this stage operate at a scale that will see these benefits realised to a degree that is measurable.

Anecdotal accounts from community members as well as observations by project staff indicate positive outcomes from community management of ranching areas. Protection of ranching sites in Maliwaliw Island, Eastern Visayas from *H. scabra* fishing not only resulted in the rebuilding of sandfish population but also the re-emergence of other sea cucumber species. The presence of small individuals (<150 g) suggests that recruitment to the population has already taken place in the area, plausibly as an outcome of rebuilding local stocks. Similarly, fishers in the Victory area in Northern Luzon have long noted that the ranching area has acted as a source population, improving sandfish recruitment more broadly in the area.

The project action to pilot Sustainability Plans under activity 4.2 (Test and refine models for integration of release strategies into improved models for community-based resource management) sought to address these points - particularly a. and b. above. The momentum generated early in the project for institutionalising integrated sea cucumber management in Anda, Northern Luzon through the executive order unfortunately was not maintained. Following the election, the project did not have the capacity to re-engage with new leaders. However there was a positive environmental spin-off in that a local inactive marine protected area was revived through this agreement. Similarly, in the Eastern Visayas node, governance work around the sea ranches has led to further collaborative work among. The potential remains for sandfish ranching to be the impetus for increased local engagement with inshore sustainable resource management.

8.4 Communication and dissemination activities

Internally, project meetings were both regular and ad-hoc. Annual meetings provided an opportunity for the whole team to a) initially engage in training in technologies and techniques applicable to all nodes relating to environmental monitoring, sandfish culture and community engagement, and b) share outcomes for project trials and experiments. The Philippines nodes met twice yearly in addition to annual meetings to ensure consistency between approaches, collate data and to share lessons.

Throughout the program, all main partners continued regular meetings with community participants. These were two-way learning encounters, with local knowledge, progress and issues with project activities, and project results shared and discussed.

The following presentations were given by team members at national and international conferences (9 international; 14 national):

1. Altamirano, JP and Noran-Baylon, RD. Nursery culture of sea cucumber *Holothuria scabra* in sea-based floating hapa bag nets: effects of density and rearing duration. Asia-Pacific Aquaculture 2018 (APA 2018). Taipei, Taiwan. 23-26 April 2018
2. Altamirano, JP, Juinio-Menez, MA, Uy, WH and dela Cruz, MT. Community-based marine ranching of sea cucumbers: a viable option for sustainable fisheries in the tropics. 7th World Fisheries Congress (WFC2016). Busan, South Korea. 22-27 May, 2016
3. Altamirano, JP, Juinio-Meñez, MA, Uy, WH, dela Cruz, MT, Rodriguez, BDR, Hair, C, and Mills, D. Understanding bio-physical variability in sea cucumber ranching sites in the Philippines. World Aquaculture 2017 (WA2017). Cape Town, South Africa. 26-30 June 2017
4. Altamirano, JP, Noran-Baylon, RD, and Recente, CP. Challenges and prospects for sea cucumber pond culture in the Philippines. 14th National Symposium in Marine Science (PAMS14). Nasugbu, Batangas, Philippines. 13-15 July 2017
5. Altamirano, JP, Recente, CP, and Noran RN. 2015. Substrate Preferences of Sandfish *Holothuria scabra* juveniles: Implications for Grow-out and Sea Ranching. 5th International Symposium on Stock Enhancement and Sea Ranching. Sydney, Australia, 11-14 Oct, 2015.
6. De la Cruz, MT, Diodoco, RP, and Villamor, JL. Preliminary Study on the Movement of Sandfish Juveniles on Sea Ranch in Maliwaliw Island, Salcedo, Eastern Samar. 14th Philippine Association of Marine Science Conference - 13-16 July 2017 at Chateau Royale Hotel, Nasugbu, Batangas.

7. De la Cruz, MT., Villamor, JL and Diodoco, RP. Can Sandfish, *Holothuria scabra* (Jaeger), Alter the Particle Size Composition and Components of the Sediment? 14th Philippine Association of Marine Science Conference - 13-16 July 2017 at Chateau Royale Hotel, Nasugbu, Batangas.
8. de Peralta GM, Catbagan TO, and Juinio-Meñez MA. Effects of nutrient enrichment on the growth and survival of early juvenile sandfish (*Holothuria scabra*). 12th National Symposium in Marine Science. Tacloban City, Philippines. 24-26 October 2013.
9. de Peralta GM, Sinsona MJ, and Juinio-Meñez MA. Development of intermediate grow-out systems for *Holothuria scabr*a. 13th National Symposium in Marine Science. 13th National Symposium in Marine Science. General Santos City, Philippines. 22-24 October 2015.
10. Duy, N.D.Q. Application of micro-algae concentrates as a larval food source for hatchery culture of sandfish. World Aquaculture 2017 (WA2017). Cape Town, South Africa. 26-30 June 2017
11. Edullantes CMA, Gorospe JRC, and Juinio-Meñez MA. Evaluating advanced nursery systems for unconditioned sandfish *Holothuria scabr*a juveniles. 14th National Symposium in Marine Science. Nasugbu, Batangas, Philippines. 13-15 July 2017.
12. Gorsope JRC, Lambio KA, Edullantes CMA, Tech E, Faacunla V, and Juinio-Meñez MA. Pilot experimental community-based rearing of sandfish *Holothuria scabr*a northern Palawan, Philippines. 14th National Symposium in Marine Science. Nasugbu, Batangas, Philippines. 13-15 July 2017.
13. Lambio KA, and Juinio-Meñez MA. Grazing on periphyton by sea cucumber *Holothuria scabr*a early juveniles. 14th National Symposium in Marine Science. Nasugbu, Batangas, Philippines. 13-15 July 2017.
14. Lambio KA, Cuvin-Aralar MA, and Juinio-Meñez MA. Growth of *Holothuria scabr*a juveniles in a periphyton-based ocean nursery system. 10th WESTPAC International Scientific Conference. Quingdao, China. 17-20 April 2017.
15. Noran-Baylon, RD, Altamirano, JP and Recente, CP. Rearing performance of floating hapa bag nets for early juvenile sandfish *Holothuria scabra*. World Aquaculture 2017 (WA2017). Cape Town, South Africa. 26-30 June 2017 (POSTER)
16. Rodriguez BD, Juinio-Meñez MA. Spatio-temporal variability in the sediment productivity in a seagrass bed of Bolinao, Pangasinan. 13th National Symposium in Marine Science. General Santos City, Philippines. 22-24 October 2015.
17. Rodriguez BD, Juinio-MeñezMA. Factors affecting the in situ feeding behavior of adult *Holothuria scabr*a . 12th National Symposium in Marine Science. Tacloban City, Philippines. 24-26 October 2013.
18. Sinsona MJ, and Juinio-Meñez MA. Effects of food abundance on the diel burying behaviour, growth, and survival of juvenile *Holothuria scabra*. 16th International Echinoderm Conference. Nagoya, Japan. 28 May – 1 June 2018.
19. Sinsona MJ, Rodriguez BD, and Juinio-Meñez MA. Growth and survival of *Holothuria scabr*a reared in floating hapas in response to different environmental factors. 13th National Symposium in Marine Science. General Santos City, Philippines. 22-24 October 2015.
20. Suyo JGB and Altamirano JP. That's my spot! Local fishing and its implication on sandfish *Holothuria scabra* sea ranching in Pandaraonan, Guimaras, Philippines. 8th National Conference in Gender and Fisheries of the National Network on Women in Fisheries in Philippines Inc. (WINFISH). Iloilo City, Philippines. 28-30 September 2016. (won Best Presentation Award).
21. Suyo, JGB and Altamirano JP. Mapping the correlates of project participation: The case of sea cucumber (*Holothuria scabra*) ranching in Pandaraonan, Guimaras, Philippines, 66th British Phycological Society Annual Meeting. Southend, Essex, England. 9-11 January, 2018 (POSTER).

22. Suyo, JGB and Altamirano, JP. Gender, Resource Use and Coastal Management: The case of sea cucumber ranching in Pandaraonan, Guimaras, Philippines. 6th Global Symposium on Gender and Aquaculture and Fisheries (GAF6) at the 11th Asian Fisheries and Aquaculture Forum (11AFAF). Bangkok, Thailand. 3-7 August 2016
23. Tomas E, Rodriguez BD, de Peralta G, Catbagan T, Lambio KA, Rioja RA, Sinsona MJ, and Juinio-MeñezMA. Establishment of a pilot sandfish restocking site in Anda, Pangasinan.13th National Symposium in Marine Science. General Santos City, Philippines. 22-24 October 2015.

A project evaluation workshop was conducted by the SEAFDEC team in Concepcion, Iloilo on March 1, 2017, engaging a diverse range of stakeholders from the community, industry academia and government. Project performance rating was high in terms of “Environment improvement” by all groups (8.0-9.8). High rating on “Increase in fisheries stocks” were given by both local government and community groups (9.75-10.0), but the project was rated lower by the academic group (7.6), with the justification the claimed project benefits such as stock rebuilding tended to be anecdotal, with a lack of quantitative data. “Community participation” and “Government support” also had lower ratings of 7.4 and 6.8 from the academic group, indicating that more focus on social linkages need to be developed in future engagements. Recommendations from the workshop include (1) Strengthen law enforcement and support from local government, (2) Further communication activities to all stakeholders, (3) Increase and enhance capacity of NIPSC hatchery, (4) Consider other sites for establishment/expansion of sea ranch sites and/or nurseries.

9 Conclusions and recommendations

9.1 Conclusions

The project achieved substantial diversification across different social/environmental ranching contexts and improvements in culture and ranching technologies, with strong buy-in from communities, industry, and local governing institutions in the process. The project approach to engaging in diverse settings across three counties (four including PNG through related project FIS/2010/054 - *Mariculture Development in New Ireland, Papua New Guinea*) has provided important new information on commonalities and idiosyncrasies of sandfish ranching under a range of environmental, institutional and social settings, and approaches to their integration in culture systems. While the project fell short of developing viable, economically sustainable community enterprises and learning sites for scaling, research outcomes removed substantial bottlenecks to future success and highlighted remaining areas for research engagement.

Notably, new research on larval feeding has removed a stubborn and recurring bottleneck to juvenile production – live algal production. Scale-out of hatchery technology early in this project, despite the expert training provided, again experienced multiple impacts from poor water quality and pathogen introductions from live algal culture. The use of commercial algal pastes, as pioneered through project research, will likely be adopted broadly in sandfish hatchery systems, simplifying culture and reducing investment and infrastructure requirements in hatchery systems.

In the Philippines, collaborative research with communities developed and refined ranching technologies that better integrate communities into culture processes at an earlier (nursery) stage. This diversifies the livelihood options available through ranching, enhancing potential benefits to communities and further building the case for future investment in this sector. Conversely, in Vietnam limits to diversification were identified: sea ranching trials were unsuccessful (where pond farming is viable) for environmental and governance reasons, while project field observations and laboratory experiments showed that shrimp ponds in the Philippines are generally not suitable for sandfish culture, and ranching is the best option in this setting. These outcomes provide clear guidance for future investments.

