Pacific Island coastal reef fisheries: A case study from Mitiaro, Cook Islands

Antony Vavia

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Abstract

Small-scale fisheries of remote islands within the Pacific are often challenged with inadequate information and data. With rapid ocean-related challenges such as climate change and overfishing becoming increasingly experienced worldwide, the need to understand the status of Pacific Island small-scale fisheries is becoming increasingly recognised. With small-scale fisheries being critical to the survival of many coastal communities, lack of information creates difficulties predicting any ongoing environmental changes. Therefore, establishing baseline fishery data and identifying trends within remote island fisheries may reveal threats to food security and livelihoods, and opportunities to minimise them.

In this thesis, I draw on a case study on the island of Mitiaro, Cook Islands to address three approaches of obtaining fishery information in the Pacific that form an overall holistic approach to understanding remote Pacific Island fisheries. My first approach was by collecting specific life-history trait information of two coral reef fish species heavily targeted for consumption. The population dynamics of these species highlighted a very rapid growth in size and suggested that they quickly reach sexual maturity. In terms of the species' importance and contribution to Mitiaro's subsistence fisheries, this information may suggest a level of resilience to fishing pressures and thus being able to make inferences towards food security measures. The second approach involved the collection of catch data of the Mitiaro fishery. This provided a broader lens of the Mitiaro fishery by establishing family/species catch ratios, identifying fishing techniques, and calculating catch-per-unit-effort (CPUE) of both coral reef and nearshore pelagic fishes – valuable information to identify ongoing changes and long-term trends. Lastly, the third approach to understanding the Mitiaro fishery was by analysing its socio-ecological components. In terms of resource management, it is important to recognise what should be obvious: when managing a resource, success relies on managing people. Therefore, understanding the social anatomy of key actors, including the worldviews, existing knowledge, practices, cultural traditions, and governance systems associated with a fishery is essential to developing and implementing successful resource management strategies.

This thesis aims to address the data and information paucity that could prove critical to developing resilience in Pacific Islands remote communities by adapting to the growing challenges these communities face. Collecting from a wide range of sources of fishery information can be useful to identifying appropriate avenues for resource management. Although this case study applies to a local context, the overall holistic approach is adaptable and may be applied to understand other Pacific Islands remote small-scale fisheries.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Antony Vavia

Co-authored Works

Chapters 3 and 4 of this thesis form the works of two separate studies which are being submitted to be considered for publication in a peer-reviewed journal.

Study one (Chapter 3 in this thesis)

Population dynamics of Mitiaro surgeonfish.

Contribution: Antony Vavia designed the project, collected, and analysed data and wrote the manuscript (80%). Elizabeth Laman-Trip contributed to analyses (10%). Armagan Sabetian contributed to fieldwork sample processing and reviewed and provided feedback on the manuscript (10%).

Dr. Elizabeth Laman-Trip Dr. Armagan Sabetian

Study two (Chapter 4 in this thesis)

Mitiaro: A case study of a remote Cook Islands fishery.

Contribution: Antony Vavia designed the project, collected, and analysed data and wrote the manuscript (80%). Armagan Sabetian contributed to analyses and reviewed and provided feedback on the manuscript.

Dr. Armagan Sabetian

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Chapter 1

Introduction

1.1 Background

Small scale fisheries (SSF) are recognised for their vital contribution to food security and socio-economic development at commercial, artisanal and subsistence scales (Chuenpadgee, 2012; Cochrane et al., 2011). At a global scale, these fisheries also create a high-profile interest for Blue Economic initiatives (Cohen et al., 2019). For many small island or atoll nations (just referred to as 'small islands' hereafter), marine resources also have cultural significance. These fisheries may provide the only source of income, while for others, it may be their only means of food security. Terrestrial food sources in many small islands are limited for a variety of reasons, such as the lack of agriculturally suitable land or poor coralline soil, in which case the dependence on fisheries becomes significantly more important for the viability of human populations (Beckerman, 1977; Taylor et al., 2016).

The Pacific Ocean is home to many small island developing states (SIDS) consisting of small landmasses spread over thousands of kilometres of ocean space, the populations of which are almost exclusively inhabited within coastal regions (UN-Habitat, 2015). Thus, coastal communities have an intrinsic relationship with the marine environment for wellbeing and survival, a trait ubiquitous across the Pacific. High population density is typical of small island nations, making food security a Pacific-wide concern that requires an improved understanding of the gaps for fish supply and sustainability (Bell et al., 2009a; McGregor et al., 2009). Therefore, Pacific Island nations' fisheries are instrumental to the lifestyles of many rural and often isolated communities (Bell et al., 2009; Dalzell et al., 1996).

The marine environment faces several challenges with high density populations which has been identified as one of the key threats to Pacific coastal fisheries (Gillet, 2014). These include increased fishing pressure particularly close to urban areas, inadequate resource management strategies, climate change, and anthropogenic sourced pollution (Mcclanahan et al., 2008; Nañola et al., 2011). The range of these challenges can vary across large volcanic islands to small coralline and oligotrophic islands, taking into account the interconnectivities with other habitats (Brodie et al., 2012), of which the population density can also differ markedly. Consequently, the ecological and biological characteristics of coral reef organisms can vary at spatial, temporal, and latitudinal scales and play a role in how available ecosystem services are utilised (MacNeil et al., 2010). Given the fragility of coral reef ecosystems and the many stressors that can impact their trophic integrity (Hughes, 1994), it is critical to study and understand the associated ecological and social dynamics of fisheries across SIDS.

Although the importance of coastal reef fisheries in the Pacific has long been recognised, many fishery agencies suffer a paucity of data across this sector (Chuenpagdee et al., 2006; Dalzell et al., 1996; Kittinger et al., 2013). Lack of focus on small scale fisheries (SSF) is attributed to poor research network connectivity, and lack of academic and scientific infrastructure in

developing countries in contrast to economically developed nations with well-established research institutes (Oliveira et al., 2016). This challenge coexists with governance and institutional limitations, which has potential for economic and practical implications, especially for communities that depend on natural commodities for food security, socio-economic wellbeing, and development (Béné et al., 2010; Hanich et al., 2018). However, scientific approaches have often led to top-down management that disregards the critical social elements involved in fisheries (Jentoft et al., 1998; Pauly, 2006). Governance strategies that overlook resource users are criticised for leading unsuccessful management strategies (Ayers & Kittinger, 2014; Chuenpagdee et al., 2006; Ruddle, 1998). This is often observed about the implementation of MPAs (marine protected areas) where governance focuses on ecological success at the expense of society (Bennett & Dearden, 2014), and with customary rights to resources (Aswani et al., 2007; Cinner & Aswani, 2007; Friedlander et al., 2013). In other words, poor compliance in response to management regulations can occur due to the neglect of local livelihoods, including the integration of socio-cultural, financial, and political contexts within rural community (Schwarz et al., 2011). Researchers and institutes that are informed with the socio-cultural elements of their target community are likely able to address these information deficits, thus minimising ill-informed decision-making processes (Nunn et al., 2014; Oliveira et al., 2016). The contribution of local values, perceptions and knowledge of marine environments have long been recognised (Hall-Arber & Pederson, 1999; Johannes et al., 2000; Sabetian & Foale, 2006; Walter & Hamilton, 2014).

Therefore, investigating coastal reef fisheries requires a two-part process: ecological and social. The former underlines the hard science for biological and ecological inquiries within fisheries. This thesis will outline two fisheries scientific research approaches. Firstly, life-history empirical estimations that can be used to determine sustainable fishing benchmarks (Ault et al., 2008; Gough et al., 2020); and secondly, describing fish assemblages through fishery-dependent and independent investigations (Reis-Filho et al., 2019). The social context cannot be removed from fisheries, as a fishery only exists with societal interest and interaction. Qualitative approaches assessing local fisher community livelihoods, discourses, practices, and culture around marine resource management can offer insight into how scientific findings and governance strategies may be received (Wencélius et al., 2022). It also may assist in developing locally relevant adaptive solutions, particularly for remote coastal communities, to marine threats that align with local livelihoods as opposed to incorporating national or global agendas (Nunn et al., 2014).

It is within the context above, that this thesis endeavours to investigate the coastal reef fishery of the island of Mitiaro, a small outer island of the Cook Islands to understand the dynamics of a small island fishery and establish a knowledge-baseline and a case-study in the Cook Islands. These complex systems require robust approaches to gaining sufficient and relevant information

that identify challenges within fisheries and highlight the opportunities that may influence the success across ecological and social systems. Therefore, I investigate the Mitiaro fishery at three levels. At the detailed level, I assess the life-history status of two popular reef fish species that are targeted for consumption. At a broader level I analyse the catch landings of the Mitiaro fishery. I also demonstrate the diverse local values of the Mitiaro fishery, including traditional knowledge to understand the governance system and interests that may prove critical to local planning and outcomes to marine resource management.

