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OPTIMIZING SPAT COLLECTION STRATEGIES AND CULTURE METHODS OF NATURALLY PRODUCED BLACK-LIP PEARL OYSTERS, *PINCTADA MARGARITIFERA* (LINNAEUS, 1758), FOR LOCAL COMMUNITIES IN FIJI

by

Charlene Patrina Erasito

A thesis submitted in fulfilment of the requirements for the degree of Master of Science in Marine Science

School of Agriculture, Geography, Environment, Ocean and Natural Sciences

The University of the South Pacific

March, 2021

Declaration of Originality

Statement by the Author

I, Charlene Patrina Erasito, declare that this thesis is my own work and that, to the best of my knowledge, contains no material previously published, or substantially overlapping with material submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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Statement by Supervisor

This research was performed under my supervision, and to my knowledge, is the sole work of Ms. Charlene Patrina Erasito.

Date 29/03/2021

Dr. Rajesh Prasad
Principle Supervisor

Dedication

To my family,

The world may be my oyster,

But you are my pearls.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

% – Percentage

ACIAR – Australian Centre for International Agricultural Research

APM – Antero-posterior Measurement

AVHRR – Advanced Very High Resolution Radiometer

CTN – Cord Technical Nakasai

DVM – Dorso-ventral Measurement

FJD – Fijian Dollar

ICDC – Integrated Climate Data Centre

mm – Millimetre

MoF – Ministry of Fisheries

MOP – Mother-of-Pearl

PARDI – Pacific Agribusiness Research for Development Initiative

POM – Particulate Organic Matter

PIM – Particulate Inorganic Matter

SE – Standard Error

SPM – Suspended Particulate Matter

SST – Sea Surface Temperature

USD – United States Dollar

USP – University of the South Pacific

WW – Wet Weight

YSI – Yellow Springs Instruments

Abstract

Lack of efficient methods for local spat collection and growth of pearl oyster spat circumvents pearl oyster supply to pearl farms in Fiji. Optimizing spat collection strategies and intermediate growout of the black-lip pearl oyster, *Pinctada margaritifera,* could possibly maximize revenue generation associated with cultured pearl industry based livelihoods in local communities. This research aimed to investigate timing and duration of spat collector deployment as well as the effect of an intermediate culture method for *P. margaritifera* in Namarai Bay, Fiji Islands.

The timing of spat collector deployment is a critical aspect in collecting pearl oysters. Results showed that spat collectors deployed during warmer months recruited a higher number of *P. margaritifera* compared to cooler months. Fifteen *P. margaritifera* spat were harvested during warmer months (January to June 2017) compared to zero during cooler months (July to December 2017). In addition, spat collectors deployed from October 2016 to June 2017 (8 months) and October 2016 to December 2017 (14 months) recruited approximately 45 and 43 *P. margaritifera* respectively. Hence, deployment of spat collectors at the beginning of Fiji's rainy summer season (October) could be ideal to recruit more *P. margaritifera* compared to the dry winter season (May).

Furthermore, the longer spat collector deployment duration resulted in a greater proportion of *P. margaritifera* spat that were near minimum seeding size of 100 mm, which is preferred by pearl farmers. All of the oysters (100%) harvested after 14 months had reached a 'size refuge' greater than 50 mm, making them less vulnerable to predation. This would be beneficial for local communities who earn income through spat sales. However, only 38% of oysters harvested after 8 months reached a 'size refuge'. Shorter immersion times (8 months) provided a higher number of smaller sized spat that would need to be grown in intermediate culture methods after removal from spat collectors, which could prove costlier for local communities.

Intermediate culture methods are widely used to increase the growth and survival rates of spat. This research has shown that spat grown in panel nets increased significantly in size and weight with 100% survival after 6 months. Growth rates of *P. margaritifera* in panel nets were very similar to other countries. However, when compared to spat

that remained on spat collectors, spat grown in panel nets were significantly smaller in DVM, APM and WW (see page vii for abbreviations). As such, the need for intermediate culture methods by local communities is debatable and further research needs to be conducted using cost-benefit analyses comparing spat remaining on spat collectors with those grown in other culture methods. Selection of intermediate culture methods must take into account economical and practical considerations for local communities in Fiji.

Chapter 1 Introducing the Black-lip Pearl Oyster

The splendour of pearl oysters captivates humanity by its explicit reflection of the ocean through its pearls and shells. The inside of the shell showcases shiny nacre with lips of gold, black or silver and various overtones of green, pink, purple, and red (Gervis & Sims, 1992). These iridescent shells have been treasured since their first discovery dating back to the 4th millennium BC (Strack, 2008). Various religious texts mention natural pearls found within these oysters and suggest a deep reverence and admiration (Strack, 2008). Pearls are the only gems produced by living animals making them unique (Taylor & Strack, 2008).

At present, pearl culture occurs on a global scale with minimal reliance on the formation of natural pearls. This activity was made possible through the revolutionary discoveries of Japanese scientists (Gervis & Sims, 1992; Taylor & Strack, 2008), and extensive research carried out over the past century. The five most commercially important species of pearl oysters are *Pinctada margaritifera, Pinctada fucata, Pinctada maxima, Pinctada mazatlanica* and *Pteria penguin* (Southgate et al., 2008). In the Western Pacific, *P. margaritifera* is of vital social and economic importance for the production of high quality black cultured pearls.

1.1 Description & Taxonomy

Pinctada margaritifera (Linnaeus, 1758) is commonly known as the black-lip pearl oyster. The common name given is because of the internal features of the shell's nacre. The shell's internal surface comprises of a silvery iridescent nacre with pink, red or green tint that develops into a darkened, black or smoky distal rim, hence, "black-lip" (Gervis & Sims, 1992). The laterally compressed shell has two valves connected at its base by an elastic-like ligament called a hinge. The hinge controls the opening and closing of the shell.

The external surface of the shell showcases a pattern of finger-like projections or growth processes that extend towards the distal border (Gervis & Sims, 1992). The shell's external colouration is typical of green, bronze, brown or black hues. Distinct white rays or clustered blemishes that further widen away from the hinge are also noted (Alagarswami, 1983; Wada & Tëmkin, 2008). The average adult black-lip pearl oyster measures approximately 120 mm dorso-ventrally and 100 mm antero-posteriorly (Wada & Tëmkin, 2008).

The black-lip pearl oyster's current taxonomic framework is presented below:

Kingdom: Animalia

Phylum: Mollusca

Class: Bivalvia

Order: Pterioida

Family: Pteriidae

(Gervis & Sims, 1992; Wada & Tëmkin, 2008)

1.2 Distribution & Habitat

Pinctada margaritifera distribution spans approximately 18,000 km within the Indian and Pacific Oceans (Gervis & Sims, 1992; Lal et al., 2018). They are found in the surrounding littoral and sublittoral zones of Eastern Africa, to a depth of approximately 40 m in the pristine lagoons of French Polynesia (Gervis & Sims, 1992; Lal et al., 2018; Wada & Tëmkin, 2008). The black-lip pearl oyster can also be found in the Cook Islands, Fiji, Hendorabi Island in Iran, and Checheng in Taiwan (Lal et al., 2018).

In the wild, pearl oysters permanently attach to hard substrates using byssal threads or byssus (Gervis & Sims, 1992). Byssus are fibres secreted by the byssal gland through the muscular foot. Attachment takes place when the tip of the foot touches a surface, allowing byssus to be secreted. Byssus hardens quickly in seawater forming a strong bond (Gervis & Sims, 1992). Attachment to living or dead corals and rocky substrates is common for black-lip pearl oysters in the wild. On pearl farms, however, they attach to artificial materials such as spat collectors, panel nets or any other "cultch" (Alagarswami, 1983; Kishore et al., 2014).

1.3 Feeding

The black-lip pearl oyster is a filter feeder. It feeds on the suspended particulate matter (SPM) present in seawater (Lucas, 2008). SPM can be organic or inorganic. Particulate organic matter (POM) includes various types of phytoplankton, microalgae and faeces. Examples of particulate inorganic matter (PIM) are sediments and microplastics (Gardon et al., 2018; Lucas, 2008). The pearl oyster feeds when water flows through the mantle cavity allowing the filtering of SPM through its gill filaments (Lucas, 2008).

1.4 Sexual Maturity

Pearl oysters are protandrous hermaphrodites (Sims, 1992). Males require less energy for gametogenesis and therefore grow much faster compared to females. As a result, young oysters are predominantly male and later change to female. Alternation of gender occurs after energy demands for growth have decreased and can be diverted to the formation of female sex organs (Saucedo & Southgate, 2008). Even sex ratios generally occur around the fourth or fifth year to reach a sex ratio adjacent to 1:1 (Chávez-Villalba et al., 2011; Sims, 1992). Sex change begins when black-lip pearl oysters are around 90 mm in DVM (Pouvreau et al., 2000).

According to Saucedo & Southgate (2008), black-lip pearl oysters can begin producing sex cells at the end of their first year. Gonadal development generally begins in their second year (Gervis & Sims, 1992; Saucedo & Southgate, 2008). However, sexual maturation of some individuals have been observed at the end of their first year at less than 80 mm DVM (Tranter, 1958). The smallest DVM recorded for a black-lip pearl oyster with mature gonads was approximately 40 mm (Pouvreau et al., 2000).

1.5 Life Cycle

Pearl oysters are broadcast spawners. Sperm and eggs are released into the water column where fertilisation takes place. Larval development typically occurs for 16 – 30 days (Gervis & Sims, 1992). Free-swimming planktonic larvae develop a foot which enables movement over the substrate to select a suitable area for settlement (Saucedo & Southgate, 2008). Juveniles then attach to the substrate by byssal threads (Gervis & Sims, 1992). "Spat" is the term used for larvae or juveniles that have permanently attached to a surface (Saucedo & Southgate, 2008), after undergoing the different larval stages. Spat mature into adults between one to two years.

1.6 Pearl Culture in the Pacific

Three of the six subspecies of *P. margaritifera* are found in the Pacific region. *Pinctada margaritifera* var. *galstoffi* is found in Hawaii whereas *P. margaritifera* var. *cummingi* is found in French Polynesia and the Cook Islands. *Pinctada margaritifera* var. *typica* is found throughout the Central and Western Pacific including Fiji (Gervis & Sims, 1992; Lal et al., 2018). These subspecies were classified exclusively on morphological characteristics (Lal et al., 2018).

The exploitation of black-lip pearl oysters began over two centuries ago (Coeroli et al., 1984; Intes, 1986). Its beautiful iridescent shell and natural pearls made it one of the most valuable species in the Pacific (Andrefouet et al., 2016; Cabral, 1989; Secretariat of the Pacific Community, 2013). Human desire for pearlescent buttons, jewellery, various ornaments and natural pearls was the driving factor in the severe decline of natural pearl oyster stocks (Andrefouet et al., 2016; Cabral, 1989; Coeroli et al., 1984; Tisdell & Poirine, 2000). As such, to ease pressure on natural stocks, the idea of collecting and culturing young pearl oysters developed in the Pacific.