In Australia, the project demonstrated the viability of important components of an industry/community partnership model – without achieving a fully independent model for Aboriginal livelihood generation through sandfish ranching. Broad benefits from the project's engagements were independently documented, and persist through follow-on initiatives. In the current institutional setting, the committed and transparent engagement of the industry partner with resource and market access remains key to overall success.

The project provided important new information regarding multi-scale stochastic and spatial environmental variability within and among potential ranching sites across broad geographies. While understanding these dynamics are an important step in developing robust ranching systems, the project was not able to use these data to identify a set of environmental suitability indicators for ranching sites. Inference was in part limited by the lack of consistent and longer-term growth and survival data from ranching trial sites. This relates both to the biological limitations to tagging/marking sandfish, but more troubling was the low levels of recovery at many ranching sites after periods beyond a few months, particularly in the Philippines. The dynamics of post-release survival, and predation specifically, are not well understood. Further research in this area will be key to ranching success.

Environmental shocks (notably typhoons/cyclones) have been a consistent feature throughout the history of ACIAR sandfish culture projects, and the current project was no exception. Systems resilient to such shocks will be important moving forwards, and will increase benefit to communities as the ability to rapidly re-engage with cash-crop markets provides a clear boost to community and household resilience.

Lastly, high levels of enthusiasm and engagement among partner community organisations, and particularly from women and women's groups, was notable through the scaling elements of the project. This stresses the importance for research on potential benefits and scaling to progress beyond a technology and economic focus, adding gender and livelihoods framings to research and engagement.

This project continued the staged successes of a long-term and substantial investment by ACIAR into sandfish ranching and restocking. Project outcomes, as summarised in the end of project review, provide clear directions for future investments, and a plausible pathway to successful scaling of sandfish sea ranching.

9.2 Recommendations

This project was reviewed in June 2016 and the following eight major recommendations for future research were made to address current production bottlenecks:

1. Optimise juvenile production methods through a better understanding of fine-scale culture requirements and enterprise system options.
2. Diversify and scale up juvenile production systems (Philippines, Vietnam).
3. Optimise survival of released juveniles through a deeper understanding of key ecological influences and predation.
4. Embed future work more fully within a Sustainable Livelihoods Approach framework.
5. Implement a range of strategies to enhance research capacity and outputs.
6. Include a publication strategy in the next project phase to support writing and drive publication outputs.
7. Leverage opportunities through formalised collaborative approaches.
8. As part of the socioeconomic research, develop gender strategies for female integration in sandfish production and post-production activities.

The project research team concur with these recommendations, which provided a basis for the follow-on project FIS/2016/122 '*Increasing technical skills supporting community-based sea cucumber production in Vietnam and the Philippines*'. The project seeks to improve technical skills and the reliability of current culture methods to support increased production capacity of community-based sandfish culture in Vietnam and the Philippines.

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Concurrent outputs from the National Sea Cucumber program in Philippines (ACIAR project contributions noted in acknowledgements):

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20. Manguilimotan, L- Thesis, Master of Science in Fisheries-- Seasonal effect of sea cucumber *Holothuria scabra* seapen farming on the ecology of the shallow-waters of Maliwaliw Island, Salcedo, Eastern Samar, Philippines

11 Appendixes

11.1 Appendix A: Vietnam farmer survey

Between project design and implementation, market conditions in Vietnam shifted considerably. Where 30 pond farmers in the central region had been enthusiastically farming sea cucumbers during the design phase, by implementation most had switched to other species. To understand reasons behind this, the RIA3 team conducted a survey of 20 (67%) of former sea cucumber farmers. Raw data from these surveys is presented in this appendix, as it can serve as an important data source/baseline for future industry development initiatives in Vietnam.

Questions	Farmer 1	Farmer 2	Farmer 3	Farmer 4	Farmer 5	Farmer 6	Farmer 7	Farmer 8	Farmer 9	Farmer 10
1. Are you still farming sea cucumber? (No? – go to Q5)	No	No	Yes	No	No	No	No	No	Yes	No
2. How many ponds are you now using for sea cucumber			5						1	
3. How many Ha of ponds for sea cucumber			0.3 ha/pond						0.4 ha	
4. In 2014 what was your total production of sea cucumber?			2 tons						0.7 tons	
5. in 2014, what was your total production of other species?	6 tons of snails	4 tons of snails	0	9.5 tons of snails	2 tons shrimp 3.5 tons snail	10 tons of snail	6.5 tons of snail	14 tons of snail	9.5 tons of snail	5 tons of snail
6. If reduced or stopped sea cucumber production since 2013, what species instead?	Snail	Snail		Snail	Shrimp and snail	Shrimp and snail	Snail	Snail	Snail	Snail
7. If stopped or reduced sea cucumber farming, why? Sea cucumber discount or others rise	Both	Sea cucumber discount		Both	Sea cucumber discount	Other species increase	Sea cucumber discount	Both	Both	Sea cucumber discount
8. If stopped or reduced sea cucumber farming, when?	Nov. 2013	Sep. 2013		April 2013	May 2013	March 2013	Feb. 2013	Feb. 2013	Jan. 2013	Oct. 2012
9. What was the price when you stopped or reduced farming?	No one bought	70,000/kg gutted		60,000/kg gutted	45,000/kg gutted	40,000/kg gutted	50,000/kg live	30,000/kg live	50,000/kg live	40,000/kg gutted
10. Would you farm again or increase production if prices went up?	Not known yet	yes	yes	Not known yet	No	Not known yet	Yes	No	Yes	No
11. What would the price be for you to start again or increase your current production?	80,000/kg	Over 100,000/ kg	100,000/ kg	About 150,000/ kg	Over 140,000/ kg	About 120,000/ kg	Over 100,000/ kg live	90,000/kg	Over 100,000/ kg	Over 100,000/ kg
12. If Babylon snail or shrimp prices reduced, would you start farming sea cucumber again?	Not known yet	No	yes	No	If sea cucumber increases	No	If sea cucumber increases	No	yes	No

Questions	Farmer 11	Farmer 12	Farmer 13	Farmer 14	Farmer 15	Farmer 16	Farmer 17	Farmer 18	Farmer 19	Farmer 20
1. Are you still farming sea cucumber? (No? – go to Q5)	Yes	No	No	No	No	No	No	No	Yes	No
2. How many ponds are you now using for sea cucumber	1								1	
3. How many Ha of ponds for sea cucumber	0.3 ha								0.4 ha	
4. In 2014 what was your total production of sea cucumber?	0.6 tons								0.5 tons	
5. in 2014, what was your total production of other species?	5 tons of shrimp	9 tons of snail	3.5 tons of snail	5 tons of shrimp	6 tons of snail	11 tons of snail	4 tons of snail	3 tons of shrimp	5 tons of snail	6 tons of snail
6. If reduced or stopped sea cucumber production since 2013, what species instead?	Shrimp	Snail	Snail	Shrimp	Snail	Snail	Snail	Shrimp	Snail	Snail
7. If stopped or reduced sea cucumber farming, why? Sea cucumber discount or others rise	Sea cucumber discount	Both	Other Species increase	Sea cucumber discount	Other species increase	Sea cucumber discount	Both	Sea cucumber discount	Both	Both
8. If stopped or reduced sea cucumber farming, when?	Feb. 2014	Aug. 2013	May 2013	Oct. 2013	Jan. 2014	Jan. 2013	Nov. 2013	Jan. 2014	March 2014	Nov. 2013
9. What was the price when you stopped or reduced farming?	70,000/kg	No one bought	10,000/ head	45,000/kg gutted	30,000/kg	55,000/kg gutted	No one Bought	20,000/kg	40,000/kg	No one Bought
10. Would you farm again or increase production if prices went up?	Yes	No	Don’t know yet	Don’t know yet	No	Don’t know yet	No	No	Don’t know yet	No
11. What would the price be for you to start again or increase your current production?	100,000/ kg	Over 150,000/ kg	Over 30,000/ head	110,000/ kg	100,000/ kg	Over 100,000/ kg	Over 100,000/ kg	Over 100,000/ kg	Over 90,000/kg	Over 100,000/ kg
12. If Babylon snail or shrimp prices reduced, would you start farming sea cucumber again?	Yes	No	No	No	No	No	No	No	No	No

11.2 Appendix B: Pen experiment statistical analysis

Prepared by Carlo Mattone – JCU Marine Data Technology Hub

11.2.1 Statistical Methods

Data for the pen experiments were checked for errors and inconsistency in results. After initial assessment we observed that recapture rates of sea cucumber was <50% for the majority of the Philippines' sites in the first quarter, with almost no recaptures in the second quarters. This mean that in order to evaluate growth across sites and among pens, we focused on the first quarter data in order to have enough replication. These low recapture rates were not observed for the sites in Papua New Guinea, however we decided to use the data collected after 4 months (re-sampling occurred bi-monthly) for ease of comparison. Sites in Victory, Philippines, were excluded from analysis because of missing environmental data, which did not allow for direct comparison with the other sites.

We firstly carried out Principal Components Analysis (PCA) to assess the variability in replication among sites and times (i.e. at the beginning of the experiment and after the 1st quarter): this was done to assess if mean sediment structure was representative of the pens. Multivariate regression tree analysis (mCART), based on a Bray-Curtis dissimilarity distance, was performed using sediment properties as dependent variables and location as explanatory factors, to assess sediment characteristics across sites and pens.

We utilized univariate classification and regression trees (CARTs) to assess whether mean sediment structure (i.e. seagrass cover, %chlorophyll, %phaeo pigment, % liable and refracted organic matter, penetrometer reading and grain Size), and location (i.e. sites and pen) could predict sea cucumber weight after the first quarter. We also utilized a random forest model, with the same variables and dependencies as the CARTs to evaluate if weight could be reliably predicted using the sampled variables.

All tests were conducted using R open source software (RCoreTeam 2019) employing the 'rpart' package for the CARTs (Therneau et al. 2015), the 'mvpart' package for mCARTs (De'ath 2007), and the package 'vegan' for the PCA (Oksanen et al. 2019).

11.2.2 Results

Most of the sites in the Philippines had very low recapture rates after release, generally only finding < 25 sea cucumbers after the first quarters and < 5 in the second quarter (Figure 1). The only exceptions were Tubajon sites and pen A of Polopinya, which were still able to find a full subsample of 50 individuals. The PNG sites while they had a much higher sea cucumber density, had strong recapture rates, with the sole exception of Enuk (Figure 2).