1.2 Aim and Objectives

The aim of this thesis is to establish baseline fishery data with a socio-ecological approach to understanding remote islands subsistence-based fisheries. This information can be used to detect ongoing changes in marine resources to ensure sustainable marine management and food security. To do this, I have three objectives:

Objective 1: Establish population dynamic values of two prevailing reef fish important to the Mitiaro fishery.

Objective 2: Estimate abundances and catch of the Mitiaro fishery to calculate catch-per-unit-effort (CPUE), identify fishing methods, and establish species catch ratios.

Objective 3: Understand the socio-ecological dynamics including the values, worldviews, and traditional ecological knowledge between Mitiaro people and marine resources.

1.3 Thesis organisation

Chapter Two will provide a comprehensive literature review of the dynamics, challenges, and gaps of Cook Islands coastal fisheries, including the knowledge and customs that shape management. This chapter will also establish the methodological approaches and contexts of my research.

The third chapter of this thesis describes population dynamics of two commonly targeted functional reef fish species, *Ctenochaetus striatus* and *Acanthurus achilles* by determining the

age, growth, and maturity estimates (Objective 1). This chapter will also provide gonadal examinations to determine reproductive seasonality.

The fourth chapter will cover the results of the CPUE data to identify stock status, species catch ratios, fishing methods, and fisher dynamics (Objective 2). This chapter will also outline the abundance and distribution assessments from UVC data estimating fish assemblages.

Chapter Five provides a holistic view of the Mitiaro fishery through an ethnographic approach that outlines local values, practices, and concepts of Mitiaro people pertaining to marine resource use and management (Objective 3).

Chapters Three and Four are manuscripts that have been submitted for peer-reviewed publication. Chapter Five is being prepared for peer-reviewed publication.

Finally, Chapter Six of this thesis is a conclusive segment describing the integration of biological, ecological, and social concepts within Pacific small-scale fisheries that contribute toward sustainable resource management and food security.

Chapter 2

Literature Review

2.1 Overview

Below, I provide a literature review outlining challenges and knowledge gaps to provide context of my research. Firstly, I will introduce the Cook Islands as the nation of interest pertaining to the marine sector. Specifically, I highlight the values and challenges of coastal resources across subsistence-, artisanal- and commercial-fisheries and how they contribute to the Cook Islands economy and livelihoods. I also provide historical and current contexts of existing Cook Islands traditional resource management systems. This includes and how these management systems relate to Cook Islands values and commitments, and how they may differ from other contemporary marine management systems.

In this review, I present three approaches to establishing baseline fishery data for a remote coastal community which address the objectives outlined in Chapter One. This includes relevant research that establishes the importance of the nexus at which quantitative and qualitative methods to fisheries research are critical within the Pacific Islands. Firstly, I provide an overview of the contribution of age-based population dynamics to fisheries management. Secondly, I outline a common approach to fisheries research through catch compositions, abundance distributions, and catch-per-unit-effort. Lastly, I establish the importance of an ethnographic approach to understanding livelihoods, knowledge, and cultural elements surrounding a small fishery.

2.2 Cook Islands coastal reef fisheries

The Cook Islands consist of 15 Island groups in the southwest Pacific (two of which are uninhabited), spread between 9- and 22-degrees' latitude, across an exclusive economic zone (EEZ) of over 1.8 million square kilometres. The country's capital, Rarotonga is considered the mainland containing most of the nation's population and economic development, and each other island is considered an 'outer island'. Second to tourism, the fisheries industry in the Cook Islands is the largest contributor to the Gross Domestic Product (Cook Islands Government, 2015). Given that these two environmental and biodiversity-based sectors are intrinsically linked, the health of coral reefs is integral to the viability of both. As such, there are renewed and concerted efforts for the conservation of coral reefs, protection of biodiversity, and sustainability of coastal fisheries. Moreover, the Cook Islands provides a unique scenario where tourism is heavily concentrated on only two of the fifteen islands, namely Rarotonga and Aitutaki. Therefore, on the remaining islands human existence is heavily influenced by subsistence- and artisanal-based lifestyles. On the outer islands, coastal fishing is mainly carried out for subsistence purposes and their vast distances make commercial endeavours with markets in Rarotonga or Aitutaki financially unfeasible in most cases.

For a while, remote islands were thought unlikely to have the capacity for commercial coastal fisheries (Dalzell et al., 1996). This is based on the notion that small populations provide inadequate labour forces. In former reports, Cook Islands' coastal subsistence fisheries have produced an estimate of 276 tonnes of catch in 2014 with an estimated value of $2,000,000NZD – accounting for 2.4% of the overall estimated fisheries revenue i.e., coastal commercial, offshore sectors, freshwater, and aquaculture (Gillett, 2016). However, the effort and expenses associated with small island economic growth is hindered through logistical constraints such as shipping availability and costs, and maintaining market standard could be unprofitable, underlining small coastal community's reliance on the critical ecosystem services. This lack of economic opportunity alone redirects pressure on marine resources through the Cook Islands' small-scale subsistence fisheries which remains, for the most part, under-studied while maintaining a healthy marine ecosystem for the tourism industry.

The Cook Islands tourism sector, like many other Pacific nations is a primary driver of economic growth, attracting foreign investment, promoting infrastructural development, and providing employment (Kumar et al., 2020; Solomona, 2009), capitalising on the nation's popular tropical landscapes, beach views, coral reef snorkelling and diving locations, and fishing charters. However, some areas of tourism and development in the Cook Islands have been suggested to cause pollution resulting in negative marine impacts including lagoonal eutrophication, increased temperatures, algal blooms, and faunal fatalities (Chand & Lal, 2022; Evans, 2006; Rajkovics, 2006). Furthermore, ciguatera poisoning – a common food-related toxin prolific in the Cook Islands has previously been related to increased nutrient levels and the degradation of coral reef systems (Rongo & van Woesik, 2011). Ciguatera poisoning is caused by the ingestion of reef fish and some invertebrates that contain toxins produced from algal dinoflagellates such as *Gambierdiscus toxicus*, which can induce gastrointestinal and neurological disorders. As a result of ciguatera outbreaks, a socioeconomic review revealed an overall decrease in reef fish consumption between years 1989 and 2011, and increased pressure on pelagic species (e.g., tuna, flying fish) (Rongo & van Woesik, 2012; Solomona, 2009). This resulted in an estimated revenue loss of $723,000NZD of reef fish harvest with increased consumption in canned fish and meat (e.g., poultry, corned beef, pork, mince). On the other hand, local marine reports have encouraged tourism blue economic alternatives in outer islands to help alleviate pressure on fisheries by diversifying incomes, supporting economic growth and livelihoods (Kora et al., 2018).

To date, there are few academic literatures that document Cook Islands reef fisheries where most available literature is limited to local government and external scientific organisation reports. Nevertheless, with an overview of Pacific Island reef fisheries, available documentation reveals fisheries are in no doubt monumental to the economies and livelihoods of coastal-based communities. Cook Islands surveys have shown that subsistence-, artisanal-,

and commercial-based fishing accounted for 55%, 35% and 10% relative to the local fishing population, respectively (Solomona, 2009). Other global coral reef fisheries research has documented catch rate declines from overfishing. In the Maldives, the tourism and fisheries sectors relying on the marine environment have caused conflicts within management through resource partitions between interest groups leading to overexploitation risks (Nistharan et al., 2017; Rasheed et al., 2016; Shakeel & Ahmed, 1997). Overfishing and catch rate declination has had variable responses to a magnitude of factors including fishing methods, species targeting, food insecurity, rapid population growth, and management of protected areas (Bell, Albert, et al., 2018; Bell et al., 2009a; Russ & Alcala, 1989). Over time, the high value of Caribbean small-scale fisheries has evolved where subsistence and commercial fisheries have observed declines in catches, overseeing the governance challenges, infrastructure development, coexisting tourism and fisheries resource rights, and marine protection measures (Dunn et al., 2010; Oliveira et al., 2016).