Japanese influence throughout the Pacific led to the initiation of pearl farms in many Pacific countries (Uwate et al., 1984). At present, the Pacific Ocean accounts for most of the production of black cultured pearls from a geographical standpoint (Southgate & Lucas, 2008). Black cultured pearls are considered the most valuable aquaculture commodity currently being produced in the Pacific and *P. margaritifera* is the most valuable aquaculture species (Ponia, 2010). French Polynesia and the Cook Islands are the foremost producers of black cultured pearls in Oceania (Ponia, 2010; Subasinghe, 2017).

1.6.1 French Polynesia

Exploitation of pearl oysters began in the Gambier Islands in 1802 (Coeroli et al., 1984; Intes, 1986). For over a century Mother-of-Pearl (MOP) exports fluctuated between 100 tonnes to 1300 tonnes per year which led to severe pearl oyster decline (Intes, 1986). The phasing out of this exploitative industry after 1940 as a result of newly favoured plastic buttons and lack of natural pearl oyster stock gave birth to a more sustainable industry; The Cultured Pearl Industry (Coeroli et al., 1984).

Black pearl production began in the early 1960s (Southgate et al., 2008). Jean-Marie Domard initiated the first round black pearl grafting experiments. These experiments took place in Hikueru and on the island of Bora Bora with black-lip pearl oysters through the help of Japanese technicians (Intes, 1986; Southgate et al., 2008). Expansion of pearl farming was rather slow until the 1980s. Roughly 115 farms, both cooperatives and privately owned (Intes, 1986), developed into more than 2500 pearl farms from 1986 to 2001. However, the number dwindled to only 516 within the next six years (Southgate, 2007).

Today, French Polynesia is the largest producer of black cultured pearls in the world (Andrefouet et al., 2012; Subasinghe, 2017). French Polynesia produces almost 90% of the black cultured pearls on the international market (Haoatai & Monypenny, 2011). As such, their pearl industry is the leading income generating industry regarding exports (Chávez-Villalba et al., 2011; Southgate, 2007).

1.6.2 Cook Islands

Pinctada margaritifera (indigenous name - "pārau") is one of only two species of pearl oysters belonging to genus *Pinctada* present in the Cook Islands. The other species is *P. maculata* (Sims, 1988). The gold-lip pearl oyster (*P. maxima*) was also present in the early 20th century after successful transplantation and culture experiments conducted by the Lever Brothers from Australia (Gervis & Sims, 1992; van Pel, 1955). However, by the 1980s this species became non-existent in Cook Islands' lagoons (Sims, 1988).

A study by van Pel (1955), suggested that Manihiki lagoon was the ideal area for pearl oyster growth and aquaculture. This lagoon has since been transformed into the hub of the pearl farming industry for the Cook Islands (Ministry of Marine Resources, 2018; Pacific Islands Forum Fisheries Agency, 1993). However, in less than 20 years the value of black cultured pearl exports decreased from approximately USD 18 million to less than half a million dollars annually. Approximately 12 pearl farmers operate solely from Manihiki producing black pearls sold mostly on the domestic market to tourists (Ministry of Marine Resources, 2018). Domestic sales rose from 10% in 2000 to 30% in 2007 (Ponia, 2010). As such, export statistics regarding black cultured pearls is not a clear representation of pearl production.

1.6.3 Fiji Islands

Pearl farming in Fiji began more than 50 years ago. Yasuharu Tokito established the first pearl farming project at Ovalau Island (Chaudhari, 1998), before moving to Vukanicula Bay, Gau Island, in 1966 (Uwate et al., 1984). This Japanese and Fijian joint venture was developed to produce pearls from *P. margaritifera* (indigenous name - "civa") and *Pteria penguin* (indigenous name - "melamela"). The project was later moved to Namarai Bay in 1968 (Uwate et al., 1984). The North-eastern coast of Viti-Levu was the centre for pearl farming for more than 20 years. In 1998, Tokito began pearl farming at Nasea Levu Point, Vanua Levu (Chaudhari, 1998). However, these ventures did not reach the commercial level for black pearl production.

Commercial black pearl production finally began in 2000 (Southgate et al., 2008). Justin Hunter established the first commercial pearl farm in Savusavu Bay, Vanua Levu (*J. Hunter Pearls Fiji*, n.d.). J. Hunter Pearls took over an experimental farm started by Fiji's Ministry of Fisheries (MoF) and turned it into a commercial venture (R. Prasad, personal communication, July 8, 2019). Fiji Pearls has since grown and contributes immensely to the growth of the Fiji pearl industry. The black cultured pearl is the second highest income generating fisheries commodity in Fiji, with tuna being the first (Pacific Agribusiness Research for Development Initiative, 2014). In 2011, there were eight major pearl operators in Fiji (Chand et al., 2011). The current value of the Fiji pearl industry is approximately more than $13 million/annum (Bolatagici, 2016).

1.6.4 Importance of the Pearl Industry

The culturing of oysters and pearls is of vital importance to local communities in the Pacific. The French Polynesian pearl industry provided employment for more than 7000 people on 800 farms across 30 islands (Chávez-Villalba et al., 2011). One out of every four families earned a living through pearl industry based livelihoods (Tisdell & Poirine, 2000). Also, since the establishment of the pearl industry, many locals returned to their original outer islands from the main island, Tahiti. This counter-urbanization improved living standards on smaller outer islands by the creation of employment on pearl farms. A significant portion of the work on pearl farms revolves around the ocean and on small boats. These employment opportunities are more suitable for the lifestyle and environment that Pacific Islanders are accustomed to (Tisdell & Poirine, 2000). As such, the pearl industry employs thousands of Pacific Islanders, improving their standards of living while maintaining aspects of their traditional lifestyles and utilizing available natural resources.

Development of pearl industry based livelihoods is particularly ripe in Fiji. The Ministry of Fisheries (MoF) initiated a national spat collection program in 2013 (Kishore et al., 2018). Technical and financial support from the Australian Government through agencies such as the Pacific Agribusiness Research for Development Initiative (PARDI) and Australian Centre for International Agricultural Research (ACIAR) has contributed tremendously to the success of this program. More than fifteen communities have already participated in pearl-farm focused training. Training ranged from spat collection methods and production of half-pearl and Mother-of-Pearl (MOP) to value addition and management of sustainable and profitable businesses (Pacific Agribusiness Research for Development Initiative, 2014). Two villages in Vanua Levu, Fiji's second largest island, earned a combined income of FJD 8,200.00 from the sale of their first harvest of spat in 2013. The income enabled one village to build a shop while the other invested in MOP handicrafts and half-pearl production (Pacific Agribusiness Research for Development Initiative, 2014). Hence, the development of a win-win situation where local communities develop a new source of income and easement of the lack of spat, a major bottleneck.

1.7 Thesis Overview

Developing efficient methods of local spat collection and growth of pearl oysters circumvents lack of pearl oyster spat supply to pearl farms and provides an additional source of income for local communities in Fiji. A review of previous studies regarding spat collection strategies based on deployment periods and immersion times, and the value of a common intermediate culture method in pearl oyster growout is provided in Chapter 2. The methodology for the experiments carried out in this study is described in Chapter 3. Results of the experiments are presented in Chapter 4, followed by a Discussion Chapter and concluding remarks in the final chapter.

1.7.1 Aims & Objectives

This research aims to determine the ideal time and duration for spat collection and to evaluate the use of intermediate culture methods for *P. margaritifera* for local communities in Namarai Bay, Fiji.

This aim will be achieved through the following objectives:

i. Determination of optimum time and duration for spat collector deployment to maximize collection of *P. margaritifera* by local communities for maximum income generation.

ii. Evaluation of the growth of *P. margaritifera* in panel nets.

iii. Comparison between size and weight of *P. margaritifera* grown in panel nets and on spat collectors.

iv. Evaluation of the need for intermediate culture methods by local communities.

1.7.2 Hypotheses

The following are the hypotheses for this research:

i. Deployment of spat collectors when waters are relatively warmer (January to June) will yield a higher number of *P. margaritifera* spat compared to when waters are cooler (June to December).

ii. Longer spat collector deployment duration of 14 months compared to 8 months will result in higher income generation for local communities.

iii. *Pinctada margaritifera* grown in panel nets in Namarai Bay, Fiji, will have high survival and growth rates similar to that in other countries in the region.

iv. *Pinctada margaritifera* with an intermediate culture period in panel nets will be significantly larger in size and weight compared to those that remain on spat collectors. As such, the use of intermediate culture methods would be beneficial for local communities.

1.7.3 Justification

Insufficient supply of pearl oyster spat to pearl farms has created a major bottleneck in the industry. Pearl oyster culture stock is supplied through three methods; collection of adults directly from oyster beds, 'wild' (naturally produced) spat collection and hatchery production (Southgate, 2008). Wild spat collection is the simplest and most inexpensive method of producing pearl oysters. It is the primary method for supplying pearl oyster spat for pearl production in the Pacific. Additionally, part of the pearl industry based livelihoods revolves around spat collection that provides income for local communities through spat sales to pearl farms. Spat collection duration of 10 - 18 months is the current standard practice in Fiji with no defined deployment time. Black-lip pearl oyster juveniles are sold at FJD 5.00 per kilogram regardless of size (Kishore et al., 2018). Growout using panel nets could potentially increase the size of black-lip oysters resulting in possibly larger and heavier specimen, thereby fetching better returns to spat collecting communities. Research on the subjects of spat collector deployment duration and intermediate growout of spat, within the Fiji pearl industry, is lacking.

Optimization of spat collection and oyster growth concerning time is imperative for local communities looking to invest in pearl industry based livelihoods. This research aims to provide insight into ideal spat collection strategies regarding the timing and duration of spat collector deployment. The influence of panel nets on the growth of black-lip pearl oysters will help determine the need for intermediate culture methods. Such information will be especially useful for local communities engaged in spat collection in order to maximise efforts and revenue. Hence, this study will facilitate improvement in spat collection methods leading to income generation for local communities and a better supply of spat to support Fiji's growing pearl industry.

Chapter 2 Overview of the Literature

2.1 Pearl Oyster Supply

The stock of oysters for culture are supplied to pearl farms in three ways; collection of adults, hatchery production and wild spat collection (Gervis & Sims, 1992; Southgate, 2008). Collection of adults from the wild can be considered the most direct method of obtaining *P. margaritifera* that are ready for black pearl production (Southgate, 2008). The repercussions of this method, however, are negative. As observed in French Polynesia and the Cook Islands, poor control of collection quotas resulted in overfishing, which led to depletion of natural pearl oyster stocks (Intes, 1986; Sims, 1993; Southgate, 2008). Overfishing of adult oysters also leads to fewer naturally breeding stock and decline in recruitment of new oysters in nature over subsequent generations. Hatchery production and spat collection were deemed as more sustainable means of supplying culture stock to remedy the situation created by overfishing (Coeroli et al., 1984).