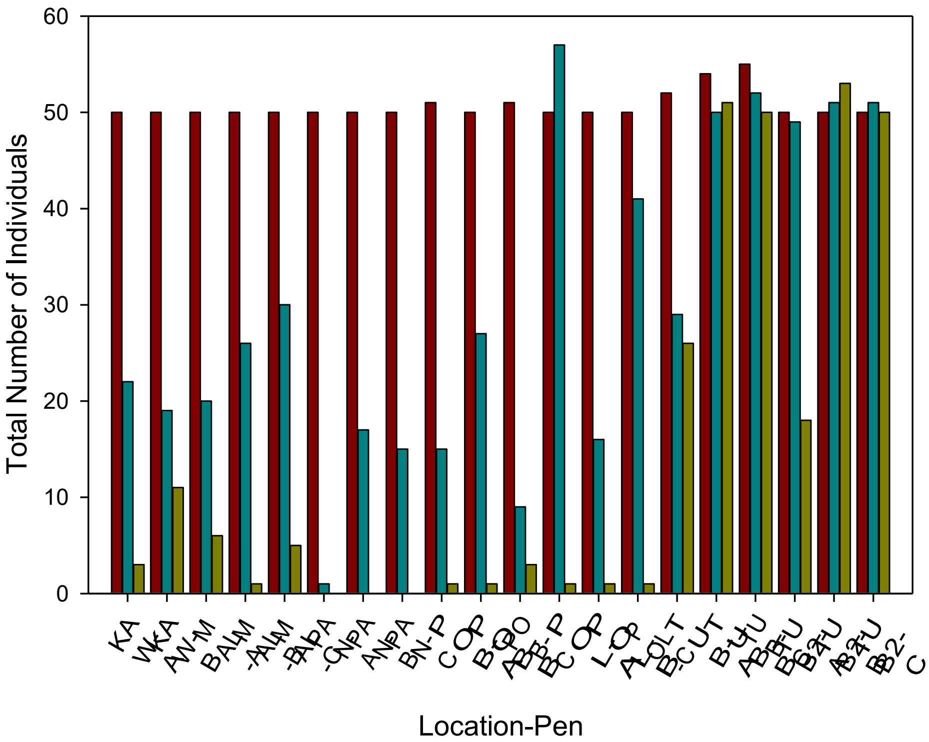

Figure 1: Total number of sea cucumber recaptured after the initial release (Red= initial release; Blue = 3 months; Yellow= 6 months) at the different sites and Pans in the Philippines

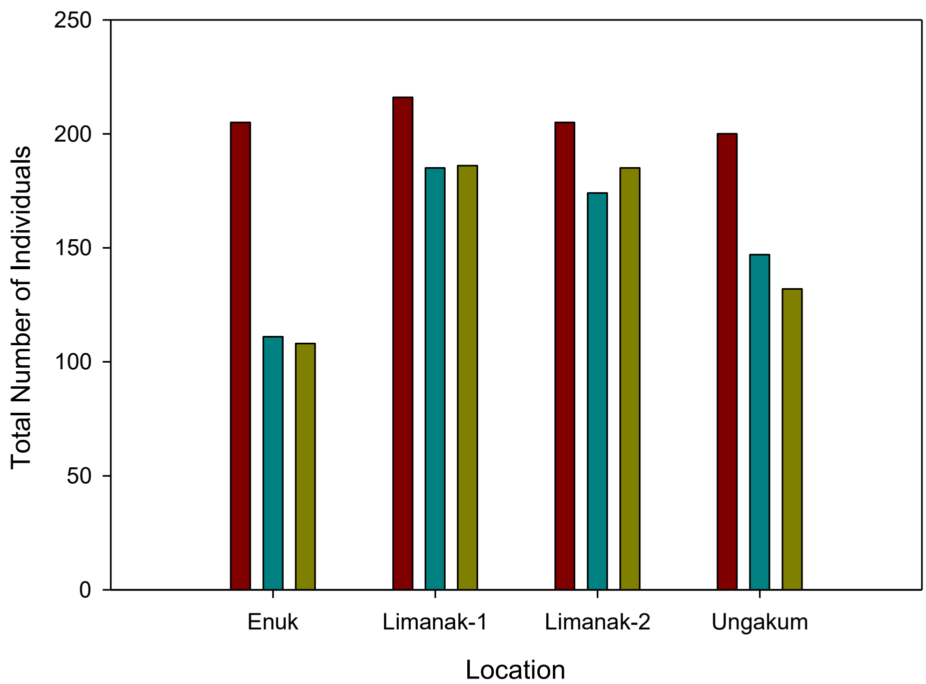

Figure 2: Total number of sea cucumber recaptured after the initial release (Red= initial release; Blue = 4 months; Yellow= 6 months) at the different sites in Papua New Guinea.

The weight data of the sea cucumbers before release and after re-sampling in the second and third quarter still show growth, however the spread in variability increases substantially (Figure 3). In the majority of the cases pens within the same location seems to have similar trajectories. Growth in the four sites in PNG provide the cleanest trajectory, likely due to the higher frequency of resampling (Figure 4).

There is clear differentiation between sediment structures across locations: in particular, the PNG locations cluster away from the Philippines locations (Figure 5). Within location, there is low variability with most replicates clustered close together. When the vectors of the variables are super-imposed on the ordination, it become visible that the major separation among sites is due to seagrass cover and % fine sediment: PNG is characterized by higher presence of fine sediment size, and low seagrass cover.

The multivariate regression trees constructed using the sediment structure as measured at the beginning of the experiment and after the first quarter, show similar trends, with the sites at PNG being very similar among themselves, mostly due to a lower presence of seagrass cover. Interestingly sampling period was not important in classifying the sediment characteristics, with sites having the largest influence (Figure 6).

The univariate regression tree carried out on sea cucumber weights following re-sampling after the first quarter, showed that the best predictor for weight distribution was site (Figure 7). Interestingly the major split was to separate out most PNG sites (Enuk, Limanak 1 and Limanak 2), Malawani (MAL) and Kawit (KAW), which have the higher overall growth for that period, from the other sites. The remaining splits were based on organic matter content and chlorophyll, however this may be due to data ‘overfitting’. The random forest model constructed to predict weight based on sediment characteristics and sites managed to explain about half of the total variance (43.88%). Similarly to the univariate CART the most important variable when constructing the model was sites (Figure 8), followed by refractory organic matter. Likely indicating that the majority of the variability in results is likely due to intrinsic sites characteristics.

11.2.3 Discussion points

- High variability in ‘survival/escape/poaching’ leads to very low recover rates after period 1. The only exception are the PNG sites and Tubajon 1 and 2.
- The sediment analysis shows that the PNG sites as well as Philippine sites MAL and POL have very low seagrass cover, and higher presence of fine and medium sediments. All other sites have high seagrass cover and this does not vary between samples at T=0 and 3 months.
- The weight data show that larger individuals were found at PNG sites after 1 sampling period, (to note that PNG was sampled after 4 months as opposed to 3 months) except at Ungakun, but also at Philippines sites KAW and MAL.
- Initial weight at time 0 varied across sites, but not enough to suggest it influenced growth outcomes in the first quarter.

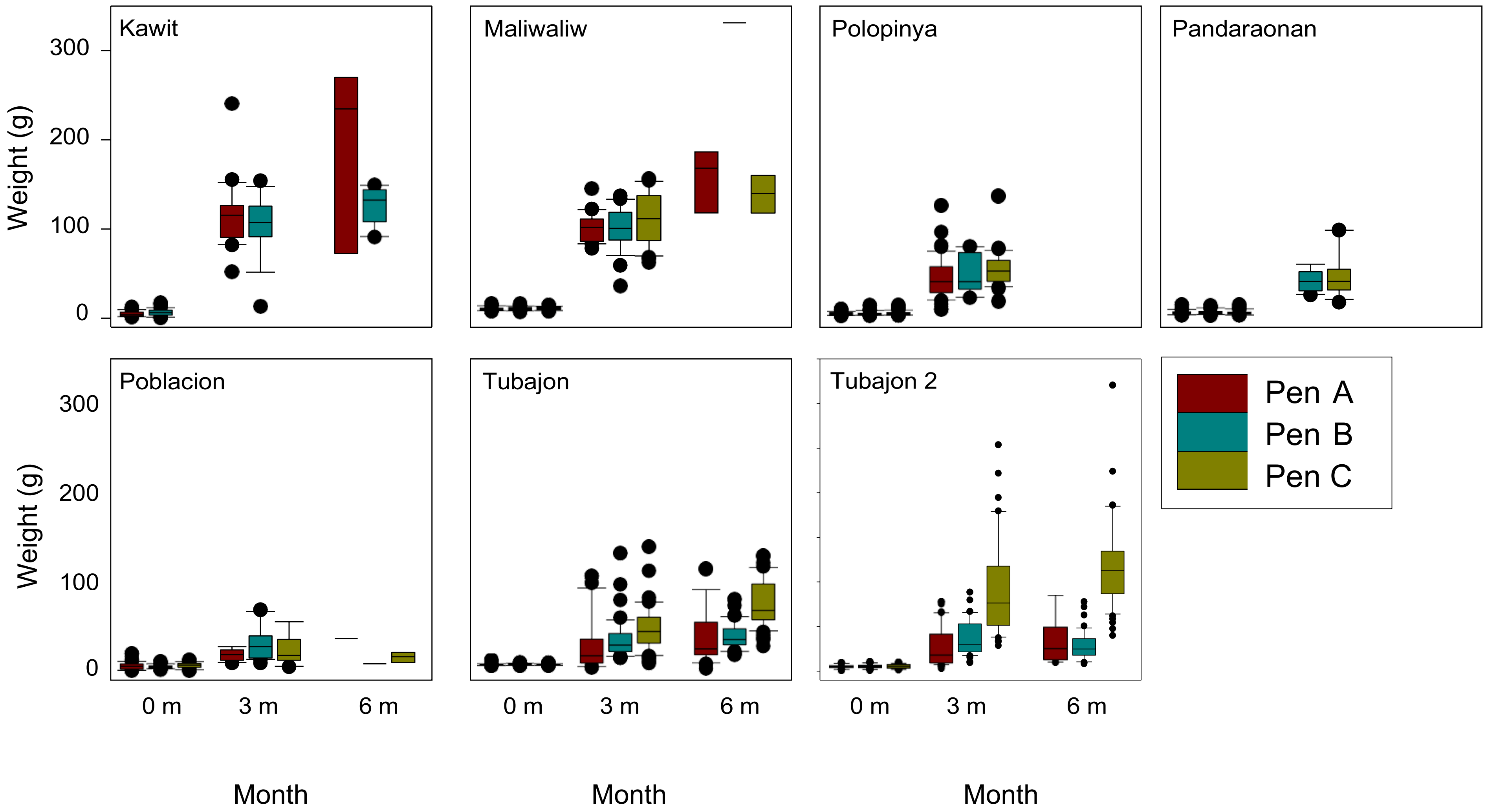

Figure 3: Boxplot of the size distribution in the Philippines sites and across pens and sampling events (release, 3 months, 6 month)