More in-depth local research is required at both qualitative and quantitative scales in order to discern threats to resource sustainability that prevents long-term food security and survival. The long-term sustainability can be defined by the fishery's ecological, social, and economic success. This involves investigations of fish stocks, fishers themselves, and the management systems in place that govern them. Management systems can be complex in that the different associated key stakeholders have various motives for resource exploitation and protection. For example, the Cook Islands, like many other Pacific nations have customary tenure systems (CMT), unwritten and flexible traditional practices that administer resource access or restrictions. Additionally, due to the paucity in fisheries information, understanding local fisheries data in terms of catch and obtaining supplementary data on the nature of local fishers is critical. Such information would assist in identifying patterns or changes within a fishery that can be triangulated with valuable traditional ecological knowledge that may prove rich in data-poor locations. Life history and population dynamics on the other hand, will assist in providing deeper and robust assessments of specifically targeted species that prove as valuable resources for both sustenance and livelihood purposes.

2.2.1 Customary marine tenure in the Cook Islands

Marine protected areas (MPA) are increasingly being promoted as important conservation and fisheries management tools (Cohen & Foale, 2013; Fernandes et al., 2005; Leleu et al., 2012; McClanahan et al., 2006a). The methods used to regulate marine protection can vary greatly, across temporal closures (e.g., spawning or migration seasons), permanent closures, or various levels of restricted access (Fernandes et al., 2005). However, marine protected areas are not an exclusive concept to modern fisheries science. Various forms of marine closures and restrictive

resource access have historically been exercised as part of CMT systems in the Pacific Islands (Hviding, 2006).

The integration of customary forms of management with modern fisheries science is of increasing interest to scientists and management institutions (Ban & Frid, 2018). Cinner and Aswani (2007) provide an extensive review of the synergies and challenges between customary marine conservation and Western contemporary approaches. Deconstructing and understanding the different systematic processes, purposes and concepts of environmental protection has proven to be a challenge that needs to be resolved to successfully conserve marine resources. Contemporary Western methods of fisheries management in the Pacific Islands lack the levels of indigenous ecological knowledge required to elicit compliance from local communities (Cinner & Aswani, 2007; Mackay, 2007). On the other hand, CMT systems may lack some scope to adopt features of contemporary scientific, social, and economic dynamics, and could benefit from specific biological parameters such as age, growth, reproductive parameters, and size limits. That is not to say that customary systems are rigid and inflexible as there are examples of their ability to incorporate fisheries science with local decision-making processes (e.g., Wilson et al., 2006; Aswani et al., 2007). In some cases, CMT systems may be considered too flexible and unstructured to adopt certain contemporary MPA measures (Chambers, 2016; Hviding, 1998; Johannes, 2002).

Across the Pacific Islands, customary tenure is usually constructed through generations of human-environment interactions involving observations of seasonal and ecological cues. The sharing of ecological knowledge ensures the continuity of customs and traditions concerning resource use (Cinner & Aswani, 2007; Islam & Berkes, 2016; Vaughan & Ayers, 2016). Fisheries scientists intending to incorporate the use of CMT for MPA initiatives must be cognisant of their complexity. For example, a common misperception is that CMT systems have not always been instated with the purpose solely for conservation. Many local decision-making processes are often conceptualised through spiritual and cultural lenses that govern rights of access, uphold social status, and resource management – both exploitation and protection (Cinner & Aswani, 2007; Hoffmann, 2002; Islam & Berkes, 2016; Nunn et al., 2014; Vaughan & Ayers, 2016). Notwithstanding, conservation aims are not totally incompatible with CMT systems. For example, (Aswani, 1998) noted that fishers in the Solomon Islands adopt locally optimal foraging strategies whereby their fishing movements orient from less to more productive grounds which allow for rehabilitation of the former. In this case, the restriction of access to previously fished grounds through customary tenure had an unintended environmentally positive outcome.

Like MPAs, Pacific CMTs can be permanent or temporary, allow for certain types of harvest, or apply restrictions on marine activities (e.g., recreational swimming, fishing). However, the types of CMT in the Pacific are known to be flexible but viable tools for resource

management, making them robust in their application and periodic harvests (Jupiter et al., 2014). The cross-generational nature of CMT management strategies allow for development and refinement from observation and experimentation; a practice of a trial-and-error approach to resource responses to activities and seasons – cause and effect, and evaluation for adjustable CMT regulations (see also Chambers, 2016; Johannes, 2002). Thus, forming the basis of traditional ecological knowledge (TEK). Hviding (1998) noted that CMT regulations are unwritten and continuously adapt to match resource conditions; locked-in rules would lead to failure. Other literature also recognises the socio-ecological complexities of CMTs and suggest the potential success of hybrid resource management strategies (Aswani & Hamilton, 2004; Aswani & Ruddle, 2013; Bennett & Dearden, 2014). However, regardless of the efficacy of CMT systems as conservation tools, there is widespread agreement on two points; 1) the success of coral reef fisheries management in the Pacific Islands relies heavily upon the understanding of existing CMT systems, and 2) TEK contained within the CMT frameworks is a reservoir of historical knowledge which if combined with scientific research could place communities in a better position to introduce sustainable management or conservation strategies (Aswani & Hamilton, 2004; Hviding, 1998; Islam & Berkes, 2016; Vaughan & Ayers, 2016; Wilson et al., 2006).

In the Cook Islands, local CMTs are known as 'ra'ui' which are put in place to protect local resources and are enforced through traditional authority (Tiraa, 2006). Historically, ra'ui were primarily established for the protection of certain food sources to be harvested for cultural or other significant events (Hoffmann, 2002; Tiraa, 2006). It was the cultural and spiritual nature that encompassed these cultural events (e.g., interisland affairs, funerals, spiritual celebrations) that aided the commitment to resource abstinence and compliance with the ra'ui due to fears of disownment, banishment from the village or tapu (sacred taboos) (Dixon, 2016).

The Cook Islands currently have a unique governance body as a self-governing state since 1965 but in free association with New Zealand. Ra'ui have been used to conserve and protect environmental resources (Tiraa, 2006) both prior to and after the arrival of European missionaries in the 18th century. However, due to post-colonial influences under the British Protectorate, it was until 1915 that the laws under The Cook Islands Act gradually caused a cease of land and sea ownership, at least by displacing parts of indigenous authority. These changes came along with Western legal frameworks, legislative systems, and international trade development. As a result, by the 1970s, ra'ui discontinued in Rarotonga due to the decrease in dependency on natural resources. However, in response to depleting marine resources and concerns for tourism, a bid to implement marine protection was made in which national and international stakeholders agreed to support if it was community-led (McClanahan et al., 2006b). Thus, ra'ui was re-instated in Rarotonga with approval from the government in 1998. This was a significant event as ra'ui has spiritual and cultural importance to the indigenous

population and was regarded as a tool to encourage compliance amongst the communities of Rarotonga. Locals are more likely to respect customary rules as they are implemented by community and traditional leaders, whereas government enforced restrictions may appear to be politically driven and culturally challenging (Hoffmann, 2002). Therefore, adopting ra'ui (or other forms of CMT systems around the Pacific) have proven more welcome than their Western counterparts as the systematic processes and concepts of MPAs may be culturally unfamiliar to indigenous communities in developing nations and lacks community gravitas (Cinner & Aswani, 2007; Drumm, 2004; Mackay, 2007).

As culture and tradition are the historical and present primary incentives that aid in the prevention of ra'ui violation, there is an increasing number of modern influences encouraging CMTs. Non-government organisations and other conservationists deliver awareness programs educating communities of marine resource protection against the threats of climate change, illegal commercial fisheries, and other external capitalistic factors. Despite ongoing marine resource sustainability concerns, compliance is not always achieved. Although there are no official records of ra'ui violations (Miller, 2008), I have received several personal anecdotal accounts of people that infringe upon the rules. These acts of violation have often contended with ra'ui regulations due to avaricious intentions, resembling a localised tragedy of the commons. In some cases, the lack of ra'ui compliance is due to closures being instated within popular fishing zones or have been designated in areas with disputed land rights (including reefs), ultimately having a negative impact on the livelihood and wellbeing of community members (Tiraa, 2006).