Hatchery production of *P. margaritifera* allows for the production of larvae with artificially selected traits inherited from broodstock (Gervis & Sims, 1992; Southgate, 2008). For instance, black-lip pearl oysters that showcase favourable traits such as rapid growth rates or good nacre colouration may be chosen as broodstock in hatcheries. This method of acquiring *P. margaritifera* is the most reliable for a continual supply of juveniles. However, it is also the most expensive and demanding of the three methods of procuring culture stock. Despite efforts to simplify hatchery production, it is still financially and technologically demanding, making it difficult for local communities in Fiji to currently utilize as a source of culture stock (Kishore et al., 2018). As such, spat collection is the most sustainable and the simplest method of supplying *P. margaritifera* for the Fijian pearl industry.

Spat collection is generally inexpensive and can be done in any lagoon with naturally occurring pearl oyster stocks (Sims, 1993). Natural or artificial materials known as ‘spat collectors’ are placed in the water as substrates for *P. margaritifera* larvae to settle on and grow into juvenile pearl oysters (Gervis & Sims, 1992). These juvenile *P. margaritifera* can either remain on spat collectors to mature into adults or be transferred to intermediate culture systems such as panel nets and chaplets (Friedman

& Southgate, 1999b; Gervis & Sims, 1992). Despite the simplicitiy and ease of spat collection, spatfall needs to be sufficiently high in order for it to be an efficient method of supplying *P. margaritifera* (Fong et al., 2005). The timing of spat collector deployment and duration of deployment are key factors that influence the success of spat collection strategies (Southgate, 2008).

2.2 Spat Collector Deployment Period and Duration

The timing of spat collector deployment is a critical aspect in collecting pearl oysters. Deployment of spat collectors must align with the availability of competent planktonic pearl oyster larvae in the water column (Southgate, 2008). Unplanned deployment of spat collectors could result in recruitment of non-target species and fouling organisms (Gervis & Sims, 1992). Pearl oyster larvae availability and recruitment onto spat collectors depends on the gametogenic cycles and spawning events of adult pearl oysters, which is linked to changes in temperature, food availability and other environmental aspects (Gervis & Sims, 1992).

Breeding patterns of *P. margaritifera* differ inter-annually between geographical regions. In French Polynesia, it is described as 'continuous' with an 'opportunistic' reproduction strategy resulting in little to no rest period throughout the year (Pouvreau et al., 2000). Despite the lack of a discrete breeding period, major spawning intensities for *P. margaritifera* are mainly observed during the summer and winter seasons (Pouvreau et al., 2000; Tranter, 1958). Major spawning intensities possibly result in a higher number of *P. margaritifera* spat collected during some months compared to others. As such, seasonal variations in recruitment intensity has been observed in different latitudinal regions.

In Tanzania, spat collectors deployed every two months for a one-year period collected *P. margaritifera* spat throughout the year (Ishengoma et al., 2011). A total of 4263 *P. margaritifera* were collected from three different sites. Spat collectors were composed of mesh bags, rubber tiles and strings of coconut husks (Ishengoma et al., 2011). The average individual spat per collector ranged from 0.9 ± 0.05 to 3.1 ± 0.09 spat per collector (Ishengoma et al., 2011). Spat collectors harvested during the dry season from June to October yielded consistently high numbers of spat compared to the wet season from December to April (Ishengoma et al., 2011). The maximum number of *P.*

margaritifera spat, however, was collected at the beginning of the rainy summer season from September to December (Ishengoma et al., 2011). Ishengoma et al. (2011) postulated that the increase in temperature during this period affected the spawning intensity of *P. margaritifera* resulting in peak recruitment. This result was also supported by Pouvreau et al. (2000).

Furthermore, Beer & Southgate (2000) investigated temporal variation in pearl oyster species recruitment on spat collectors for a one year period in Australia. Majority of the bivalve recruits on spat collectors belonged to the Pteriidae family with a variety of species from genera *Pinctada, Pteria* and *Electroma* (Beer & Southgate, 2000). Seasonal variation in recruitment intensity on spat collectors was shown by all species (Beer & Southgate, 2000). A total of 231 *P. margaritifera* spat were harvested from approximately 120 – 140 collectors deployed from March 1995 to March 1996. Spat collectors were composed of a combination of shade cloth and mesh bags and deployed at 2 m and 6 m depths. The average number of individual spat per collector ranged from 1.6 – 1.9 spat per collector (Beer & Southgate, 2000). *Pinctada margaritifera* recruitment was distinctly bimodal with a major peak from May to June and minor peak from February to March (Beer & Southgate, 2000). These results corresponded with the two distinct spawning cycles, identified by Tranter (1958), from March to August (autumn-winter) and September to February (spring-summer) in Australia (Beer & Southgate, 2000). Despite the consistency in high numbers of spat per collector during the summer period, the winter maximum in recruitment of spat per collector suggested that spawning intensity is not only influenced by warmer waters but may also be influenced by colder waters (Beer & Southgate, 2000).

In the Solomon Islands, similar studies have been conducted on the variation in abundance of *P. margaritifera* spat on collectors (Friedman et al., 1998; Oengpepa et al., 2006). Friedman et al. (1998) investigated the availability of *P. margaritifera* larvae from 'open' reef systems. The term 'open' reef systems is used to describe the fringing and barrier reefs that are characteristic of high-island nations in the central-western Pacific (Friedman et al., 1998). Water movement is generally less predictable in 'open' reef systems compared to the 'enclosed' atolls of French Polynesia and Cook Islands (Friedman et al., 1998). Findings from this two year sampling program led to the conclusion that spat could be collected throughout the year, but were most abundant on collectors deployed in October and January aligning with the rainy summer period (Friedman et al., 1998). The average individual spat per collector during the October and January deployment periods ranged from 3.0 – 4.6 spat per collector at the two sites (Gizo and Noro) with the highest spat recruitment. At other sites, the average individual spat per collector ranged from 0.1 – 0.5, however, spat collectors deployed in October ranged from 0.5 – 2.0 spat per collector (Friedman et al., 1998). Despite results showing potential for *P. margaritifera* culture in the Solomon Islands, the authors stated that the long-term variability of spat abundance needed to be assessed before black pearl culture could be considered economically viable (Friedman et al., 1998). As such, Oengpepa et al. (2006) investigated the temporal variability in spat abundance over an eight year period at two sites (Gizo and Noro) in the Solomon Islands. Results showed seasonal variation in abundance of *P. margaritifera* spat (Oengpepa et al., 2006), and supported the pattern of a summer maximum reported by Friedman et al. (1998). *Pinctada margaritifera* recruitment was higher on spat collectors deployed between November and April compared to July and October (Oengpepa et al., 2006). The lowest mean spat abundance per collector over the eight-year period was 0.7 and the highest was 4.9. A significant effect of deployment period on abundance of spat on collectors was identified (Oengpepa et al., 2006).

In Fiji, research on the timing of spat collector deployment is limited. Only two studies have investigated recruitment patterns of *P. margaritifera* in Fiji. An unpublished study by Vilisoni (2012) found that a major spat recruitment peak occurred in April and a minor peak in December during a one year sampling program in Savusavu Bay. Recruitment of *P. margaritifera* spat onto collectors was significantly different for each month, however, no difference was found between the three stations tested within Savusavu Bay (Vilisoni, 2012). Though this study presented baseline knowledge for recruitment of *P. margaritifera* in Savusavu Bay, the same results cannot be assumed for other sites in Fiji until tested.

Kishore et al. (2018) investigated the recruitment of *P. margaritifera* and *Pteria penguin* onto spat collectors at 29 sites across the Fiji Islands. Spat collectors were deployed at the beginning of the rainy summer season between November 2013 and January 2014 then harvested after 10 to 15 months (Kishore et al., 2018). Spatial variation in recruitment of *P. margaritifera* was observed, however, further research on optimum deployment periods is needed for a more efficient spat collection strategy to be developed. As such, there is a need for more research regarding the timing of spat collector deployment. This will further optimize spat collection strategies to increase *P. margaritifera* supply to pearl farms in Fiji.

Immersion time or 'soak' time is the duration of spat collector deployment. Generally, spat collectors are deployed for up to six months before pearl oysters are harvested (Gervis & Sims, 1992). In French Polynesia, *P. margaritifera* are harvested from spat collectors after six months at a DVM of approximately 50 – 65 mm and then transferred to on-growing systems (Coeroli et al., 1984; Pouvreau & Prasil, 2001). In some lagoons in French Polynesia and the Cook Islands, however, spat is left to grow on collectors deployed for up to 24 months (Friedman & Southgate, 1999b). The longer immersion time allows oysters to grow bigger on spat collectors, and reduces costs by avoiding the need for intermediate culture methods.

Shorter immersion times have also been investigated. A study by Friedman & Bell (2000) reported that immersion times of three to four months are more ideal compared to six months. Oengpepa et al. (2006) reported similar maximum numbers of *P. margaritifera* using a two month immersion time as the six month immersion time by Friedman & Bell (2000). These shorter immersion times provide higher numbers of smaller sized *P. margaritifera* while longer immersion times provide low numbers but larger sized *P. margaritifera* spat which may be closer to the minimum seeding size of 100 mm (Friedman & Bell, 2000; Southgate, 2008).

High numbers of small sized *P. margaritifera* are acceptable if there are adequate on-growing systems available and qualified personnel to care for it. Factors such as site accessibility and availability of qualified support staff from pearl farms or MoF influence spat collector immersion times in Fiji. In most situations, *P. margaritifera* that are larger in size are preferred by pearl farmers. Larger oysters require less husbandry efforts minimizing the growout time of oysters to a suitable size for pearl seeding (Kishore et al., 2018). It is also highly likely that the survival rates of larger sized spat would be higher and therefore preferable to pearl farmers. It means minimal loss of spat purchased. In Fiji, spat collectors are usually deployed for 10 – 18 months (Kishore et al., 2018). No research has been done using an immersion time greater than the standard 6 months but less than the minimum 10 months. In addition, a longer immersion time greater than 10 months but less than 18 months needs to be tested to investigate the size and weight of *P. margaritifera* harvested from these collectors. As such, due to the time limitations associated with this project, 8-month and 14-month deployment durations were investigated.