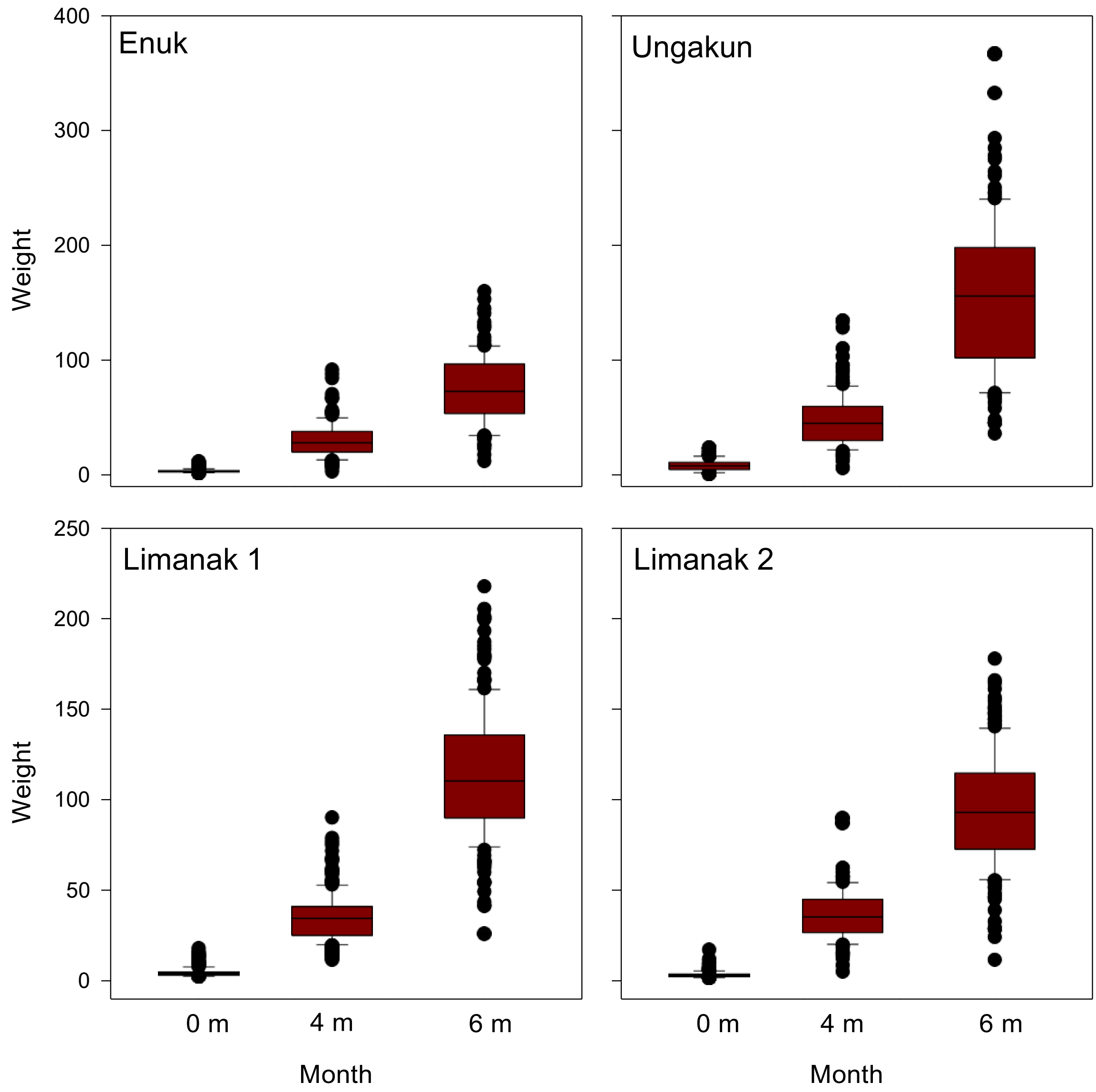

Figure 4: Boxplot of the size distribution in the pen experiments in Papua New Guinea per sampling event (release, 4 months, 6 month)

- Interestingly, the PNG sites and MAL also have similar sediment structure, while KAW seem to be different, while in reality it only has higher Seagrass cover and still very well distributed sediment between fine and medium size. POL (which shows low overall Sea cucumber growth is grouped together with PNG sites instead,]as it has low seagrass (in common with PNG) and much finer sediment structure.
- It would appear that seagrass density has no influence on sandfish growth, suggesting this may be a parameter to drop from future monitoring programs to save on labour. Data could be further analysed to test for the influence of seagrass prevalence in the wider area before moving to drop this parameter.
- Fine and medium sediment (but not silt – the finest fraction) seem to be the best predictors for pens with higher growth, however this is not a particularly strong relationship.

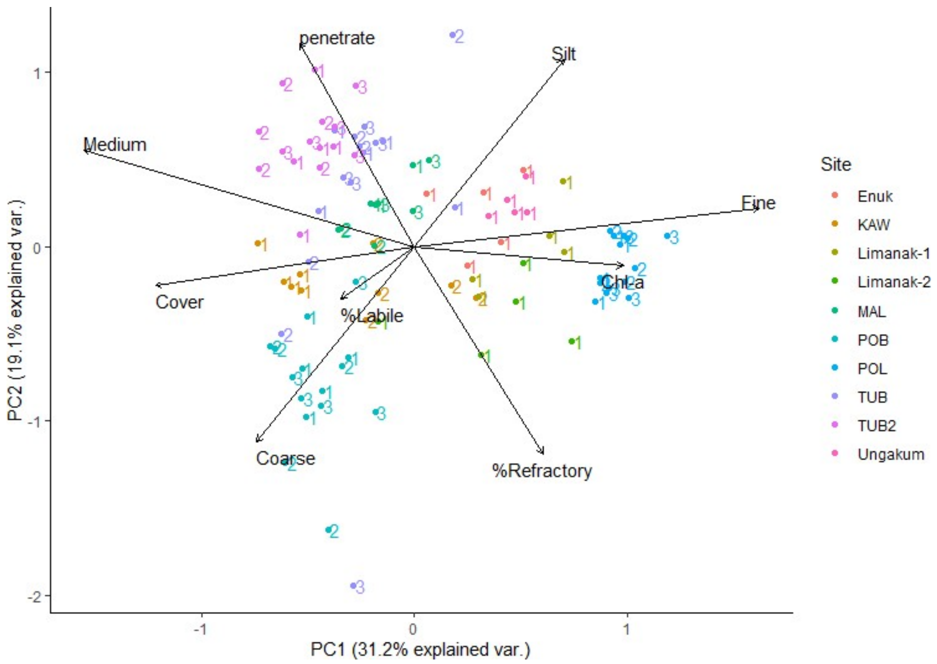

Figure 5: principal component analysis (PCA) for the ordination of the sediment composition using all replicates and sorted by pen number (i.e. 1, 2 ,3) at each location (KAW = Kawit, MAL = Maliwaliw, PAN = Pandaraonan, POB= Poblacion, POL, Polopinya, TUB = Tubajon, TUB2= Tubajon 2). The physical variables were superimposed the ordination using loading vectors (Cover= % Seagrass cover, Chl-a = % Cholorophyll-a, %Labile= % Labile organic matter, % Refractory= % Refractory organic matter).

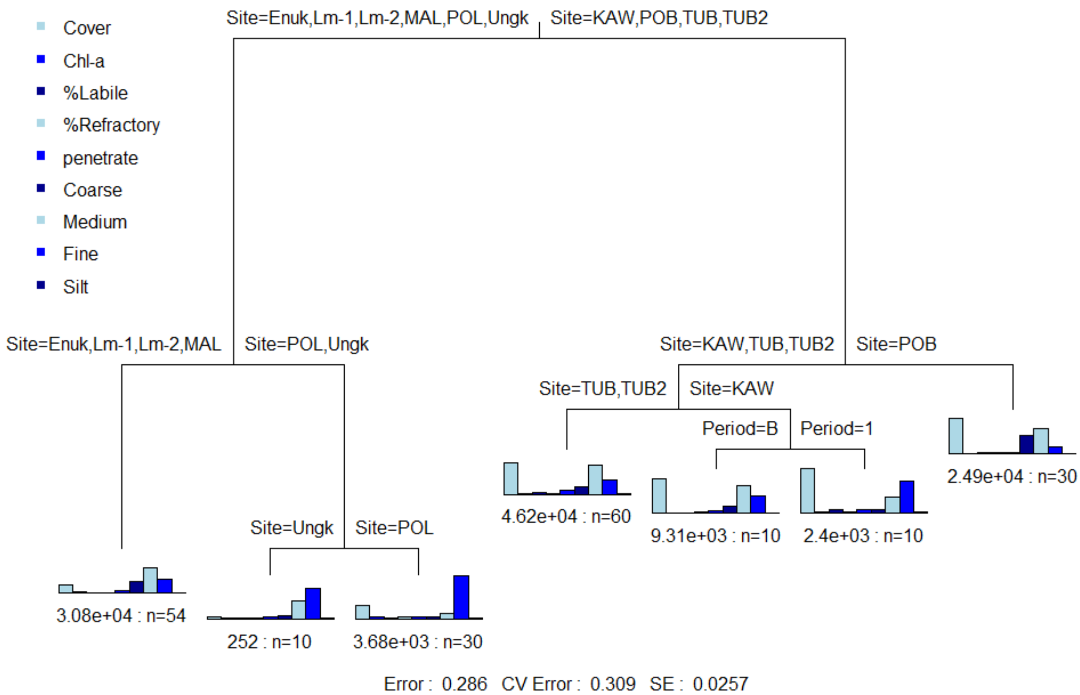

Figure 6. mCART for the sediment composition at the different locations (see main text figure x for abbreviations), the values at each terminal node represent estimated mean and number of observations.

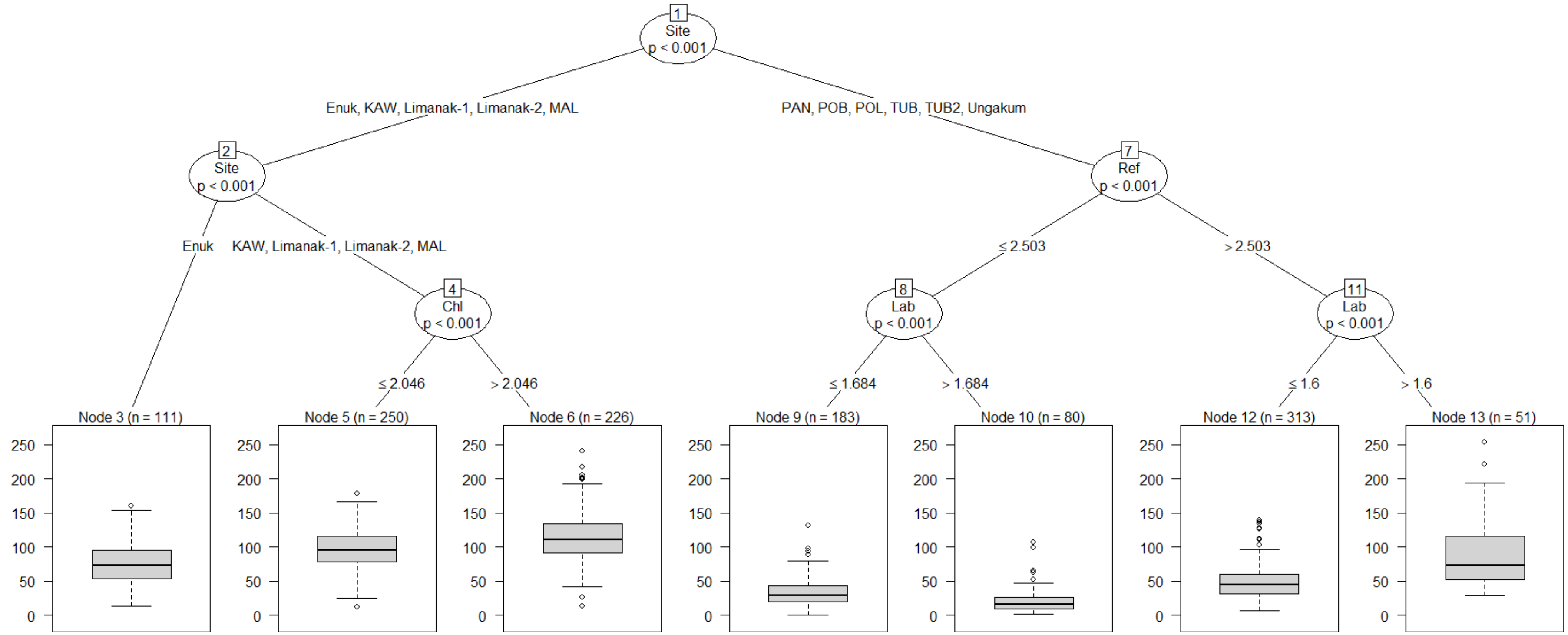

Figure 7. Univariate regression tree carried out on the sea cucumber weights following re-sampling after the first quarter (3 months) using Sites and sediment properties as predicting variables (Seagrass cover, %chlorophyll, %phaeo pigment, %Liable and Refracted organic matter, Penetrometer and grain Size)