In terms of the ecological responses to ra'ui, there are not many published accounts of their impacts on marine organism assemblages. Personal observations have highlighted favourable fishing outcomes during ra'ui openings due to supposed increased abundances, or with access to larger fish. An interdisciplinary case study describes that ra'ui resulted in higher fish assemblages than non-protected sites. However, only one site was investigated leading to a statistically challenged result (Hoffmann, 2002). There are, however, initial reports registered by the Cook Islands Ministry for Marine Resources displaying overall growth in assemblages, particularly in marine invertebrates despite being fluctuations across multiple ra'ui sites (Saywood et al., 2002). Another robust study across 6 ra'ui and paired control sites (unprotected) showed higher densities of certain fish species within ra'ui using standard MPA assessment strategies. However, integrating habitat types as a covariate made the results heterogenous across sites. Another study suggests that protected areas with periodic closures such as ra'ui favours short-lived fish and exploit the often-larger long-lived fish species (Cohen & Foale, 2013). Accounting for the social and ecological dynamics associated with ra'ui (or any protected sites) makes generalising MPAs impossible. Therefore, SSF management, in requires robust case-by-case research approaches (Cochrane et al., 2011). In this context this requires

implementing interdisciplinary strategies that unite the biological and cultural aspects of a fishery.

2.3 Age-based population dynamics

A wide range of ecological, biological, and population dynamics information can inform our understanding of fish ecology and fisheries science. Age-based demographic studies are critical to understanding fish stock vulnerability to fishing pressure and their subsequent ability to respond to those challenges (Abesamis et al., 2014). Many studies have investigated the plasticity of fish demography through age and growth analyses globally (Choat & Axe, 1996; Craig et al., 1997; Donovan et al., 2013; Gust et al., 2002; Meekan et al., 2001; Morais & Bellwood, 2018; Taylor et al., 2019). Age and growth estimates also have implications for management and conservation in localised areas, where longevity, asymptotic growth and reproductive parameters of the same species or families of fish can differ spatially and across a latitudinal scale (Berumen et al., 2012; Robertson et al., 2005; Trip et al., 2008a). For example, a life history investigation of the butterfish, *Odax pullus* along New Zealand's latitudinal gradient found that *O. pullus* grew slower, reached a larger asymptotic length, and survived longer in higher latitudes compared to their lower latitude counterparts (Trip, Clements, et al., 2014). The implications of these outcomes are valuable in determining estimated minimum sizes at which species populations are likely to spawn as well as determine mortality rates. Thus, informing management that can generate size quotas that will allow stock to reproduce, and minimising the level of exploitation to wild fish stocks. Furthermore, deducing spawning seasons may influence the implementation of seasonal bans or MPAs that allow stock numbers to increase safely.

From a resource management perspective, population dynamic investigations of functional species are also critical in understanding their role within ecosystems, the mechanisms which drive specific traits, and their capacity to withstand human impact and habitat degradation (DeMartini et al., 2008; Dortel et al., 2013; Marshell & Mumby, 2012; Robertson et al., 2005; Russ & Alcala, 1989; Trip, Craig, et al., 2014). A demographic analysis of various commercially important parrotfishes in Micronesia helped determine their resilience to exploitation (Taylor & Choat, 2014). The life-history analyses suggested that some parrotfishes may not be vulnerable to overexploitation due to their short lifecycles and high plasticity. This suggests that responses to exploitation may be species-specific and further complicated by spatial, environmental, or anthropogenic parameters. However, an investigation on one of the most abundant surgeonfishes in Indo-Pacific coral reefs, *Ctenochaetus striatus*, found latitudinal demographic variation which fishing pressure could not explain (Trip et al., 2008b). In other words, the trend in demographic variation implies that the life-history traits are

associated with the specific ecological parameters of each location i.e., temperature, habitat, and nutritional access etc. (Robertson et al., 2005), and that differences in growth rates can obscure the impacts of fishing pressure on demographic profiles (Taylor et al., 2019).

A review of coral reef fishes' resilience to fishing pressure and closures showed larger, long-lived, slower-growing, and late sexually matured fishes to be more vulnerable to overfishing (Abesamis et al., 2014). This corresponds with the general concept that fishes in lower trophic levels (i.e., smaller maximum body sizes, faster maturity rates and shorter life spans) are less vulnerable to overexploitation (see Pauly et al., 1998). In a general sense, larger-bodied carnivorous coral reef fishes such as emperors (Lethrinidae), snappers (Lutjanidae), trevally (Carangidae), groupers (Serranidae), and sharks are more vulnerable to fishing pressure than the smaller-bodied fishes such as parrotfishes (Scaridae), surgeonfishes (Acanthuridae), wrasses (Labridae), angelfishes (Pomacanthidae) and fusiliers (Caesionidae). Some small-scale fisheries cases have been observed to adjust fishing strategies in response to fishing pressure by transitioning from larger fishes to smaller species to ensure food security and income (Roeger et al., 2016). Fishing down the trophic level is common in fisheries which has also shown in archaeological records (e.g., Butler, 2001). The size-effect notion is best described by Pauly et al. (2002) where fisheries inevitably tend to target and remove larger fish, which reduces the mean trophic level within the local marine ecosystem.

2.4 Abundance and distribution and CPUE

In addition to age, growth, and life-history research, abundance and distribution studies are also critical in estimating the standing stock size of fish species. CPUE (catch per unit effort) is a standard measure for estimating fish stocks by evaluating broad trends in catch over time and is valuable in monitoring long-term trends (Zeller et al., 2021). CPUE data can identify fish family ratios caught by fishers, specific species catch ratios in each family. Besides documenting details of caught fish, it will help to document the fishing behaviour of local fishers, including fishing frequency, fishing techniques and inventory used, fish targeting, vessel type, gender roles, age dynamics of fishers, and site preferences (Li et al., 2022; Robinson et al., 2015). Furthermore, it gives the opportunity to triangulate this data with ethnographic and interview data obtained from local informants.

In most cases, notably in the Pacific and other developing countries, official subsistence or artisanal catch data is lacking which is an impediment to understanding the nature of small-scale local fisheries (Chuenpagdee et al., 2006; Teh & Sumaila, 2013; Zeller et al., 2006). Therefore, documenting CPUE can provide baseline data against which a variety of factors such as seasonality abundance can be compared in the future. These estimates are often corroborated

with underwater visual census (UVC) data and can make other environmental inferences. For example, CPUE and UVC have been used to determine night spearfishing pressure being primarily responsible for parrotfish decline, highlighting an important food source and pressure on functionally important grazers and bioeroders (Aswani & Sabetian, 2010). Changes in CPUE can indicate shifts or trends of targeted species abundance, which can be used to determine whether stocks are overexploited and in turn help inform resource management (Rhodes et al., 2008). While not being CPUE, early ethnographic and archaeological evidence also suggests changes in marine resource targeting from high ranked (larger) fishes to lower ranked (smaller) fishes if high ranked fish abundances declined, indicating fisher behavioural changes in the Cook Islands (Butler, 2001).

2.5 Ethnography of fisheries

Ethnography is a qualitative method often associated synonymously with participant observations, interpretive research, and case studies, which contributes to the debate around its value to scientific research (Hammersley, 2016). An ethnographic approach aims to understand human behaviour in their natural settings as opposed to conditions generated by the researcher (Brewer, 2000). As such, the role of the researcher is critical. Those that contend ethnographic research and overall cultural anthropology often argue social sciences case-specific methodologies that are difficult to replicate, the unstructured data collection, human bias in research design and subjective researcher observations, data analysis and interpretation (Bergseth et al., 2017). The methods in which social and cultural research adopt provide valuable information in human affairs that conventional science practices cannot attain appropriately or effectively on its own. A researcher subjecting themselves to intimate, yet objective and minimal subjective influences, study environments that allow observations of natures that most often cannot be quantified or in which quantification cannot explain. Developing a coherent understanding of societies within any context may explain certain phenomena that govern societies actions, and the consequences thereof.

In the context of small-scale fisheries, an ethnographic approach (often used interchangeably with ‘socioecological’) is a valuable research method to dissect the human-environment interaction. Ethnographic researchers in fisheries science highlight the integral role of humans on fish assemblages and advocate the pursuit of small-scale fisheries knowledge is imperative to gain insight on the local marine resource users and stakeholders, as opposed to having a dependency on single disciplinary quantitative approaches alone (Aswani & Ruddle, 2013; Johannes et al., 2000; Sabetian & Foale, 2006). However, it is argued that the social and natural systems involved with small-scale fisheries are incredibly complex due to each distinct

state of affairs that result in minimal comparisons across other fisheries globally. As a result, this would further marginalise small-scale fisheries populations that are already displaced due to their often-disadvantaged socioeconomic status, remote locations, and lack of political power (Chuenpagdee et al., 2006). Despite the differences in these epistemological approaches to fisheries, it is an important note that when making environmental-based decisions, fisheries management bodies are not adapting the environment itself, but instead the human interactions with the environment. Therefore, cognisance in fisheries customs, knowledge and resource-use may aid the context-specific research (Aswani & Ruddle, 2013).