2.3 Intermediate Culture Method

Various intermediate culture methods are used to grow pearl oysters that have been harvested from spat collectors. Some common methods include pearl nets, panel nets, lantern nets and box nets (Southgate, 2008). Panel nets are commonly used for ocean-based culturing of *P. margaritifera* in the Pacific (Southgate, 2008). These nets are also known as 'pocket nets' and are made of a galvanized wire frame with nylon mesh sewn to form pockets for holding oysters (Kishore et al., 2014; Southgate, 2008). Mesh and pocket sizes vary according to the size of oysters being cultured. Smaller oysters are held in panel nets with a smaller mesh size to hold oysters in place safely while larger oysters require larger mesh sizes. The total cost of buying and importing a single panel net into Fiji is estimated at approximately USD 9.00 (Johnston et al., 2019).

Apart from nets, 'ear-hanging' is another common method used in the Pacific. Ear-hanging involves drilling a small hole, approximately 2 – 3 mm in diameter, through the hinge region of the shell of pearl oysters that are 65 – 90 mm DVM (Friedman & Southgate, 1999a; Southgate, 2008). A wire or monofilament fishing line is then threaded through the hole and pearl oysters are attached to 1 m dropper ropes. Ear-hanging can be derived into two methods known as chaplets and 'cord technical nakasai' (CTN) (Ky et al., 2019). The chaplet method involves tying 10 x 20 mm pieces of monofilament fishing line, each threaded with a pair of oysters, between individual rope strands. Chaplets can hold approximately 20 pearl oysters (Friedman & Southgate, 1999a; Kishore et al., 2014). For the CTN method, a single 1 m long piece of monofilament line is threaded with approximately 40 pearl oysters. The pearl oysters are then wound tightly around the dropper rope, following the direction of the rope strands, and tied to the rope at each end (Kishore, 2010; Ky et al., 2019; Vilisoni, 2012). A single chaplet or CTN costs approximately USD 0.40 to construct from locally available materials. However, this excludes the cost of labour and a handheld

Power Drill that ranges from USD 100.00 to USD 300.00, depending on the model and brand.

Furthermore, culture method selection must examine local conditions and factors such as pearl oyster growth and survival as well as economic and practical considerations (Southgate, 2008). Southgate & Beer (2000) studied the growth of hatchery reared 8 month old juvenile *P. margaritifera* using the following five culture methods: panel nets (PN 24), 5 mm mesh inserts placed within panel nets (PN 8), 5 mm mesh inserts not placed in panel nets (INSERT), plastic mesh trays with lids (TRAY) and chaplets (EAR). Criteria such as pearl oyster growth and survival, cost of equipment, ease of construction and degree of fouling were used to assess the efficiency of each method. Panel nets (PN 24) were ranked highest followed by chaplets (EAR), then TRAY, PN 8 and INSERT (Southgate & Beer, 2000). Growth of *P. margaritifera* held in panel nets (PN 24) and on chaplets (EAR) was significantly greater in terms of DVM and WW compared to all other culture methods (Southgate & Beer, 2000). Additionally, *P. margaritifera* held in panel nets suffered no mortality (Southgate & Beer, 2000). Despite the highest ranking, panel nets were relatively expensive compared to other methods. Chaplets presented the cheapest option for culturing *P. margaritifera* spat, however, required greater input in terms of construction and were highly fouled and harder to clean. Hence, panel nets were considered the best culture method because of its ease of construction and use, degree of fouling as well as effect on *P. margaritifera* growth and survival (Southgate & Beer, 2000).

Furthermore, Friedman & Southgate (1999b) compared the growth of *P. margaritifera* in panel nets, lantern nets and trays. Smaller sized (~ 16 mm DVM) *P. margaritifera* grew faster in lantern nets compared to panel nets, however, lantern nets were harder to clean and inspect for predators. No significant difference in growth or survival rate was found between larger sized (~ 24 mm and 33 mm DVM) *P. margaritifera* grown in panel nets and lantern nets. Additionally, *P. margaritifera* (~ 24 mm DVM) glued to trays using cyano-acrylate showed significantly better growth compared to those held loosely in trays and those in panel nets. Though growth rates were high, cyano-acrylate was both expensive and difficult to apply (Friedman & Southgate, 1999b). Furthermore, predators that settled in non-divided culture units, such as trays with *P. margaritifera* glued to the bottom, had access to all the juveniles within that culture unit compared to panel nets. Culture units such as panel nets had the advantage of separating juveniles and allowing easy access to check for predators. The authors concluded that the ease of cleaning, construction and accessibility for regular inspection and removal of predators are critical aspects of culture methods in the Western Pacific (Friedman & Southgate, 1999b).

In Fiji, pearl farmers generally allow *P. margaritifera* to grow to minimum seeding size of 100 mm on spat collectors. Once minimum seeding size has been achieved, oysters are removed from spat collectors and seeded for black pearl culture. After this, the oysters are returned to the sea and grown in culture methods such as panel nets, chaplets or CTNs. Panel nets and chaplets have been used in experiments to test the effect of culture methods on byssus production and black cultured pearl quality (Kishore et al., 2014; Kishore & Southgate, 2016). *Pinctada margaritifera* cultured using chaplets produced a significantly greater number and thickness of byssus compared to those in panel nets (Kishore et al., 2014). On the other hand, Kishore & Southgate (2016) found that *P. margaritifera* cultured in panel nets produced more high quality black cultured pearls compared to those on chaplets. This information was beneficial to pearl farmers in the Pacific as black cultured pearls produced from *P. margaritifera* held in panel nets could prove to be more profitable than using the traditional chaplet based culture method.

Despite the current practice of allowing growout of *P. margaritifera* on spat collectors, no research has been conducted comparing the size and weight of *P. margaritifera* that remain on spat collectors with those that are removed and then grown in intermediate culture methods. This information could be beneficial for local spat collecting communities that earn income by selling *P. margaritifera* to pearl farmers. Economical and practical considerations must be taken into account when selecting appropriate intermediate culture methods. Studies have identified panel nets as the most suitable culture method based on *P. margaritifera* growth and survival rates and ease of use (Friedman & Southgate, 1999b; Southgate & Beer, 2000). As such, there is a need to assess the value of panel nets as an intermediate culture method to be used by local communities in Fiji.

Chapter 3 Methodology

3.1 Study Site and Spat Collector Deployment

This study was conducted in Namarai Bay on the North-eastern coast of Fiji's largest island, Viti Levu (17°31'10.79"S, 178°22'50.81"E). Namarai Bay was identified as a suitable site due to its history and current association with black-lip pearl oyster farming. The coastal community, Namarai Village, is involved in pearl oyster farming with assistance from Ministry of Fisheries (MoF) officers stationed at the Namarai Fisheries post and through the Australian Centre for International Agricultural Research (ACIAR) project (FIS/2014/060). The site is approximately 20 to 25 m in depth and is bordered by an 'open' reef system (Friedman et al., 1998) approximately 1 km from the spat collector long-line.

The long-line used in this research was part of a previous experiment by a University of the South Pacific MSc student. It was prepared and deployed with assistance from Namarai and Naocobau community members and MoF officers in late October, 2016. The long-line system consisted of a 12 mm diameter rope, 100 m in length, submerged at a depth of 4 – 5 m (Fig. 1). Two additional 10 mm diameter rope at 25 m length each were used to attach approximately 150 kg of sand bag 'anchors' at each end of the long-line. Float lines, approximately 5 m long, were tied at 25 m intervals to the long-line with at least one 300 mm diameter spherical float attached (Fig. 1). Floats that had been spray painted green were later added to the long-line at the start of this research in June 2017, to distinguish this long-line from others with factory painted orange floats that had also been setup in late October, 2016. The cost of materials to set up a single long-line was approximately USD 120.00. This cost excluded labour, boat hire and fuel.

Spat collectors were composed of black perforated plastic ribbon threaded 'accordion style' onto an 8 mm diameter black polypropylene rope that was 1 m in length (see Kishore et al., 2018). The cost of importing a single spat collector was approximately USD 0.60. Three hundred and ten spat collectors were deployed on this long-line at 30 cm intervals. The long-line was accessed by either a Namarai Youth boat or a MoF boat.

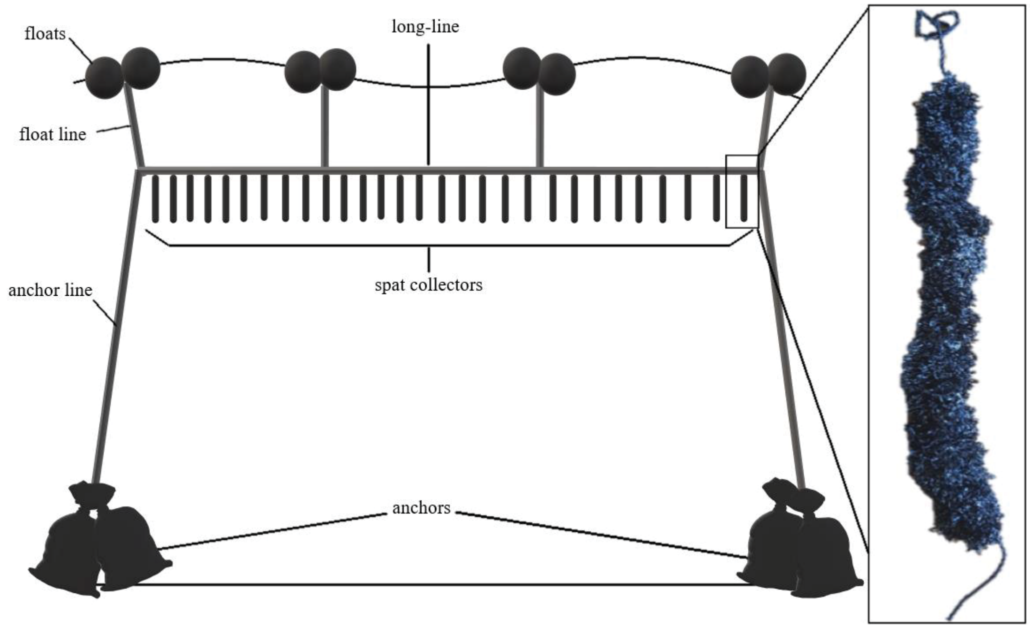

Figure 1. Deployment setup of the long-line with spat collectors in Namarai Bay and a close up of a commercial spat collector made of black perforated plastic ribbon threaded ‘accordion style’.

3.2 Experimental Setup

In June 2017, twenty-five spat collectors were randomly chosen and cut off from the long-line using a sharp knife. These collectors had been immersed for 8 months since late October 2016. The number of spat and individual morphometric measurements were recorded. DVM and APM were measured using a Vernier caliper recorded to the nearest 0.01 mm (Gervis & Sims, 1992; Saucedo & Southgate, 2008). The WW of each oyster was also measured using a ‘Kingship’ electronic scale, to the nearest 0.1 g. For the first intermediate culture period, 45 oysters were harvested from spat collectors. These oysters had a mean (± SE) DVM of 44.68 ± 1.64 mm, mean (± SE) APM of 46.16 ± 2.03 mm and mean (± SE) WW of 20.38 ± 1.80 g. The oysters were placed carefully into panel nets constructed of a galvanized wire frame with 20 mm x 20 mm mesh sewn to form 15 pockets (Kishore et al., 2014). The larger mesh size used, compared to Friedman & Southgate (1999), was because of the larger size of the oysters harvested in this study. Panel nets were then tied to the Namarai Community pearl oyster main line at 7 m depth. The section where panel nets were tied to the main line was marked by tying green spray painted floats at each end to make it easier to differentiate from the factory made orange floats.