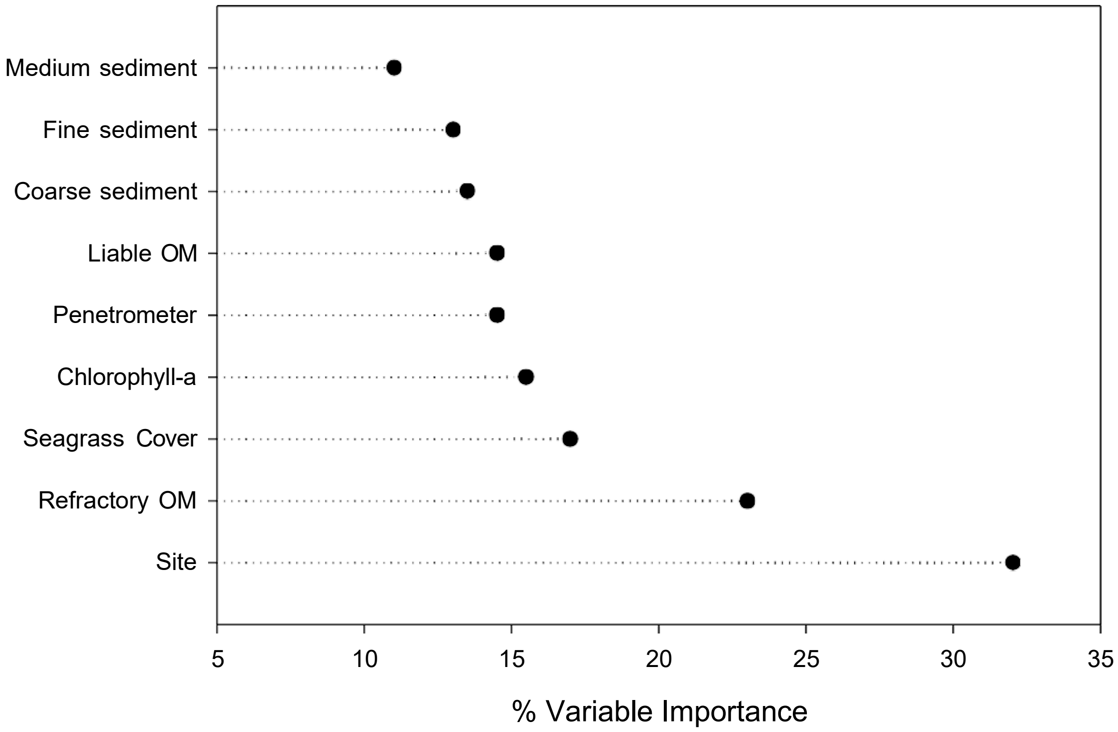

Figure 8. Random Forest plot describing the importance of each variable within the model.

11.2.4 References

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11.3 Appendix C: Distribution maps of environmental parameters

Understanding fine-scale spatial and temporal variability in ranching sites is important for site selection. Through the current project methods for measuring these parameters were adopted and adapted, and implemented at major ranching sites. The data generated provides an opportunity to conduct further analysis on outcomes beyond what have been possible as part of this final report. A representative set of contour plots are provided here to show the scales of variability in the data.

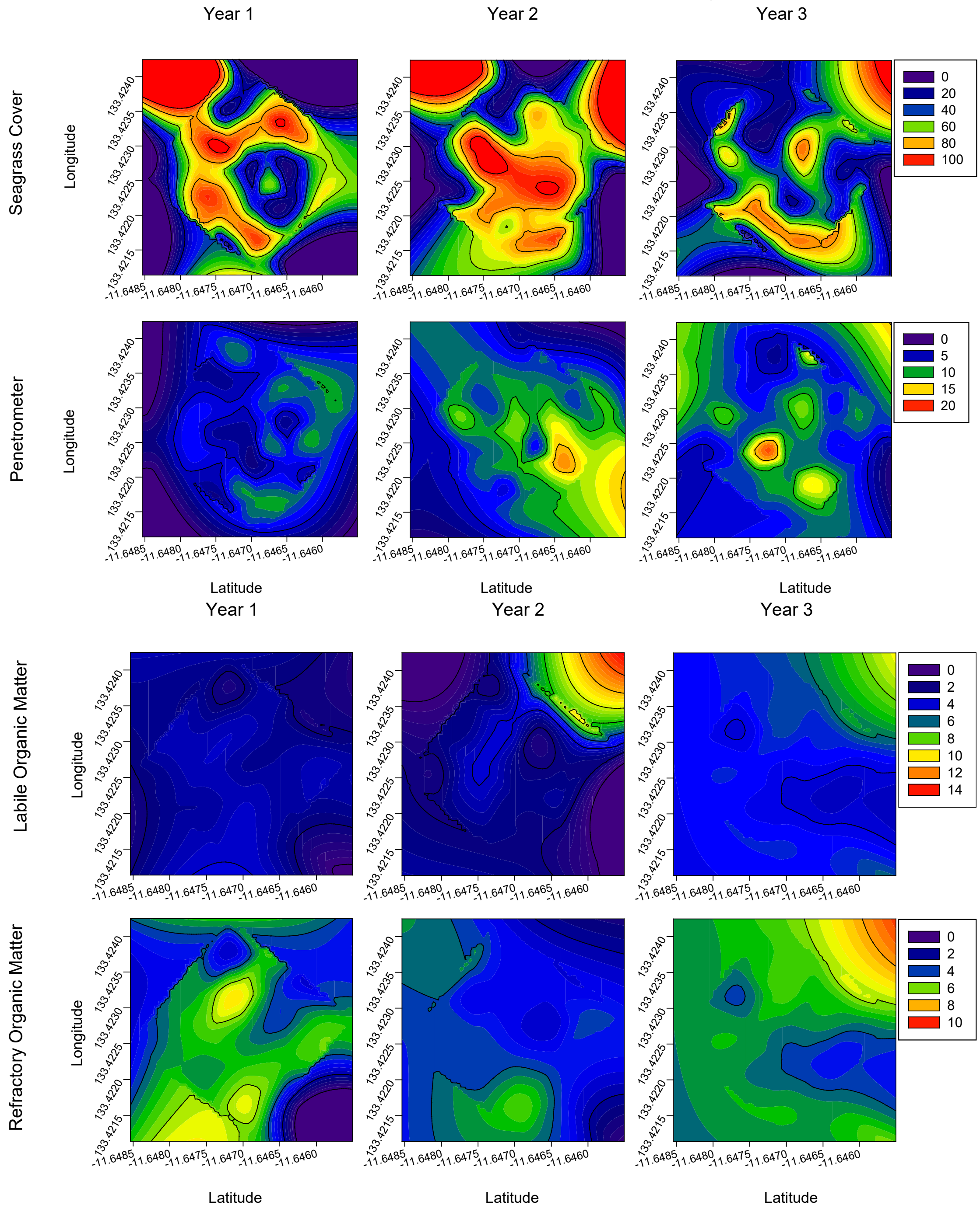

Figure 1. Variability in seagrass cover, penatormeter depth and organic matter over 3 years at the Wigu site, Goulburn Island, northern Australia.

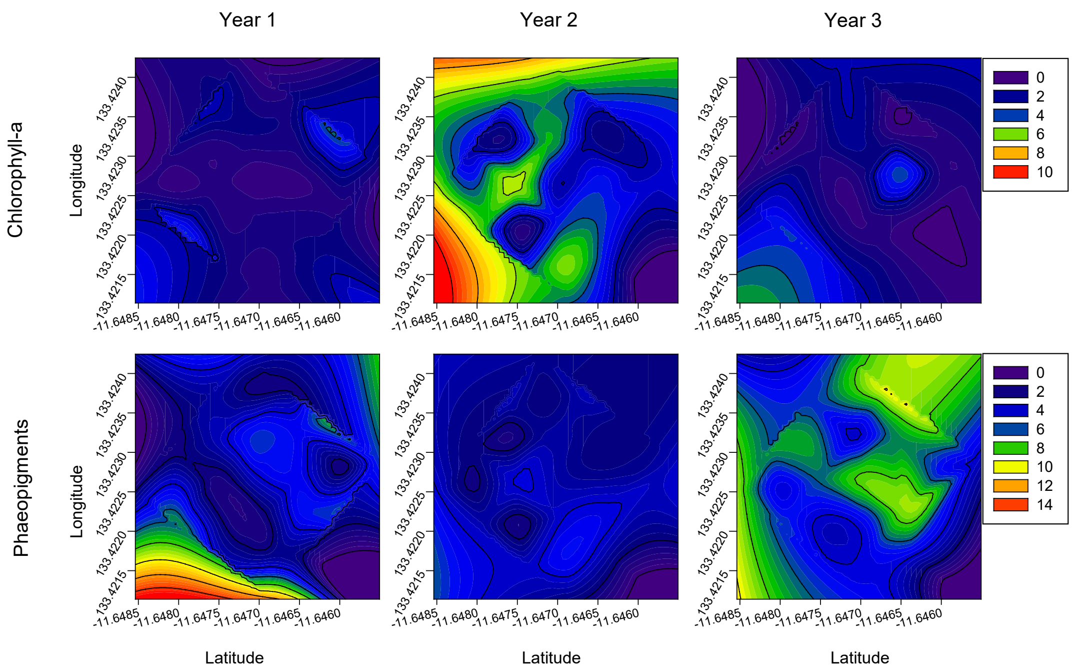

Figure 2. Variability in chlorophyll and phaeopigments in sediments over 3 years at the Wigu site, Goulburn Island, northern Australia (continues from Figure 1).