Social science research is by nature, holistic. But when combined with traditional fisheries science it can provide an effective multidisciplinary approach, where one approach can inform the other and allows designing effective management strategies (Kittinger, 2013; Reis-Filho, Schmid, Harvey, & Giarrizzo, 2019) by understanding the nexus between social and environmental dynamics. For example, participant observations and semi-structured interviews with local fishermen can form part of a multidisciplinary approach to understand small-scale Islands fisheries. These approaches entail collecting information on fisher knowledge and behaviour, local customs, fisheries gear and methods, logistical systems and economic value chains that may explain trends. Quantitative investigations such as CPUE (catch-per-unit-effort) data can then be used to validate sources of information acquired through ethnographic studies (Roeger et al., 2016). CPUE documentation can be substantiated with qualitative data to provide insight into fishery trends across spatial and temporal scales, including local fishermen observations, and how their fishing practises may have shifted in response. Such studies are also critical in forecasting local livelihoods in terms of the economic and social trends. For example, a cross-cultural investigation of the behaviours of experienced fishers in Australia and the Solomon Islands showed that the imperatives for fishing can vary heavily, influenced by livelihood, sex, age, social status, economics, and conservation (Young et al., 2016). This is further highlighted in a case study where cash economy interjects into livelihood, where the conflict between environmental conservation and food security are brought to the fore (Hardy et al., 2013).

While it is beneficial to have a high level of quantitative and experimental science for understanding the mechanisms that drive fisheries and species stock assessment (Russ & Alcala, 1989), it may have its limits in its application to resource management strategies. Conservation management of marine resources is context- and site-specific, where sole reliance on quantitative empirical science may prove insufficient in strong indigenous- and culturally-driven fisheries (McClanahan et al., 2009). Due to the paucity of coastal reef fisheries data in Pacific Islands, inferences and perspectives remain unpredictable and may continue in this direction for many generations. Obtaining spatially accurate ecological and cultural information from a diverse range of coastal fisheries may be essential for the development of fisheries

management regimes, and the building of local capacity to ensure the viability of proposed regimes. Therefore, capitalising on local knowledge, observations, and customs around the interactions between local communities and marine resources can be beneficial to marine scientists (Ban & Frid, 2018; Davis & Ruddle, 2010; Hind, 2014; Mclean & Forrester, 2018).

Investigating how human interactions drive Pacific small-scale fisheries dynamics is necessary for improved sustainability (Aswani & Sabetian, 2010). Kittinger et al. (2015) also outlines the necessity to endorse effective sustainable strategy developments that are culturally appropriate considering the socio-economic, and ecological parameters in food security of subsistence fisheries in Hawai'i. Their participatory approach involved a collaboration of stakeholders (local community, conservationists, researchers) where value of culture was highlighted, as the engagement with local communities was rarely practised in Hawai'i. A participatory approach allows for direct assessment of the needs from the community to implement an effective community-based, bottom-up management plan. This is also the case with the reimplementation of Cook Islands-based management (Hoffmann, 2002; Tiraa, 2006). In other words, researcher observations and participation can lead to the acquisition of indispensable information as well as commitment from local stakeholders.

There's also increasing evidence that integrating the socioeconomic factor within fisheries research is critical and should consider community-based approaches. For example, Kittinger et al. (2015) found that over 90% of the catch was kept for household consumption. They also identified two key cultural practises: (1) gifting of food to others (extended family, friends, wider community), and (2) food used for social gatherings such as community feasts (birthdays, weddings, funerals). By mapping catch distribution of a small-scale fishery, the details of how the reef feeds communities can be discussed. This provides insight on some of the social, cultural, and economic factors that drive fisheries, and deconstruct the supply chain to figure out what food is kept, given away or sold. Understanding the small-scale fishery supply chain dynamics may help to generate methods that improve the value and sustainability measures, and also promote more blue economic opportunities within the fishery and associated communities. Furthermore, long time-scale observations of harvesting pressures and biomass can be documented and utilised to estimate stock status, levels of exploitation activity, and evaluate management strategies for long-term sustainability. Kittinger et al. (2015) point to place-based studies as essential in supporting management at geographically relevant scales and to preserve the necessary ecosystem services that support communities.

An overarching challenge with integrating western science and the social components is the validation process of data and information. Repeatedly, western scientific epistemological backgrounds aim to exercise validation standards that are inappropriate for the qualitative measures of anthropological science (validity mismatches). Despite the differences in practice, they are both tools for education. Therefore, they require different methods to testing and

validating knowledge. This popular discussion, however, has allowed the acknowledgment of the power inequalities between the epistemological roots and recognition of adopting parallel research avenues can be undertaken to develop richer results within studies.

2.6 Summary

The isolation from urban centres of many remote Pacific islands offers logistical limitations that lead to economic challenges, inadequate research, and the underrepresentation of coastal communities. Along with these limitations are the diverse and dynamic social structures that influence marine resource management and exploitation. As such, implementing the three approaches discussed above is a robust socio-ecological approach to understanding remote Pacific Island fisheries. By accounting for the biological components of a Mitiaro fishery through population dynamics, the information can be used by planners to identify sustainability measures that may encourage increasing or decreasing fishing efforts for species. Additionally, a snapshot of the overall Mitiaro fishery provides a wide perspective of ongoing trends with fisher behaviour and marine resources over a temporal scale. By exploring the social factors and engaging with resource users of a Pacific Island fishery, we can also understand key drivers and responses of marine ecological change. This can also define culturally relevant goals that align with coastal communities leading successful resource management strategies. Therefore, this thesis addresses a critical gap in Pacific Island fisheries by targeting data paucity limitations and practicing appropriate approaches to

Chapter 3

Population dynamics of Mitiaro surgeonfish

In this chapter, I establish the population dynamics of *Ctenochaetus striatus* and *Acanthurus achilles,* two prevalent coral reef fish species targeted for consumption in Mitiaro. These species were selected for their popularity within the Mitiaro community. Establishing estimates of life-history traits such as size- and age-at-maturity, growth rates, age structure and longevity, are commonly utilised demographic parameters in fisheries science, and critical to inform fisheries management. The level of productivity for fish populations are important factors in response to exploitation. In essence, with primary concerns focusing on food security and sustainable resource management, assessing the capacity at which targeted fish populations survive against fishing pressures provides valuable information for marine resource management.

Population dynamics are known to vary across latitudinal and local scales. Therefore, this chapter also addresses the data-paucity within the Cook Islands region by also providing baseline data for the two subject coral reef fishes. Chapter Three also forms the fine-scale aspect of this thesis to the socio-ecological approach of understanding a remote subsistence fishery in the Pacific.

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3.1 Abstract

Ctenochaetus striatus and *Acanthurus achilles* are two prevalent surgeonfishes targeted for subsistence on the island of Mitiaro, Cook Islands. Population dynamics information were established for Mitiaro male and female populations of both species by estimating growth rates, age, size and weight, distributions, longevity, mortality rates and spawning periodicity. All populations portrayed initial rapid growth reaching asymptotic sizes. There were no significant differences in the length-weight relationships in both surgeonfish populations. Size-at-age plots revealed that the female population of *C. striatus* achieved faster growth, but the male populations obtained a higher asymptotic length. Meanwhile, growth patterns of *A. achilles* displayed the reverse of *C. striatus*. Results from the gonadosomatic index also suggest that spawning periodicity could be biannual for both species. However, more samples with greater size variation are recommended for improved detection of spawning periodicity and gonadal development. It is proposed that further investigations describing life-history traits for other fishery-significant populations be conducted in Mitiaro, and neighbouring islands and atolls in the Cook Islands.

3.2 Introduction

Establishing age and growth parameters of targeted species are an essential element for fisheries science and management. Within the Pacific region and other developing nations, fisheries research is mainly concentrated on commercially valuable species (Grafeld et al., 2017; Loma et al., 2009; Oliveira et al., 2016). Non-commercial (i.e., subsistence- and artisanal-based) fishing remains statistically underestimated despite these small-scale fisheries (SSF) becoming an increasingly important topic globally (Cohen & Alexander, 2013; Kittinger, 2013). Other aspects of SSF research focuses on responses to human exploitation (Nañola et al., 2011; Russ & Alcala, 1989), climate change (Cinner et al., 2012; Hanich et al., 2018), and marine protected areas (Cohen & Alexander, 2013; Jupiter et al., 2014). Although the Pacific Islands are also faced with challenges from a rapidly growing global economy (Hardy et al., 2013; Schwarz et al., 2011), food security and wellbeing of coastal communities is considered more important due to localised dependency on natural resources (Bell et al., 2009b; Vaughan & Ayers, 2016). Coastal fisheries are by far the most important food security source in the Pacific Island (Islam & Berkes, 2016; Kittinger et al., 2013; Pauly & Zeller, 2016). As it would be expected, increasing populations and economic imperatives over time could result in an increase in fishing pressures (Hardy et al., 2013) and ultimately threaten the viability for food security. Therefore, the effective management and conservation of this vital resources is key to the long-term viability and survival of coastal communities in the Pacific Islands.