Twenty-five new spat collectors were then tagged by tying 30 cm lengths of pink coloured plastic ribbon to the top of each spat collector. This was done to distinguish between the spat collectors deployed from October 2016, and the new additions from this study, on the long-line. Each of the 25 new pink-tagged collectors was then tied to the long-line using a slipknot in place of the 25 collectors that had been previously removed.

In December 2017, 25 spat collectors were randomly chosen and removed from the long-line. These collectors had been deployed for approximately 14 months since late October 2016. The black-lip pearl oysters present on these 25 collectors were removed carefully by cutting their byssal threads using a sharp knife. DVM, APM and WW were recorded for each oyster. For the second intermediate culture period, 43 oysters had been harvested from these spat collectors. The mean (± SE) DVM, APM, and WW of these oysters was 77.56 ± 1.16 mm, 82.87 ± 1.27 mm, and 89.18 ± 3.18 g respectively. The oysters were then placed in panel nets and tied to the Namarai Community main line at 7 m depth. Furthermore, spat that had been growing in panel nets since June 2017, from the first intermediate culture period, were removed and final morphometric measurements recorded.

The 25 pink-tagged collectors were also removed from the long-line. All visible black-lip pearl oyster spat were carefully harvested from the tagged collectors by severing the byssal threads using a sharp knife. The number of black-lip pearl oyster spat recruited was recorded. DVM and APM were measured using a Vernier caliper and recorded to the nearest 0.01 mm (Gervis & Sims, 1992; Saucedo & Southgate, 2008). The WW of each oyster was also measured using a 'Kingship' electronic scale, to the nearest 0.1 g.

Twenty-five new spat collectors were then tagged with 30 cm lengths of orange coloured plastic ribbon. This was done to distinguish between the spat collectors deployed from October 2016, and the new additions from this study, on the long-line. The orange-tagged collectors were then tied to the long-line using a slipknot in place of the 25 pink-tagged collectors that had been previously removed.

In June 2018, the 25 orange-tagged collectors were removed from the long-line. Spat that had settled on these collectors were carefully harvested by severing the byssal threads using a sharp knife. The number of recruits and the morphometric measurements of each spat was recorded as described above. Spat that had been growing in panel nets since December 2017, were also removed and final morphometric measurements were recorded as described above.

Spat collector deployment period and duration was investigated by comparing the number, size and weight of black-lip pearl oyster recruits on spat collectors. Morphometric measurements from spat harvested after 8 and 14 months were compared to determine whether coastal villages interested in marketing pearl oysters to pearl farmers would benefit more from a shorter or longer spat collector immersion time than normally practiced in Fiji (10 – 18 months). These oysters were then placed in panel nets to assess their growth using an intermediate culture method.

Inspection of panel nets, long-line maintenance tasks and cleaning were performed every two months. Cleaning was performed by pulling up the section of the community long-line marked by the green floats, from a boat. This could only be done when sea conditions were calm. Panel nets were untied and any fouling and predatory organisms were removed from oysters. Panel nets were then cleaned by scrubbing with a standard household scrubbing brush. Sometimes, when the sea was too rough to perform cleaning tasks on the boat, panel nets with oysters were taken to a pearl seeding shed nearby to be cleaned. After cleaning, oysters were inspected and any mortality was recorded.

The difference in DVM, APM and WW of oysters before and after being placed in panel nets for the two intermediate culture periods were compared to evaluate the size and weight increase of oysters in Namarai Bay and in other regions. Additionally, a comparison was made between the size and weight of oysters grown in panel nets and on spat collectors. Oysters harvested from spat collectors after 8 months and then grown in panel nets for 6 months were compared with oysters that remained on spat collectors for the entire 14-month period.

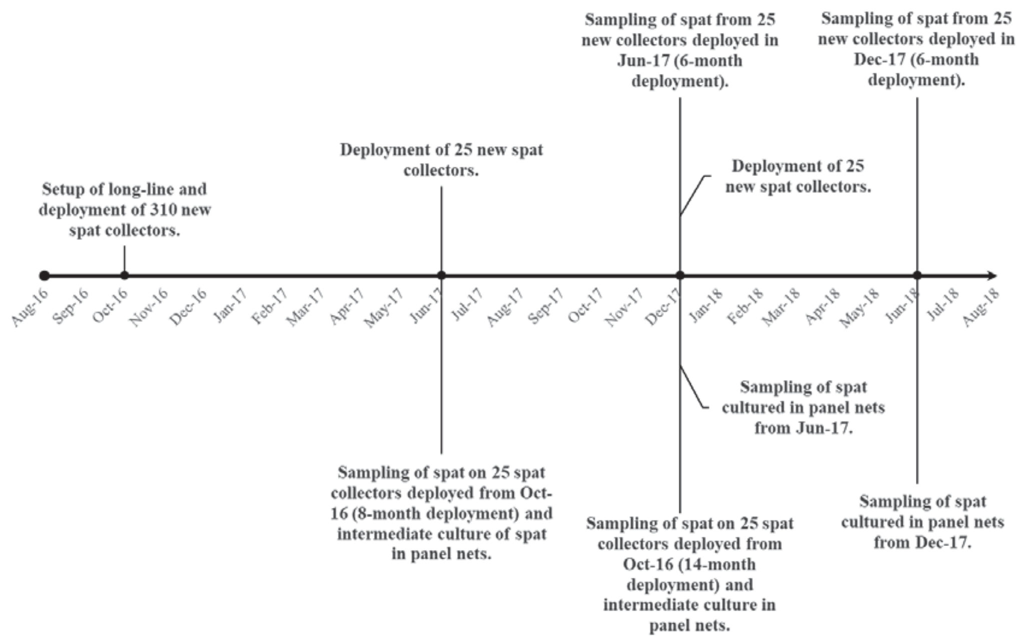

Figure 2. Timeline of spat collector deployment, sampling and intermediate culture of spat in panel nets from October 2016 to June 2018.

3.3 Statistical Analyses

Statistical analyses of all data were performed using a significance threshold of $\alpha = 0.05$ in IBM SPSS Statistics version 22. Data relating to DVM, APM and WW were assessed for normality and homogeneity of variances using Shapiro-Wilk and Levene's tests, respectively. Statistical tests were then chosen appropriately according to fulfilment or violation of normality and homogeneity of variance assumptions.

Three separate Independent t-tests assuming unequal variances, otherwise known as Welch's t-test, were used to test the differences between the mean DVM, APM and WW of oysters removed from spat collectors immersed for 8 and 14 months (Sokal & Rohlf, 2012). Welch's t-test is considered a more robust version of the Student's t-test where both heterogeneous variances and unequal sample sizes are involved (Zimmerman & Zumbo, 2009), which was characteristic of the data obtained in this study. Additionally, Type I and II error rates are better controlled under Welch's t-test compared to Student's t-test in these situations (Delacre, Lakens, & Leys, 2017; Ruxton, 2006; Zimmerman, 2004; Zimmerman & Zumbo, 1993).

Paired t-tests were used to test the significance of the increase in DVM, APM and WW of oysters before and after being placed in panel nets for 6 months (Sokal & Rohlf, 2012; Xu et al., 2017). An Independent t-test assuming unequal variances was then used to determine if the increase in DVM, APM and WW between the earlier (8-month) harvested oysters and late (14-month) harvested oysters differed significantly when grown in panel nets. Additionally, the Independent t-test assuming unequal variances was used to compare the DVM and WW of oysters harvested from spat collectors after 8 months then grown in panel nets for 6 months with oysters that remained on spat collectors for the entire 14-month period. An Independent t-test assuming equal variances (Student's t-test) was used to compare the APM of these oysters.

3.4 Sea Water Temperature Data

Seawater temperature (°C) was initially meant to be recorded daily at 1-hour intervals by a YSI Multiparameter Water Quality Sonde (6920 V2). This data logger was unable to record the seawater temperature in Namarai Bay due to a leakage resulting in complete loss of temperature data. As such, the Integrated Climate Data Center (ICDC) computed the mean monthly sea surface temperature (SST) data used in this study for Namarai Bay. The data was retrieved through the Advanced Very High Resolution Radiometer (AVHRR) infrared satellite which has a spatial grid resolution of 0.25° and a temporal resolution of 1 day (Integrated Climate Data Center, 2019; Reynolds et al., 2007).

Chapter 4 Results

4.1 Spat Collector Deployment Period and Duration

Differences in spat recruitment patterns on spat collectors were observed from the deployment periods tested in this study. Spat collector deployment occurred in October 2016, July 2017 and January 2018, at least two to three months before the lowest and highest seawater temperatures were reached for each year respectively (Fig. 3). Spat collectors deployed from July to December 2017, recruited no visible *P. margaritifera* spat or any other bivalve species spat (Tab. 1). These collectors were deployed when average seawater temperatures were relatively low in Fiji's dry mid-winter season (Fig. 3).

On the other hand, a total of 15 *P. margaritifera* spat were harvested from spat collectors deployed from January to June 2018 (Tab. 1), when average seawater temperatures were high (Fig. 3). The mean (± SE) DVM, APM and WW of the 15 oysters from the second period are shown in Table 1. APM was slightly larger than DVM while WW was less than a gram (Tab. 1). DVM ranged from 9.44 mm to 26.3 mm while APM ranged from 11.24 mm to 25.12 mm. The smallest oyster weighed 0.1 g, while the largest oyster weighed 2.4 g.

The mean (± SE) DVM, APM and WW of *P. margaritifera* harvested from spat collectors deployed in October 2016, for 8 and 14 months, are also displayed in Table 1. Eighty-eight *P. margaritifera* were harvested; 45 from spat collectors deployed for 8 months and 43 from spat collectors deployed for 14 months. As expected, oysters removed from collectors immersed for a longer period were larger and heavier ($P < 0.05$).

Table 1. Mean morphometric measurements (± SE) of *Pinctada margaritifera* collected during different spat collector deployment periods and durations.