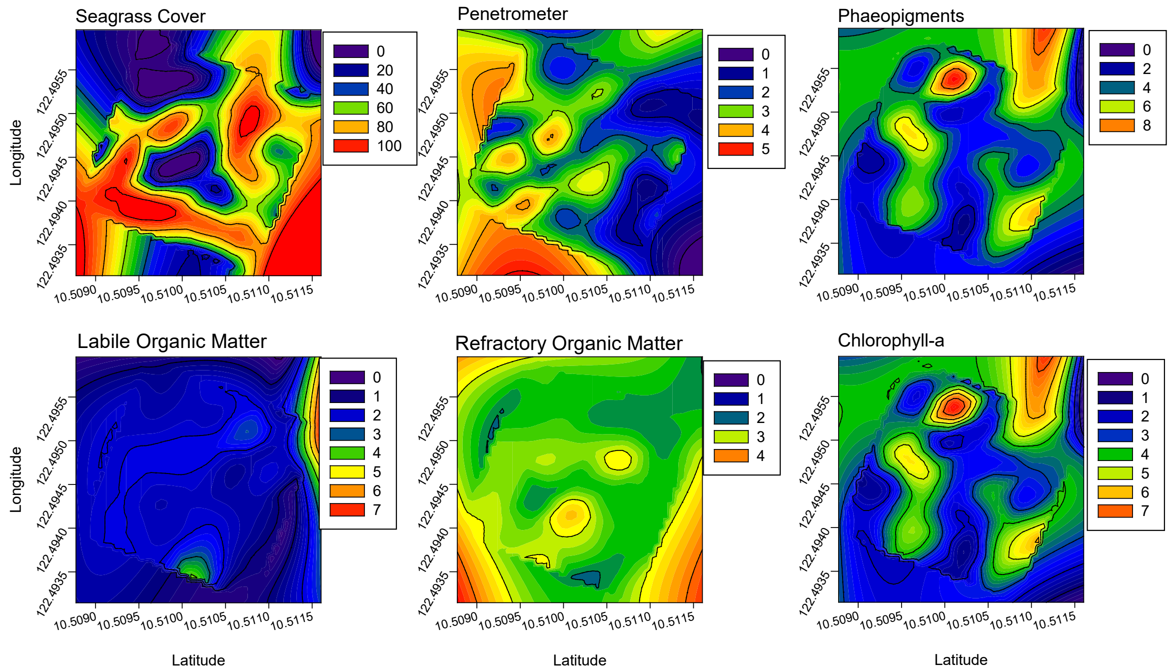

Figure 3. Spatial variability in seagrass and sediment parameters at Pandaraonan, Western Visayas (1 sampling only)

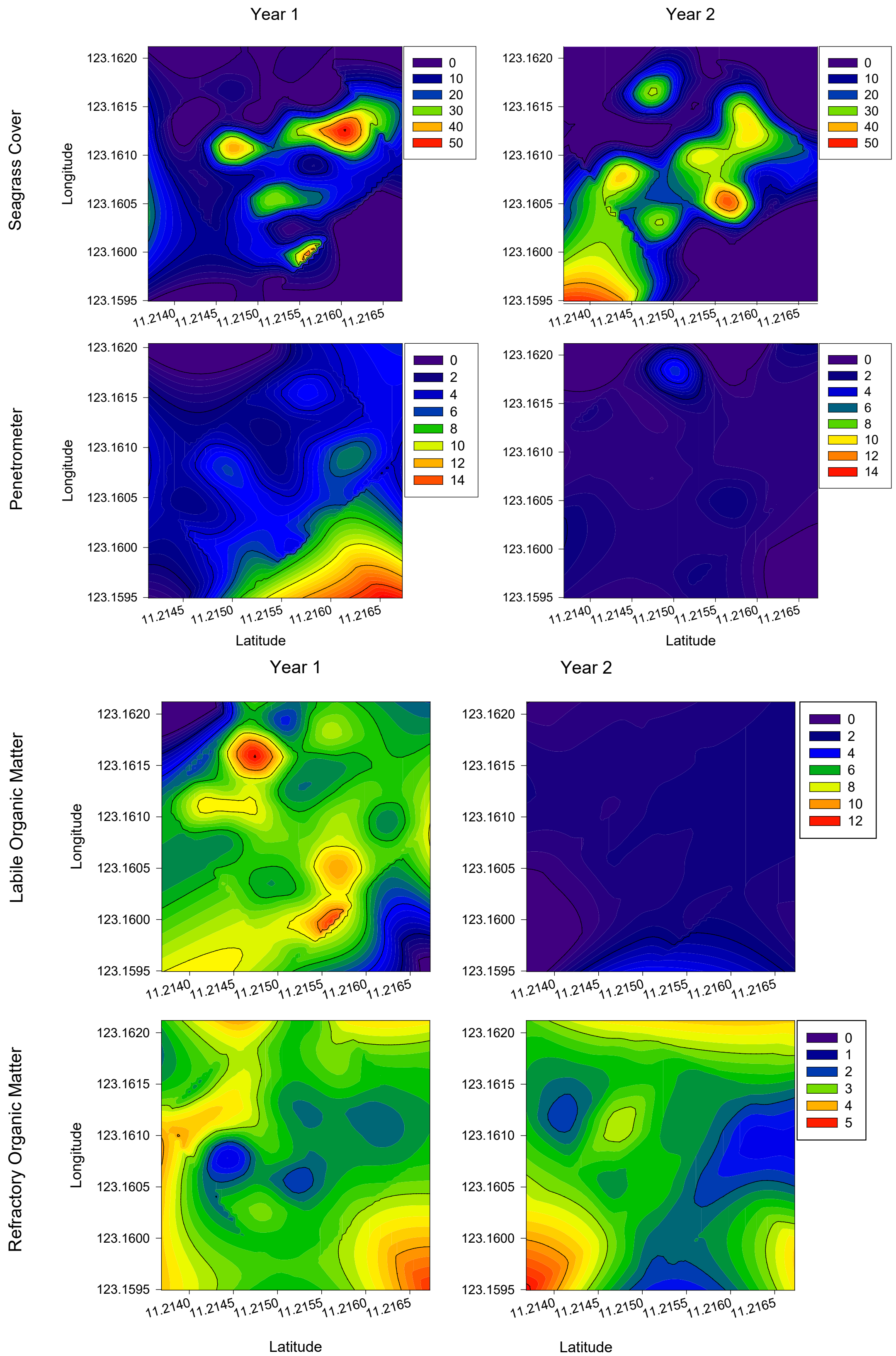

Figure 4. Variability over 2 years in seagrass cover, penatormeter depth and organic matter over 2 years at Polopinya, Western Visayas.

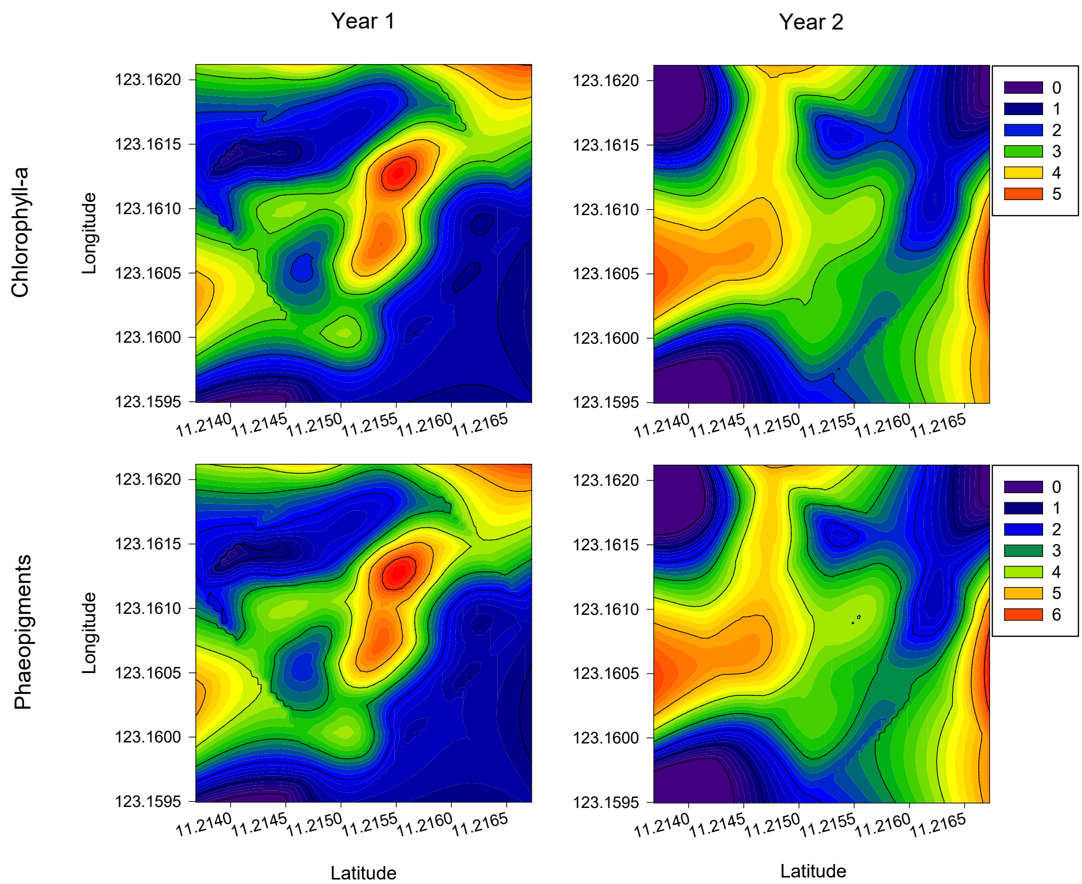

Figure 5. Variability over 2 years in in seagrass and sediment parameters over 2 years at Polopinya, Western Visayas (continued from Figure 4).

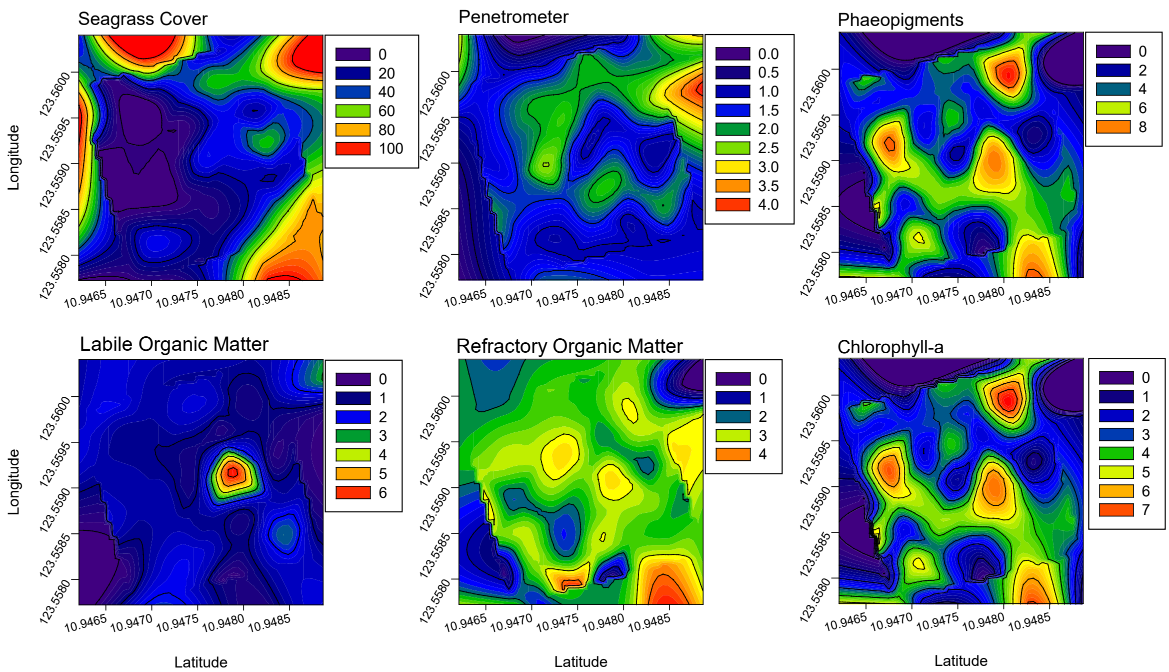

Figure 6. Spatial variability in seagrass and sediment parameters at Molocaboc, Western Visayas (1 sampling only)