Fisheries management is informed by fisheries science, a key component of which is information on the population dynamics of targeted species. This includes growth, longevity, and life-history parameters including size- and age-at-sexual maturity. Examining annual sagittal otolith increments and assessing gonadal development are considered long-established demographic tools to estimate age structure and growth rates, examine differences in size and longevity, and establishing age at maturity and spawning periodicity of reef fish within the family Acanthuridae (e.g., Randall, 1961; Arias-Gonzalez et al., 1987; Choat and Axe, 1996). Associated with growth and size are the competencies to survive, exploit food sources, and reproduce. Across species at the population level, the degree of productivity and average size within fish assemblages can influence the rate at which they are harvested and therefore have an added response to fishing pressure (Taylor et al., 2017). In turn, this supplies information that can be utilised to determine sustainable harvesting rates.

However, population dynamics exhibit variation in growth rates and age structures. Variation can be transformed by density-dependent growth characteristics such as biomass density impacts on asymptotic lengths (Lorenzen & Enberg, 2002). As one might anticipate, available nutrition and therefore energetic supply plays a role on the individual growth of fish as well as the role of predation (Gust et al., 2002; Morais & Bellwood, 2018; Ruttenberg et al., 2005).

Other cases have linked reproduction seasonality, metabolic activity and energy distribution being driven by environmental factors to life-history traits (Morais & Bellwood, 2018; Ruttenberg et al., 2005), including anthropogenic stressors and a magnitude of factors (Taylor et al., 2019)

Variation in longevity, growth rates and mean maximum sizes for different populations across spatial gradients have also been well documented. For example, Trip et al. (2008) examined the demographic variation of 15 different populations of *C. striatus* across large latitudinal and longitudinal scales. (Trip et al., 2008b) found increases in longevity at large geographical scales, longitudinally from the Indian- to Pacific Ocean along with increases in latitude. Furthermore, there tends to be variations in growth rates and sizes at geographically smaller, localised scales within each population (Gust, 2004; Gust et al., 2002; Trip et al., 2008b). Many of these variations have been linked to environmental factors including sea surface temperatures, locality, and habitat structure (Meekan et al., 2001; Robertson et al., 2005). This prompts caution around the complexity of population dynamics and that it cannot be simply generalised and requires attention with a case-by-case lens. In light of that, for the purpose of developing and applying locally relevant and accurate fisheries management strategies, it is critical to conduct localised age and growth analyses of important catch species (Caselle et al., 2011; Taylor et al., 2019). This is especially so for data-poor locations lacking any local life-history data.

The objectives of this investigation were to explore the age, growth, and reproductive dynamics of two prevalent coral reef fish species on Mitiaro Island (Cook Islands), as a case-study; *Ctenochaetus striatus* and *Acanthurus achilles* (family Acanthuridae). Acanthurids are an important functional family of fishes, where through their high grazing ability they can maintain a healthy algal turf state enabling coral reef resilience (Bellwood, Goatley, et al., 2014; Marshell & Mumby, 2015). Surgeonfish decline has been linked to ecosystem changes, including trophic cascades (Hughes, 1994; Mumby et al., 2006; O'leary & Mcclanahan, 2010), brought on by coral mortality, and the subsequent trophic vacuums filled by secondary grazers (e.g., sea urchins). Furthermore, because in terms of biomass Acanthurids are one of most abundant families on coral reefs, they are widely targeted in the Pacific by subsistence and artisanal fishers (Foo et al., 2020; Ochavillo et al., 2011; Rhodes et al., 2008; Tebbett et al., 2022).

Globally, *C. striatus* is widely distributed across the Indian and Indo-Pacific oceans (except around Hawai'i) (Choat & Axe, 1996; Ochavillo et al., 2011; Trip et al., 2008b), while *A. achilles* has been observed across the entire Pacific Ocean, from West to Eastern Central Pacific including the Hawai'i region (Friedlander, 2004; Walsh et al., 2019). In terms of foraging modes, *C. striatus* has been established as a brusher, while *A. achilles* has been observed to be more of a cropper feeder, both of which inhabit coral reef flats and shallow forereefs and crests (Nemeth & Appeldoorn, 2009; Tebbett et al., 2022). *Ctenochaetus* species have evolved with long bristle-like teeth morphology (cteno = comb, chaeta = bristle) that have enabled them to selectively feed on detrital material along algal turfs (Bellwood, Hoey, et al., 2014; Purcell & Bellwood, 1993). While targeting organic and inorganic sediment, *Ctenochaetus* also consumes diatoms and other microalgae as nutritional resources (Choat et al., 2004). *Acanthurus* forms the typical coral reef fish assemblages making them one of the most dominant herbivorous (including detritus feeding) genera in many Indo-Pacific coral reefs (Bellwood, Goatley, et al., 2014; Choat & Axe, 1996; Marshell & Mumby, 2015; Sorenson et al., 2013). Many of which are croppers like *A. achilles* with short teeth that target algal filaments (Tebbett et al., 2017). They are locally considered primary targeted coral reef fishes due to their high abundance, vulnerability to exploitation, and are desirable to the local appetite. By ascertaining the life-history traits we can evaluate whether strategies need to be developed that ensure long-term sustainability (Ochavillo et al., 2011). *Acanthurus achilles* is an interesting species due to their unique colouration patterns which makes them very lucrative to the aquarium trade.

In some areas of the Cook Islands and French Polynesia, *C. striatus* is unharvested due to ciguatera food poisoning (Arias-Gonzalez et al., 1987; Rongo & van Woesik, 2011; Tran et al., 2016). However, in Mitiaro they are consumed with no such issues. In fact, both *C. striatus* and *A. achilles* contribute highly to the coral reef-associated protein resource pool in Mitiaro (See Chapter 3). There has been a significant decline in *A. achilles* populations Pacific and low levels of recruitment brought on by high fishing pressure and their popularity in the aquarium

trade (Friedlander, 2004; Tissot et al., 2002; Walsh et al., 2019). There is no recent information of the Cook Islands' live aquarium trade. One report dates back to the 1990s outlining the trade's early success on mainland Rarotonga (Bertram, 1995). Although, no species are mentioned, it is probably that Acanthurus species were targeted. This study will be the first comprehensive assessment of their age-based population dynamics.

3.3 Materials and Methods

3.3.1 Study location

The Cook Islands consist of 15 islands scattered across an exclusive economic zone of two million square kilometres. This study was conducted on Mitiaro (19.8°S, 157.7°W), a small low lying raised volcanic island (22 km^2) in the Cook Islands located 264 km northeast of the country's capital island, Rarotonga (Figure 1). Mitiaro is an exposed oceanic island that receives intense wave action particularly on the northern and eastern sides of the island. The main residential village and harbour are located on the western side of the island. The island is surrounded by a fringing reef that supports the highest diversity of corals within the Cook Islands (Rongo et al., 2013), the highest diversity being on the western, leeward side of the island (Kora et al., 2018). The Mitiaro Harbour (Te Ao Omutu) is the primary port for fishers to depart for reef and pelagic fishing activities.

3.3.2 Sampling

Samples of *C. striatus* (n = 138) and *A. achilles* (n = 131) were collected over the period of 14 months (between March 2020 and May 2021) by donation from local subsistence fishers. In turn, only minimal portions were accepted for the study to avoid taking excess food portions from fishers and to minimise destructive sampling methods. Thus, a small sample size was collected. Some donation cases also allowed the measuring and processing of samples to then be gifted back to fishers. Individuals were targeting using snorkel and spear at daytime, mainly from the western reefs of the island adjacent to the Mitiaro Harbour between the reef crest and outer slopes of the forereef. A small portion was collected on rare occasions (weather permitted) from the eastern side of the island.