Deployment month and year	Sampling month and year	Duration (months)	Total number of oysters	DVM (mm)	APM (mm)	WW (g)
Oct. 16	Jun. 17	8	45	44.68 ± 1.64	46.16 ± 2.03	20.38 ± 1.80
Oct. 16	Dec. 17	14	43	77.56 ± 1.16	82.87 ± 1.27	89.18 ± 3.18
Jul. 17	Dec. 17	6	0	-	-	-
Jan. 18	Jun. 18	6	15	16.88 ± 1.19	17.94 ± 1.06	0.91 ± 0.19

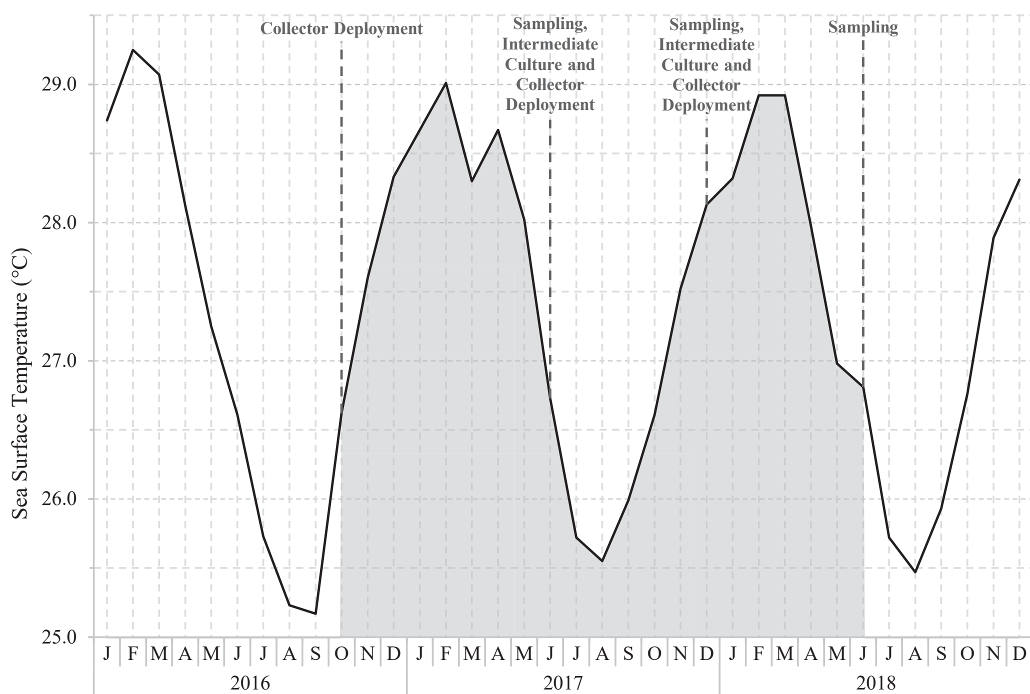

Figure 3. Mean monthly sea surface temperatures between January 2016 and December 2018 in Namarai Bay, Fiji, based on the daily Reynolds-OISST data set provided by the Integrated Climate Data Center (2019) website. The highlighted area under the graph shows the period this study was conducted. The different events conducted during this study have also been identified.

The size and weight frequency distributions for *P. margaritifera* harvested from spat collectors immersed for 8 and 14 months are displayed in Figure 4. None of the oysters removed after 8 and 14 months reached the minimum seeding size of approximately 100 mm. However, 100% of spat harvested after 14 months measured more than 50 mm dorso-ventrally, while only 38% of spat harvested after 8 months measured more than 50 mm (Fig. 4).

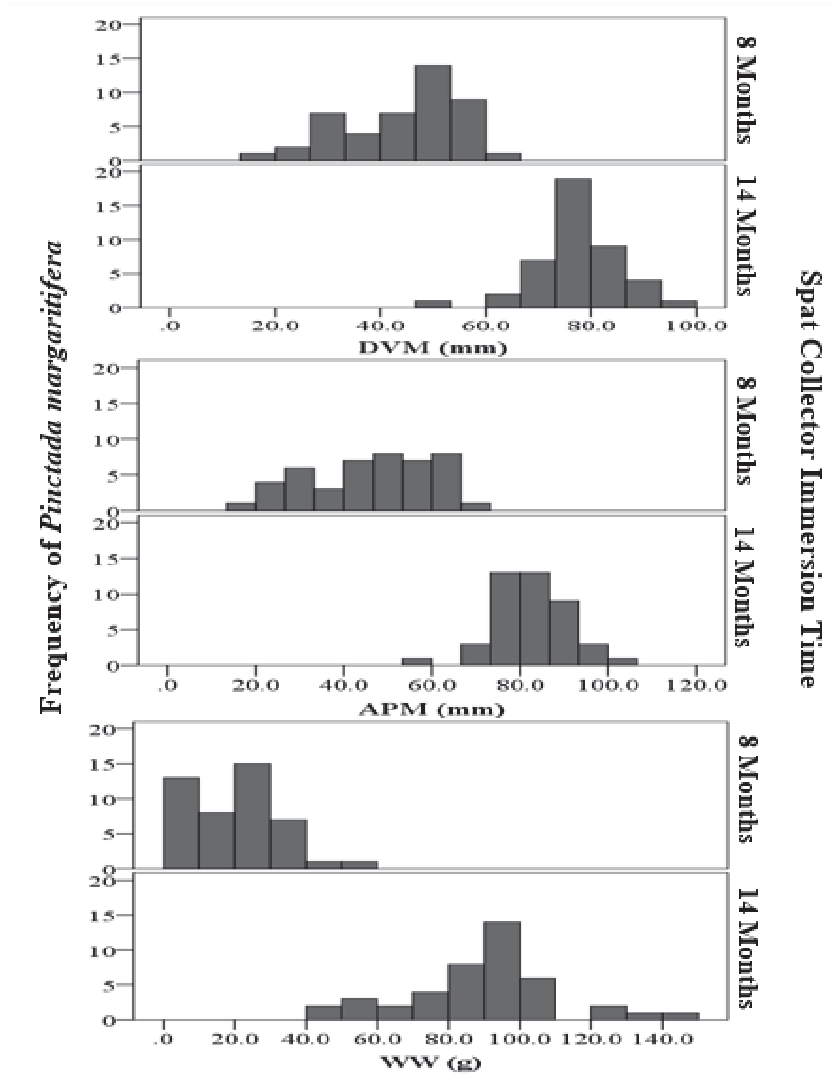

Figure 4. Size (DVM, APM) and weight (WW) frequency distributions for *Pinctada margaritifera* harvested from spat collectors immersed for 8 and 14 months in Namarai Bay, Fiji.

Fouling organisms such as ascidians, calcareous sponges, polychaetes and crustaceans were present on all collectors. Approximately 30% of each collector was covered with ascidians while calcareous sponge coverage was about 20%. Organisms such as polychaetes, box crabs and shrimp were found nestled within the folds of black perforated plastic ribbon of the spat collectors.

4.2 Intermediate Culture Method

4.2.1 Growth in Panel Nets

The increase in size and weight of *P. margaritifera* for the two intermediate culture periods are shown in Table 2. *Pinctada margaritifera* from the first intermediate culture period were referred to as "early oysters" as these were harvested earlier from spat collectors after 8 months and then grown in panel nets. *Pinctada margaritifera* from the second intermediate culture period that were harvested after 14 months and then grown in panel nets were referred to as "late oysters".

At the end of the intermediate culture periods, early oysters with an initial mean (± SE) DVM of 44.68 ± 1.64 mm had a final mean (± SE) DVM of 72.32 ± 1.54 mm. On average, DVM (± SE) of early oysters increased by 27.64 ± 1.56 mm at a rate of 4.61 mm per month (Tab. 2). Late oysters with an initial mean (± SE) DVM of 77.56 ± 1.16 mm, increased in size by 27.39 ± 0.94 mm at a rate of 4.57 mm per month, resulting in a final mean (± SE) DVM of 104.95 ± 1.49 mm. As such, statistical analysis showed that there was no significant difference in dorso-ventral growth in panel nets between the early and late harvested *P. margaritifera* ($P > 0.05$).

The initial mean (± SE) APM for early and late oysters was 46.16 ± 2.03 mm and 82.87 ± 1.27 mm, respectively. After six months in panel nets, the average (± SE) APM showed a significant increase between the two cohorts with early oysters increasing in size by 27.84 ± 1.68 mm and late oysters by 23.29 ± 0.99 mm ($P < 0.05$). The mean (± SE) APM for early and late harvested oysters at the end of the intermediate culture periods was 74.00 ± 1.64 mm and 106.16 ± 1.43 mm respectively.

The most significant increase was in shell weight ($P < 0.001$). Early oysters with an initial mean (± SE) WW of 20.38 ± 1.80 g gained an average (± SE) of 57.25 ± 2.66 g, while late oysters with a mean (± SE) WW of 89.18 ± 3.18 g gained 95.97 ± 4.14 g after six months in panel nets. At the end of the intermediate culture periods, the average weight (± SE) of early oysters was approximately 77.64 ± 4.20 g and late oysters was 185.16 ± 6.42 g respectively. Although the average DVM and APM growth rates per month were slightly higher in early oysters, late oysters appeared to invest more in shell weight. No mortality of black-lip pearl oysters was observed during both 6-month intermediate culture periods in panel nets (i.e. 100% survival).

Panel nets were moderately fouled enabling easy removal of fouling organisms using a standard household scrubbing brush every two months. Fouling organisms on panel nets were similar to spat collectors and mainly consisted of filamentous algae (30%), calcareous sponges (20%), soft corals (5%), bivalves, crabs and polychaetes.

Table 2. Mean (± SE) DVM, APM and WW growth of *Pinctada margaritifera* harvested from spat collectors deployed for 8 and 14 months and then grown in panel nets for another 6 months, in Namarai Bay, Fiji. Average monthly growth rates and test statistics (sample size, *t*-value and *p*-value) are also shown.

	Mean Growth (± SE)	**Mean Growth per Month**	***n***	***t***	***p***
DVM1 (8 month harvest)	27.64 ± 1.56	4.61mm/month	45	0.13	0.895
DVM2 (14 month harvest)	27.39 ± 0.94	4.57mm/month	43		
APM1 (8 month harvest)	27.84 ± 1.68	4.64mm/month	45	2.30	0.025*
APM2 (14 month harvest)	23.29 ± 0.99	3.88mm/month	43		
WW1 (8 month harvest)	57.25 ± 2.66	9.54g/month	45	-7.86	<0.001*
WW2 (14 month harvest)	95.97 ± 4.14	16.00g/month	43		

* denote significant differences between means in each row. There is no significant difference between means in rows without an asterisk ($P > 0.05$).

4.2.2 Use of Panel Nets Vs Spat Collectors

The mean (± SE) DVM, APM and WW of *P. margaritifera* grown in intermediate culture using panel nets and *P. margaritifera* that grew on spat collectors deployed for

14 months are shown in Table 3. DVM, APM and WW for *P. margaritifera* that remained on spat collectors were significantly greater than *P. margaritifera* that had an intermediate culture period in panel nets ($P < 0.05$). On average, *P. margaritifera* harvested from spat collectors after 14 months were 5.24 mm larger in DVM and 8.87 mm larger in APM than those that were cultured in panel nets for 6 months. Average WW of *P. margaritifera* that remained on spat collectors was 11.55 g heavier than *P. margaritifera* that were grown in panel nets for 6 months.