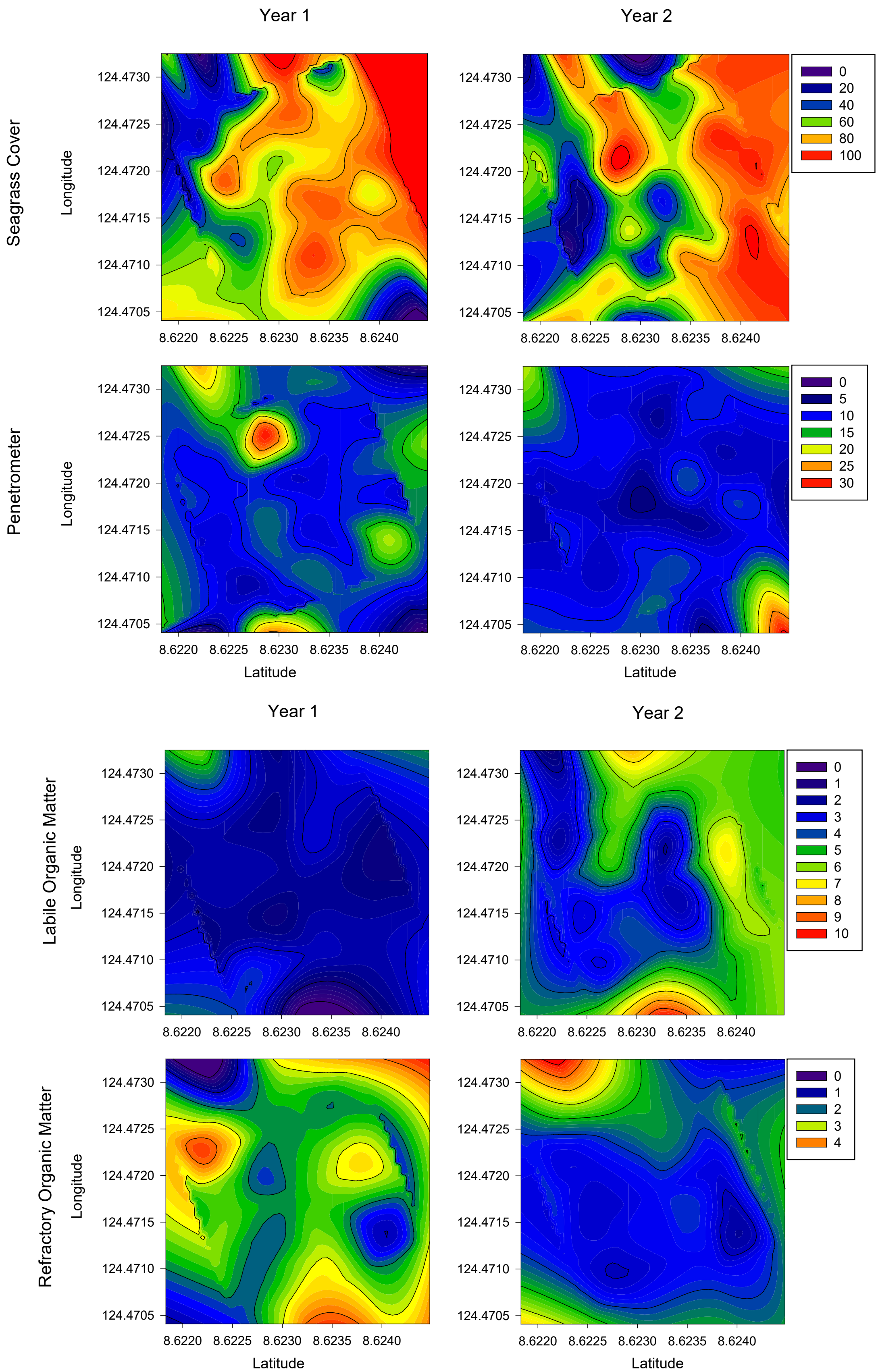

Figure 7. Variability over 2 years in seagrass cover, penatormeter depth and organic matter over 2 years at Tubajon, Mindanao.

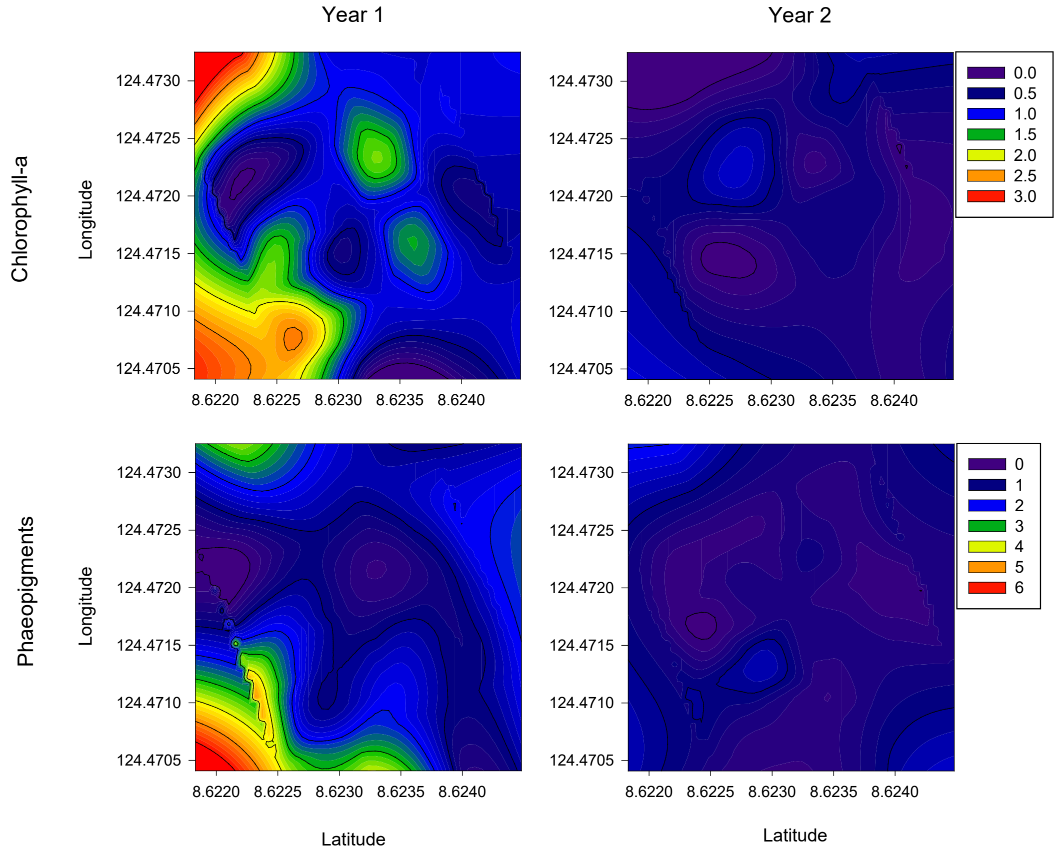

Figure 8. Variability in chlorophyll a and phaeopigment sediment assays in 2 consecutive years at Tubajon, Mindanao. (continued from Figure 7).

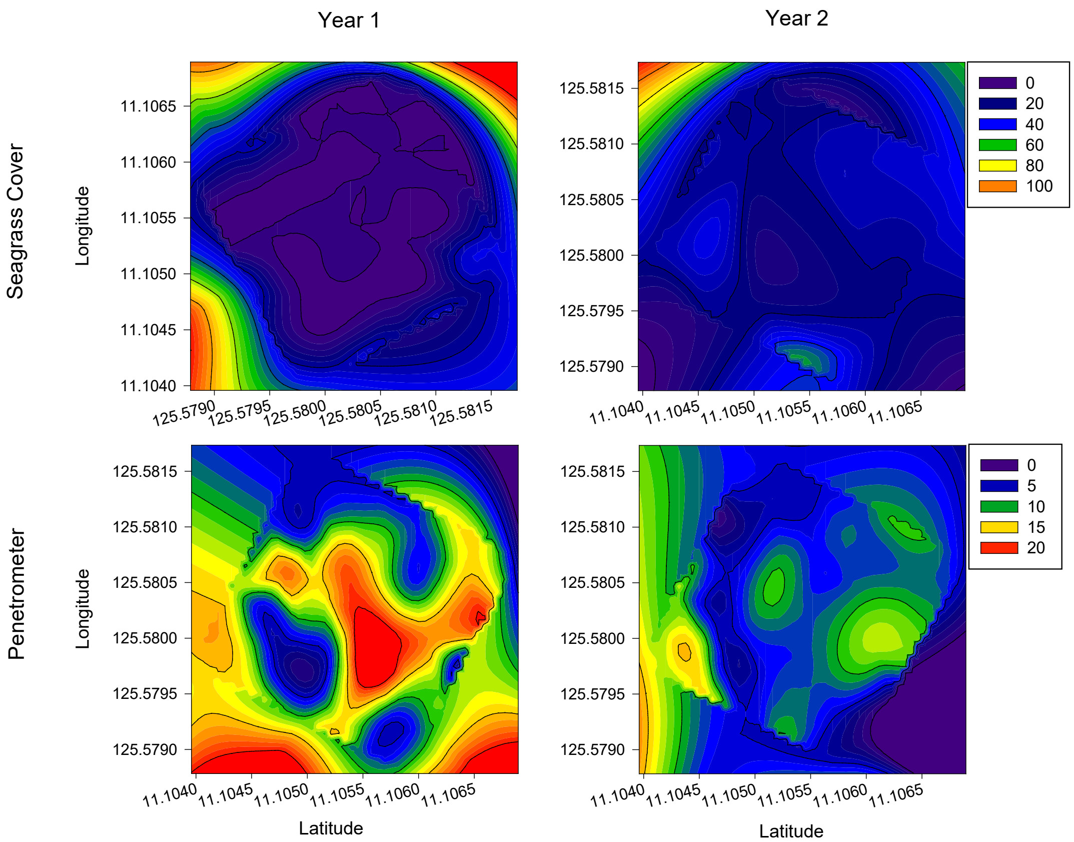

Figure 9. Variability over 2 consecutive years in seagrass cover and sediment penetrability at Maliwaliw Site 1, Eastern Visayas.