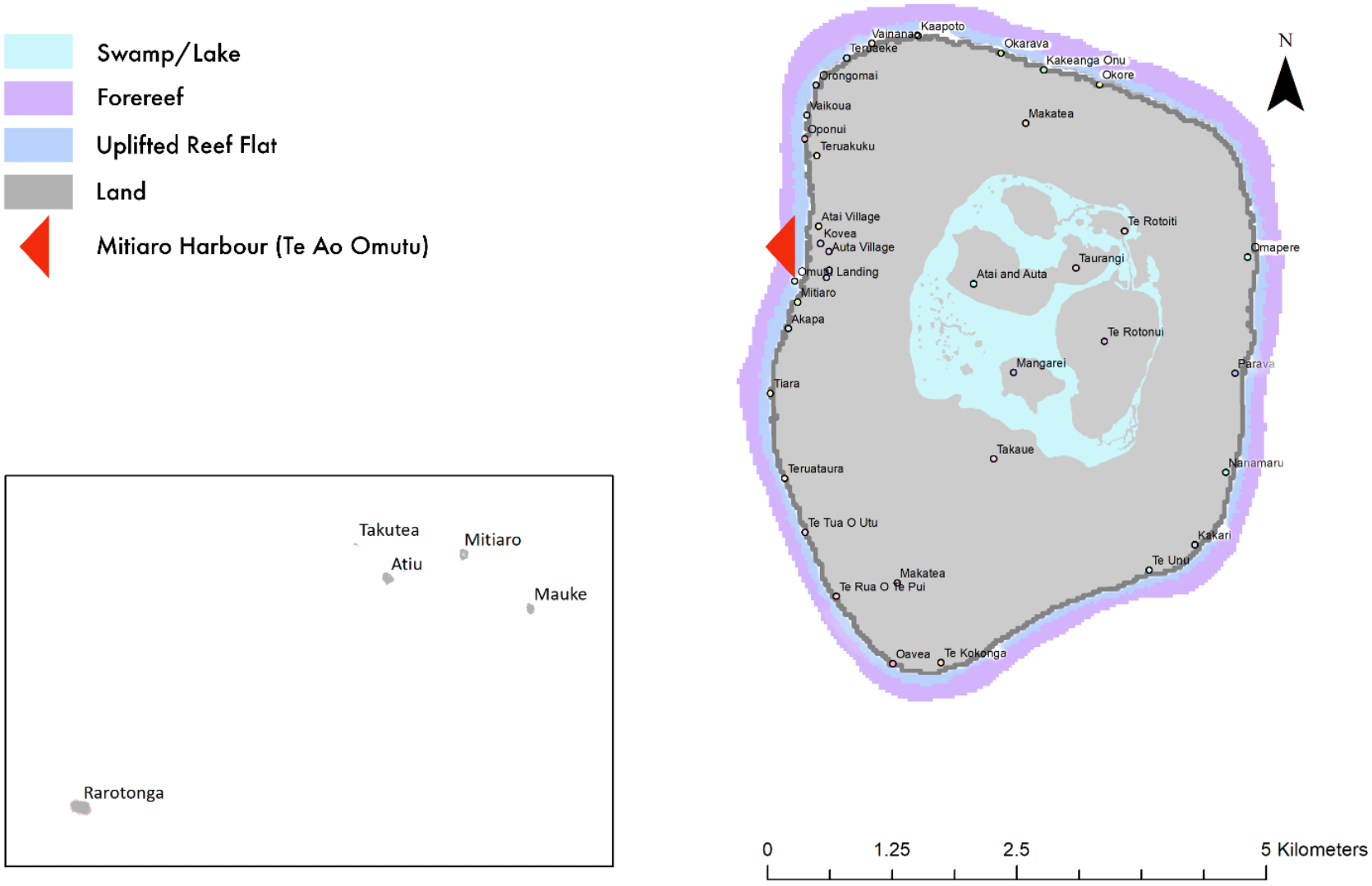

Figure 1. Map of Mitiaro, Cook Islands.

3.3.3 Age, growth, and reproductive parameters

For age estimations, sagittal otoliths pairs were removed from each individual and cleaned with ethanol. One of each sagitta pair of otoliths was randomly selected and weighed to the nearest 0.0001g using an electronic scale. The weighed otoliths were ground down with a 3000-grit wet diamond disc on the rostral and distal sides of the otolith to obtain thin traverse sections. The sections were then mounted and coated with Crystal Bond for clear examination of annual increments indicated by opaque zones of calcification. The opaque bands in the sagittae are presumed to be annual increments (Choat & Axe, 1996; E. L. Trip et al., 2008b). All annual increments were initially read by a single observer (A. Vavia) using a compound microscope and camera with transmitted light to estimate age. Randomly selected otoliths were read twice by the first observer and thrice by a second observer (A. Sabetian). Where there were reading differences, a mean reading was accepted between both observers as the estimated age. Sagittal weight and age analyses were undertaken by conducting a least squares regression to determine the relationship between sagittal weight and annual opaque band increments (age).

Length and weight distributions were modelled for *C. striatus* and *A. achilles* using the power function $W = a*L^b$ (Ricker, 1973), where W is the total weight (g), L is the fork length (mm), exponent *a* is the initial growth coefficient (y-intercept) and exponent *b* is the growth coefficient. Length-weight relationships (LWR) were evaluated separated by sex as well as a pooled overall population as described in Froese et al. (2011). Each sample was measured (FL) to the nearest mm and weighed to the nearest 0.1g. Whole samples were used for these analyses. Analysis of covariance (ANCOVA) was used to determine whether there was variation in LWR between sexes in each species.

Length and age distributions across sexes of both species were plotted. Length distribution analyses across a temporal scale are useful tools for detecting changes for a given population that can assist in predicting impacts to size and distribution. Mortality rates were also estimated for *C. striatus* and *A. achilles* from log-linear regression analyses on their age-frequency data. This was done by plotting the natural log of the number of fish within each age class against their corresponding age class. Fish younger that was not recruited based on mortality rates were excluded from the analysis.

The size and age relationship were modelled for *C. striatus* and *A. achilles* using the standard von Bertalanffy growth function (vBGF). The standard vBGF function is described as:

$$L_t = L\infty \{1\text{-}\exp [-k (t - t_0)]\}$$

L_t is the estimated length at age t, $L\infty$ is the mean asymptotic length, K is the growth coefficient describing curvature at which L reaches asymptote, t is the age of the fish in years and t_0 is the theoretical age at length zero. A lack of very small individuals was sampled which

can cause misleading estimates of the growth parameters such as underestimating early lifespan growth rates. Taking this into consideration, settlement size (t_0) of 47 mm (FL) (Ochavillo et al., 2011; Stobutzki & Bellwood, 1997) was used to constrain the model to estimate the best fit VBGF. The growth function was fitted to the total of 269 samples by minimising the sum of squared residuals between expected and observed size-at-age to model the growth of *C. striatus* (n = 138) and *A. achilles* (n = 131) (also see (Sabetian et al., 2015; Trip, Clements, et al., 2014). This was to determine the relationship between size and age across male and female populations of each species, and overall samples which included no sexual morphological distinction. The T_0 parameters between sexes were averaged and constrained to generate 95% confidence ellipses using the K and $L\infty$ parameter estimates to compare growth curves between sexes within species (Kimura, 1980).

The re-parameterised vBGF (rvBGF) was also fitted to the data (Francis, 1988). Unlike the standard vBGF, the re-parameterised function allows us to estimate expected mean size at three arbitrary ages referred to as tau, omega, and nu. Tau and nu are arbitrary age values based on the age of initial growth and asymptotic size respectively, and omega is the mean age value of tau and nu. Ages for tau and nu were 1 and 5 (L_1 and L_5), with omega being 3 (L_3) years of age to represent the datasets to cover the lifespans of *C. striatus* and *A. achilles*. Both functions are used in this study as rvBGF is well suited for describing growth, but the standard vBGF parameters are more universally utilised in age and growth analyses.

Likelihood ratio tests (LRT) was used to compare growth parameters between males and females of *C. striatus* and *A. achilles* (Kimura, 1980). The null hypothesis of no difference in growth between sexes is rejected at alpha = 0.05, with degrees of freedom (q) being the number of constrained parameters (3 constraints for coincident curves). Monthly average condition factor values were obtained using Fulton's K:

$$K = 100 * M/L^3$$

Where K is condition factor, body mass is M, and L is length.