Table 3. Mean (± SE) DVM, APM and WW of *Pinctada margaritifera* harvested from spat collectors deployed for 8 months then grown in panel nets for 6 months and *Pinctada margaritifera* that remained on spat collectors for the entire 14 months.

Culture Method	DVM (mm)	APM (mm)	WW (g)
Panel Nets	$72.32^{a} \pm 1.54$	$74.00^{a} \pm 1.62$	$77.63^{a} \pm 4.20$
Spat Collectors	$77.56^{b} \pm 1.16$	$82.87^{b} \pm 1.27$	$89.18^{b} \pm 3.18$

$^{a,\ b}$ denotes significant differences in means in columns. There is no significant difference between means in columns with the same superscript ($P > 0.05$).

Apart from growth and survival, other factors must also be considered when selecting appropriate intermediate culture methods. Table 4 provides a list of criteria that was used to assess the two methods utilized in this study to determine the best option for local communities in Fiji.

Table 4. Criteria used to assess the merits of using panel nets for intermediate culture or spat collectors for on-growing of *Pinctada margaritifera* spat by local communities.

Criteria	Culture Method	
	Panel Nets	Spat Collector
Equipment Cost	High	Low
Setup and Maintenance	High	Low - Moderate
Labour Requirements	High	Low - Moderate
Construction	Ready-to-use	Ready-to-use
Fouling	Moderate	Low-Moderate
Water Flow	Moderate	High
Growth	Good	Good
Survival	High	Moderate

Chapter 5 Discussion

This study aimed to investigate the best timing for spat collector deployment and duration, as well as the value of an intermediate culture method of *P. margaritifera* in Namarai Bay, Fiji. Results showed that a higher number of *P. margaritifera* could be yielded by deploying spat collectors from October to June. This period coincides with Fiji's rainy summer season when waters are warmer. In addition, longer spat collector deployment durations are more suitable as collectors act as culture apparatus and spat are allowed to grow on the same collector after settling. This eliminates the need for other intermediate culture methods, thus, reducing costs for local communities. Shorter immersion times of 6 months is not ideal in Fiji according to this study, however, 8-month spat collector immersion can produce similar yields as a longer immersion time of 14 months. Deploying spat collectors for 8-month periods could eventually result in higher yields; however, this comes with the added costs of intermediate culture methods such as panel nets, chaplets or CTNs. Furthermore, the need for panel nets as an intermediate culture method by local communities is debatable. Economical and practical considerations must be taken into account when assessing culture methods for on-growing of *P. margaritifera*.

5.1 Spat Collector Deployment Period and Duration

In this study, spat collectors deployed from July to December 2017 collected no discernible *P. margaritifera*. However, this did not disprove that a late spawning event in November or early December may have occurred. Such an event would have resulted in microscopic spat that were inconspicuous to the naked eye when spat collectors were removed in December 2017. A November or December spawning event is supported by *P. margaritifera* recruitment on spat collectors immersed for 8 months that were deployed from October 2016 to June 2017. The mean (± SE) DVM of *P. margaritifera* harvested from these collectors was 44.68 ± 1.64 mm (Tab. 1) which fell into the 40 – 50 mm size range for six month old *P. margaritifera* spat reported by Coeroli et al. (1984). This suggested that *P. margaritifera* spawning occurred approximately six months prior to June 2017, which was plausible evidence of a late November or early December 2016 spawning event in Namarai Bay, Fiji.

Furthermore, the collection of fifteen discernible *P. margaritifera* spat from collectors deployed from January to June 2018 suggested that another spawning event might have occurred in early February to late March 2018. The sea surface temperature was just below 29°C from February to March 2018 (Fig. 3). The mean (± SE) DVM for these fifteen *P. margaritifera* was 16.88 ± 1.19 mm (Tab. 1). A similar mean (± SE) DVM of 16.8 ± 0.4 mm for *P. margaritifera* harvested from spat collectors after three months was reported by Friedman & Bell (2000). Their results suggested that the *P. margaritifera* from our study might have settled approximately three months prior to being harvested from collectors in June 2018. This is possible evidence of a spawning event between February and March 2018 in Namarai Bay, Fiji. The recruitment patterns of *P. margaritifera* observed in this study suggested that major spawning intensity occurred during Fiji's warm, rainy summer months. The period from November to April was when higher mean monthly SSTs were recorded in comparison with the cool, dry winter season from May to October (Fig. 3).

Other research conducted on spat collector deployment periods and recruitment patterns of *P. margaritifera* in the Pacific region showed similar results to this study. Vilisoni (2012) found that major and minor recruitment peaks of *P. margaritifera* in Savusavu Bay, Fiji, were recorded in April and December 2009 following significant increases in seawater temperature in March and November 2009. In French Polynesia, five spawning peaks were recorded, possibly due to the fact that average seawater temperature was constantly above 28°C throughout that year (Pouvreau et al., 2000). A long-term study in the Solomon Islands, which has a similar climate to Fiji's, found that spat collectors deployed between November to April recruited more spat than collectors deployed from July to October (Oengpepa et al., 2006). These results are contrary to that found in Tanzania where spat collectors deployed in the dry season from June to November yielded higher numbers of spat compared to the wet season from December to May (Ishengoma et al., 2011). Studies have also shown, however, that low temperatures can influence spawning cycles (Southgate & Beer, 1997; Tranter, 1958) leading to high spat recruitment during the winter from May to June in Australia (Beer & Southgate, 2000). Clearly, spat collector deployment period appears to align with increased or decreased water temperatures, which varies in different regions. However, other factors apart from temperature such as food availability and changes in salinity and currents, could also act as cues for spawning.

In addition, spat collector conditions in this study could have affected *P. margaritifera* recruitment. None of the collectors deployed in this study were 'cured' prior to deployment. Curing refers to the process in which spat collectors may be soaked in seawater or an aerated culture of microalgae for at least 72 hours (Taylor et al., 1998). This process needs to be long enough for collectors to be covered in bacteria and microalgae without being completely fouled by larger animals (Haws & Ellis, 2000). Thus, creating a biofilm that provides a chemical cue that induces faster settlement rates in pearl oysters (Doroudi & Southgate, 2002; Taylor et al., 1998). Moreover, new collectors would have been introduced to a longline system with spat collectors that had been suspended for approximately 8 months already. These spat collectors would likely be surrounded by predators or have recruited the larvae of predators, therefore forming its own 'ecosystem'. This could have resulted in the lack of recruitment shown by both the new collectors and older collectors that were removed in December 2017.

The average individual spat per collector after six, eight and fourteen-month deployment was 0.6, 1.8 and 1.72 (n = 25 collectors) respectively. The lowest average number of spat per collector in this study was very similar to that reported in the Solomon Islands (Friedman et al., 1998; Oengpepa et al., 2006). Furthermore, the highest average spat per collector in this study was within the range reported in Australia by Beer & Southgate (2000). One possible reason for the difference in spatfall could be the higher sample number of spat collectors used in Tanzania (n = 180 spat collectors) and the Solomon Islands (n = 50 spat collectors per site) which provided more substrate for recruitment. Another reason could be the composition or type of spat collectors. For example, in Tanzania spat collectors were composed of mesh bags, rubber tiles and strings of coconut husks whereas in Australia, collectors were made of a combination of shade cloth and mesh bags which could have been more suitable for recruitment (Beer & Southgate, 2000; Ishengoma et al., 2011). Other factors such as number and type of sites, depth, and deployment timing and duration could have also affected spat recruitment.

Furthermore, *P. margaritifera* harvested from spat collectors deployed for longer periods were larger compared to shorter periods (Tab. 1). All (100%) of the oysters harvested after 14 months had a DVM greater than 50 mm (Fig. 4). These oysters are less vulnerable to predation as they have passed the 'size refuge' of 50 mm stated by

Coeroli et al. (1984), after which *P. margaritifera* are 'resistant' to predatory attacks. Additionally, larger oysters are closer to the minimum desirable seeding size of 100 mm, which minimizes the time between harvesting of *P. margaritifera* and the production of pearls (Kishore et al., 2018). Larger oysters also require less husbandry effort, thus eliminating the need for intermediate culture methods and the costs associated with importation and construction of panel nets and chaplets or CTNs.

On the other hand, only 38% of *P. margaritifera* harvested from spat collectors after 8 months had a DVM greater than 50 mm (Fig. 4). This meant that more than half of the early harvested *P. margaritifera* cohort would be more vulnerable to predation. Majority of the oysters harvested after 8 months would then need to be grown in panel nets as the minimum size for ear-hanging methods range from 65 – 90 mm (Friedman & Southgate, 1999a; Southgate, 2008). Despite the low recruitment of *P. margaritifera* at 6 months, the shorter immersion time of 8 months resulted in a similar yield as the longer immersion time of 14 months. A study by Friedman & Bell (2000) found that the yield of *P. margaritifera* recruited on spat collectors immersed for three months was significantly higher than those recruited on spat collectors immersed for six months. Also, Oengpepa et al. (2006) reported that a two month immersion time recruited maximum numbers of *P. margaritifera* that were similar to numbers recruited for the six month immersion time by Friedman & Bell (2000). In this study, the shorter immersion time of 8 months could increase pearl oyster supply in the long run, however, intermediate culture methods would need to be considered which could be costly and require more effort for local communities.

On the other hand, heavier *P. margaritifera* spat potentially generate more income for local spat collecting communities. Spat are sold at a rate of FJD 5.00 per kg irrespective of size (Kishore et al., 2018). The mean (± SE) WW of *P. margaritifera* harvested after 8 months was 20.38 ± 1.80 g, while for spat harvested after 14 months it was 89.18 ± 3.18 g (Tab. 1). Approximately 50 *P. margaritifera* would be sold per kg if harvested after 8 months compared to only 11 *P. margaritifera* sold per kg if harvested after 14 months. This means that the 45 oysters harvested after 8 months in this study would be valued at less than FJD 5.00, whereas the total value for the 43 oysters harvested after 14 months is four times this amount at approximately FJD 20.00. In other words, harvesting of *P. margaritifera* after a longer immersion time potentially increases the level of income earned for lesser number of oysters whereas the intermediate culturing of oysters associated with shorter immersion times requires more husbandry efforts and could become expensive over time. As such, more research such as a cost-benefit analysis is needed to optimize spat collection strategies by local communities in Fiji.