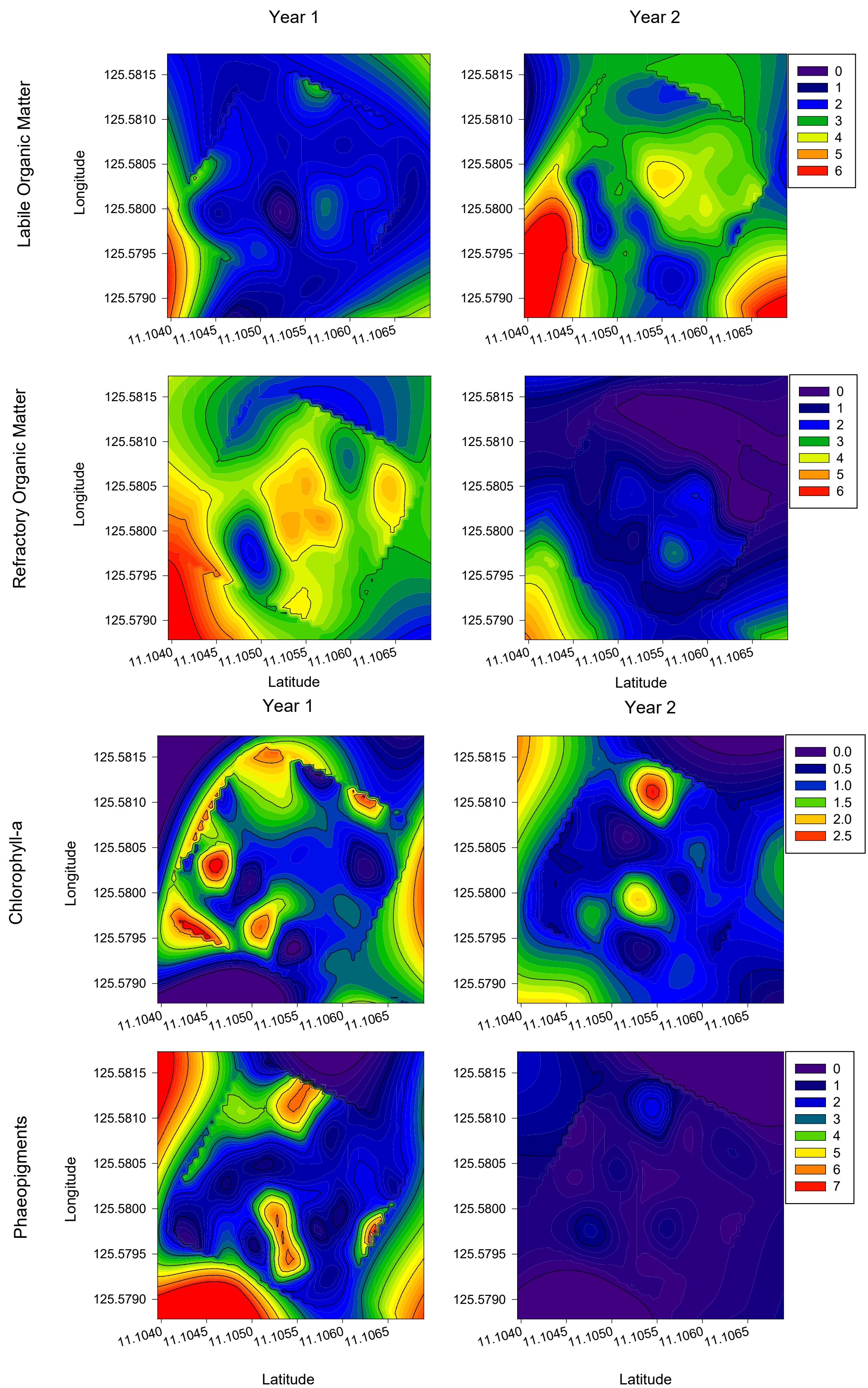

Figure 10. Variability over 2 consecutive years in organic matter, sediment chlorophyll a and phaeopigments at Maliwaliw Site 1, Eastern Visayas.

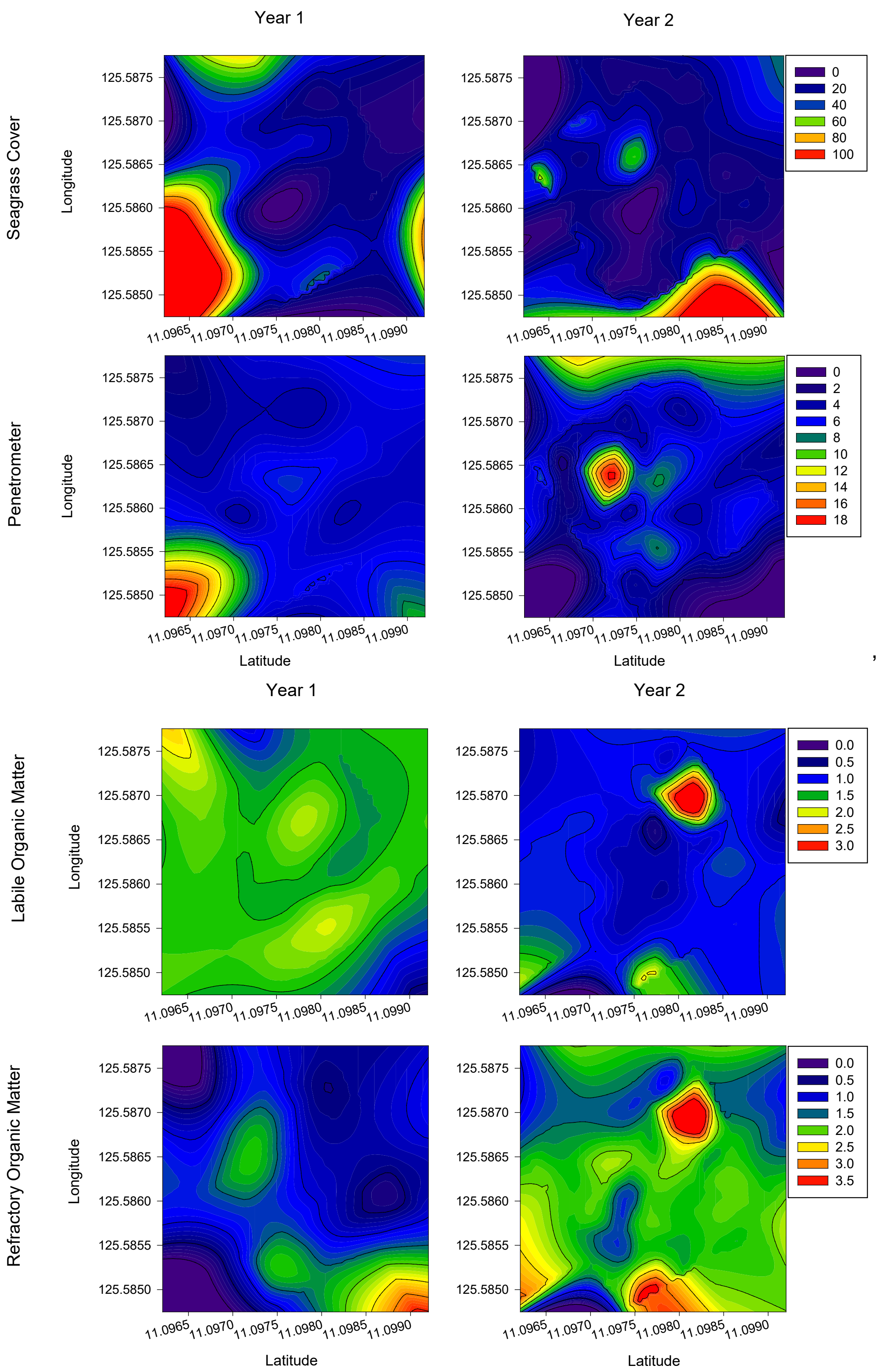

Figure 11. Variability over 2 consecutive years in seagrass cover, sediment penetrability, and organic matter at Maliwaliw Site 2, Eastern Visayas.

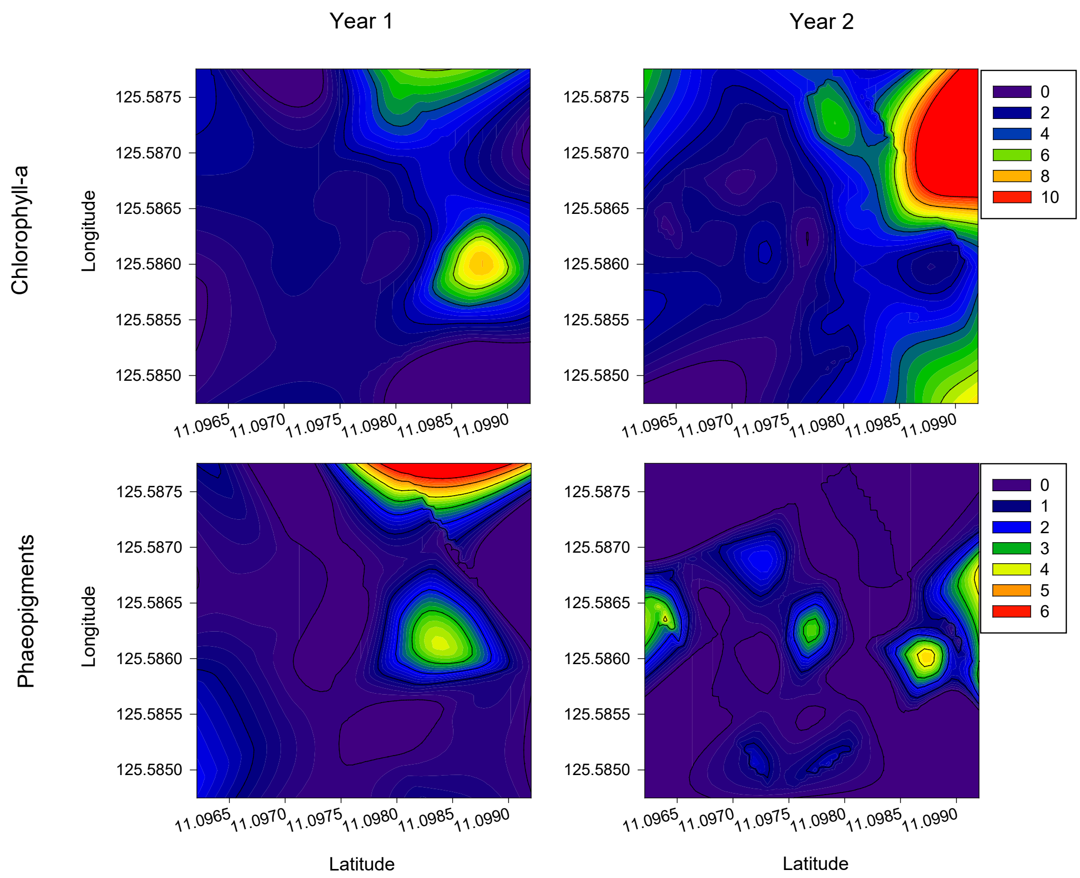

Figure 12. Variability in chlorophyll a and phaeopigment sediment assays in 2 consecutive years at Maliwaliw Site 2, Eastern Visayas. (continued from Figure 11).