5.2 Intermediate Culture Method

The average monthly DVM growth rate for the two intermediate culture periods in this study was 4.61 and 4.57 mm per month (Tab. 2). The DVM growth rate is very similar to that found in a study by Southgate & Beer (2000). Hatchery reared 8 month old *P. margaritifera* were cultured for approximately five months using panel nets, chaplets, plastic mesh inserts and trays (Southgate & Beer, 2000). Initially, the mean (± SE) DVM for 8 month old hatchery reared *P. margaritifera* was 41.50 ± 0.60 mm and increased at an average rate of approximately 4.86 mm per month in panel nets (Southgate & Beer, 2000). This average monthly growth rate was the highest out of the different culture methods tested (Southgate & Beer, 2000). In the Solomon Islands, average growth rates per month were higher for oysters of a smaller size range that were grown in panel nets. Friedman & Southgate (1999) reported that *P. margaritifera* with an average DVM of 24.00 mm increased by 22.97 mm in three months at a rate of 7.66 mm per month. Similarly, Friedman & Bell (2000) reported an average size increase (± SE) of 19.70 ± 0.40 mm for *P. margaritifera* with an initial mean (± SE) DVM of 16.80 ± 0.40 mm that were grown in panel nets for three months. The average growth rate per month for these oysters was approximately 6.57 mm per month (Friedman & Bell, 2000). Gervis & Sims (1992) stated that normal growth of pearl oysters is characterised by an initially fast increase in DVM for younger oysters, followed by an increase in shell thickness. This may explain the faster growth rates observed by Friedman & Bell (2000) and Friedman & Southgate (1999) as *P. margaritifera* were much smaller and younger than those used in this study.

Furthermore, changes in shell shape tend to become more evident as pearl oysters age. Studies have shown that pearl oysters changed from a sub-quadrate or symmetrical shape to a rectangular or oblong shape (Carreon, 2019; Saucedo & Southgate, 2008). During the larval stages, the longest shell axis is the APM. However, as the pearl oyster ages the DVM becomes the longest axis (Saucedo & Southgate, 2008). According to Carreon (2019), *P. margaritifera* exhibited a downwards allometric growth trend from

1.15 to 0.97 when APM:DVM ratios were compared in smaller (55 – 60 mm) and larger oysters (125 – 130 mm), respectively. This suggests that as *P.margaritifera* grows or ages, the APM does not increase as steadily as the DVM, which could be a possible reason for the slower APM growth rate found in this study for *P. margaritifera* harvested after 14 months (see Tab. 2). Additionally, seasonal variations in food, sea water temperature and culture location could also affect growth (Gervis & Sims, 1992; Saucedo & Southgate, 2008).

High survival rates of *P. margaritifera* is another benefit associated with the use of panel nets. In this study, wild *P. margaritifera* held in panel nets for six months reported a 100% survival rate in both intermediate culture periods. The same survival rate was also reported by Southgate & Beer (2000) in Australia. Survival rates of *P. margaritifera* in the Solomon Islands were also relatively high. *Pinctada margaritifera* cultured in panel nets for one month and three months showed high survival rates at 97.3% and 81.7% respectively (Friedman & Bell, 2000). In another study, survival rates for *P. margaritifera* grown in panel nets for three months and five months ranged from 70 – 96% (Friedman & Southgate, 1999b). Friedman & Bell (2000) found that *P. margaritifera* harvested from spat collectors after four months and then grown in panel nets for two months had a 93.5% survival rate compared to 58% survival rate for those that remained on spat collectors. High survival rates lead to increased yield, however, other economical and practical factors need to be considered when selecting an appropriate culture method.

The most suitable method for nursery culture of *P. margaritifera* spat needs to be determined using criteria such as cost of equipment, ease of construction, degree of fouling, growth and survival rates (Southgate & Beer, 2000). Criteria used to assess the merits of using spat collectors and panel nets for intermediate culture by local communities is displayed in Table 4. The cost of importing a single spat collector into Fiji is approximately USD 0.60. Although panel nets show favourable growth and survival rates, it is imported into Fiji and is expensive. According to Johnston et al. (2019), the cost of importing one panel net into Fiji is approximately USD 9.00. For local communities interested in pearl industry based livelihoods, this would be an additional cost added to the cost of constructing the long-line (~USD 120.00) and importing spat collectors. Chaplets and CTNs are widely used in Fiji by pearl farmers and can be considered a cheaper alternative for intermediate culture. The cost of constructing a single chaplet or CTN is approximately USD 0.40. However, this cost does not include additional labour requirements for construction associated with chaplets and CTNs or the one off cost of a handheld Power Drill which is approximately USD 100.00. Panel nets and spat collectors, however, come as "ready to use" with no additional construction requirements (Tab. 4). However, the process of removing oysters from spat collectors and placement into panel nets is an additional labour requirement (Johnston et al., 2019). The removal of oysters as well as the cleaning and maintenance involved in using panel nets is not only labour intensive, but may also induce stress in oysters.

Furthermore, the use of panel nets in this study did not result in *P. margaritifera* of a larger size and weight as hypothesized. On average, *P. margaritifera* harvested from spat collectors after 14 months compared to those cultured in panel nets were larger and heavier (Tab. 3). These results could be due to stress and fouling associated with the use of panel nets. Byssal attachments were also severed in order for spat to be removed from spat collectors and placed in panel nets. This could have shifted energy towards byssus production with attachment disks resulting in slowed growth rates of oysters (Kishore et al., 2014). Additionally, fouling reduces water flow which could limit food and oxygen availability (de Nys & Ison, 2008) resulting in slower growth of *P. margaritifera* held in panel nets compared to spat collectors. *Pinctada margaritifera* kept in panel nets were cleaned every two months to remove fouling organisms. This process involved scrubbing oysters and panel nets clean while they remained in the pockets. The air exposure and manual handling may have caused stress to the oysters as suggested by Haws (2002). Both panel nets and spat collectors experience fouling, however, more studies specifically focussed on the degree of fouling and composition of fouling organisms need to be conducted to better understand the extent to which fouling affects *P. margaritifera* growth.

Moreover, the larger size and weight of *P. margaritifera* on spat collectors could be due to early recruitment soon after spat collector deployment, resulting in larger oysters at the end of the experiment. On the other hand, it is also possible that late settling spat may have been harvested from spat collectors and placed in panel nets resulting in smaller oysters compared to those that remained on spat collectors. As such, the rationale for the use of panel nets by local communities involved in spat collection in Fiji is debatable as the current practice of harvesting *P. margaritifera* spat from collectors after 10 – 18 months may be adequate for higher income generation.

Chapter 6 Conclusions and Recommendations

Efficiency of spat collection strategies and growout of *P. margaritifera* supports the development of the Fiji pearl industry. Local communities earn income from pearl industry based livelihoods in the form of spat sales and pearl farming (Kishore et al., 2018). This research identifies possible areas for improvement in the timing and duration of spat collector deployment, and assesses the use of intermediate culture methods of *P. margaritifera* by local spat collecting communities before sale to pearl farmers.

6.1 Major Findings

The deployment periods tested in this study showed differences in spat recruitment patterns. Given that seawater temperatures tend to intensify spawning activity in *P. margaritifera,* spat collectors deployed during warmer months yielded more recruits compared to cooler months. As such, the period from October to June appears to be more suitable for efficient spat collector deployment in Fiji.

The duration of spat collector deployment affects the size and weight of *P. margaritifera* recruits which can influence the revenue generated from spat sales by local communities. *Pinctada margaritifera* is sold at FJD 5.00 per kg irrespective of size (Kishore et al., 2018). Longer immersion times were more suitable for harvesting a greater proportion of larger *P. margaritifera*, which are near minimum seeding size and more 'resistant' to predation. Additionally, shorter immersion times such as 6 months produced lower yield of *P. margaritifera*, however, 8-month immersion times showed similar yield as the longer 14-month immersion time. Shorter immersion times of 8 months could increase spat supply if spat collector deployment is timed correctly, however, this comes at the cost of having to invest in intermediate culture methods.

Intermediate culture methods for growout of *P. margaritifera* significantly increased growth and survival rates. Panel nets have been used extensively as an intermediate culture method. Despite the ease of use, the cost is rather high at USD 9.00 per net (Johnston et al., 2019). Additionally, the larger mean size and weight of *P. margaritifera* that remained on spat collectors compared to those grown in panel nets further dispelled the need for local communities to use panel nets.

6.2 Limitations of this Study

The time constraint associated with the Master of Science research limited the execution of this data sampling to one year. Data sampling began in June 2017, following the submission of a proposal, and ended in June 2018. Consequently, the timing of spat collector deployment in alignment with each season was not achieved. In addition, longer deployment durations of 18 to 24 months could not be tested.

Despite relatively good *P. margaritifera* recruitment on spat collectors, the size and numbers were not enough to test growth of oysters on chaplets and CTNs. Pearl oysters grown using these ear-hanging methods usually range between 65 – 90 mm in DVM. More than half of the *P. margaritifera* harvested after 8 months in this study measured less than 50 mm DVM making it impractical to use chaplets and CTNs at this stage. Furthermore, a single chaplet and CTN holds approximately 20 and 40 pearl oysters, respectively. An additional 180 *P. margaritifera* would have been needed in order to have three replicates of each culture method to support a more robust statistical analysis. In this study, the total number of oysters harvested from spat collectors after 8 and 14 months was 45 and 43, respectively. Panel nets were chosen for ease of use and favourable growth and survival rates as seen in other studies. Additionally, the *P. margaritifera* harvested could be divided into three replicates or three 15-pocket panel nets for each 6-month intermediate culture period.

The leaking of the data logger resulted in loss of *in situ* water parameter data from Namarai Bay. SST data for the North-eastern coast of Viti Levu was acquired from external sources (Integrated Climate Data Center, 2019). Satellite SST data is generally reliable and widely used in many studies (Wu, Cornillon, Boussidi, & Guan, 2017). Performance of satellite derived SST in comparison with *in situ* data loggers is fairly similar (Deidun et al., 2016), however, discrepancies may occur as a result of atmospheric contamination (Wu et al., 2017) and spatial grid resolution (Reynolds et al., 2007).

6.3 Implications for Further Research

Improvement in spat collection strategies could be achieved through detailed gonadal analysis to determine the phases of reproductive activity of adult *P. margaritifera* in Fiji. Comparison of growth, survival and cost-benefit analysis of different size or age classes of *P. margaritifera* using spat collectors, panel nets, chaplets and CTNs could also be beneficial for pearl oyster farmers. Additionally, *in situ* long-term water parameter data at different sites involved with collection and growout of *P. margaritifera* could highlight correlations between water parameters and *P. margaritifera* recruitment, growth and survival.

6.4 Recommendations

Deployment of spat collectors should occur when waters are warmer, preferably during Fiji's rainy summer season from November to April to maximize collection of *P. margaritifera*. For better spat sales, spat collectors should be immersed for longer periods to harvest larger *P. margaritifera*. Local communities could benefit greatly from longer immersion times without the use of an intermediate culture method. However, shorter immersion times for increased supply of *P. margaritifera* could be utilized, on the proviso that the cost of intermediate culture methods and additional labour requirements can be met.

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