To determine maturity estimates, conspicuous gonads were collected from the ventroposterior region of the body cavity and fixed in buffered formalin. All gonadal-area tissues were weighed to the nearest 0.001g of each specimen. Where the gonads appeared inconspicuous, tissues from the gonadal area were also extracted and fixed in case gonadal tissue was present but not visually obvious. It is important to note that measurements of gonad weight in some cases were estimated with gonadal tissue which in most cases were too light for the scale to detect weight. Samples were later identified after histological analysis and classified as male, female or unknown. For histology protocol, fixed gonadal tissues (in 10% buffered formalin) were cut and placed into cassettes for tissue processing. Embedded paraffin waxed samples were finely sectioned by microtomy and stained using Harris' haemotoxylin and eosin

and sealed with DPX medium and cover slips to be read under a compound microscope. Gonadal sex and stage classification (developmental stages of sperm and oocytes) was done for 139 individuals of *C. striatus* and 130 individuals of *A. achilles* following criteria from (Longenecker et al., 2018). In doing so, gonadal stages were based on the latest stage of development present, in which all identified specimens exhibited mature indications. General indications of histological transverse sections of male and female gonads are provided in Figure 2 and Figure 3. Spawning seasonality was estimated by investigating the relative gonad mass (wet weight) to body mass (wet weight) of male and female populations using a GSI (gonadosomatic index) for both species using the equation:

GSI = gonad weight / total body weight * 100

The mean GSI for each month was calculated and plotted. This provided an indication of the level of development of oocytes within the proximity of spawning events.

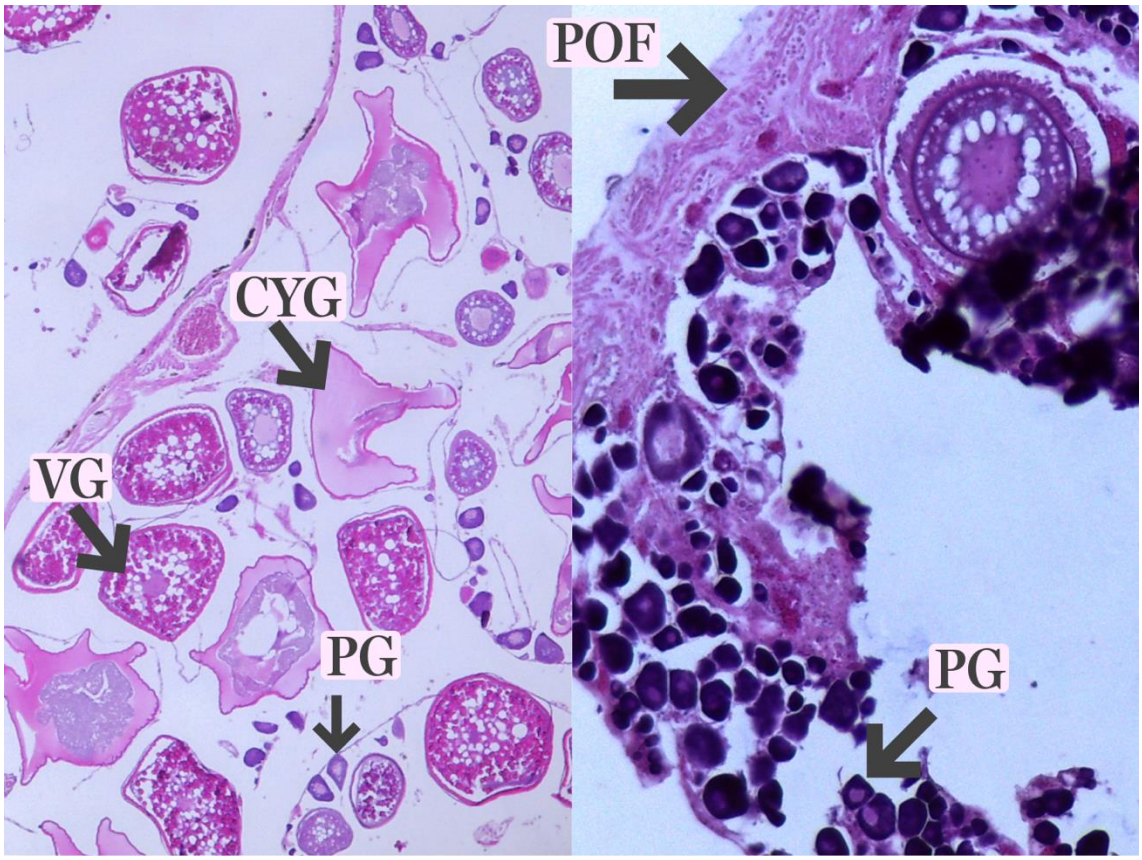

Figure 2. Histological transverse sections of female gonads of Acanthurus achilles (left) and Ctenochaetus striatus (right). Pre-vitellogenic primary growth (PG) cells are present shown by the dark cytoplasm and centred nucleus. Vitellogenic globules (VG) are also present in early (nucleus visible) and late stages (nucleus invisible). Signs of post-spawning maturity are indicated by hydration stages with coalesced yolk globules (CYG) or coalesced vitellin. Post-ovulatory follicles (POF) are collapsed follicular cells after ovulating the formerly contained oocyte indicating recent spawning.

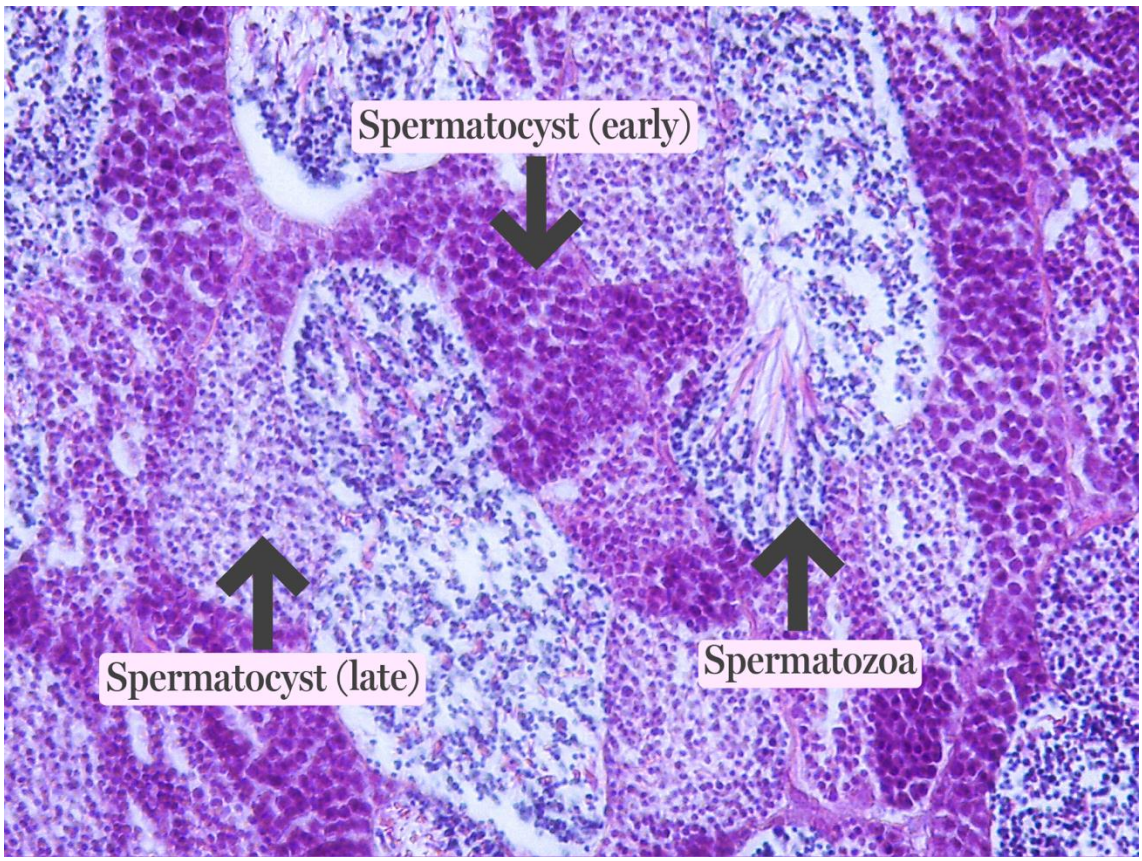

Figure 3. Histological transverse sections of mature Ctenochaetus striatus male gonads. This mature teste contains multiple structures that are also contained in immature samples (absence of spermatozoa) including the spermatocysts. Early spermatocytes divide and progressively become smaller (late). Spermatozoa-filled lumen are indicated are evidenced by the presence of flagella, which is the criterion for mature classification.

3.4 Results

Analyses for both *C. striatus* and *A. achilles* included all individuals (*C. striatus*: n = 138; *A. achilles*: n = 131) undifferentiated by sex (where sexual identification was not possible). Results partitioned by sex are also presented (*C. striatus*: n = 96; *A. achilles*: n = 85).

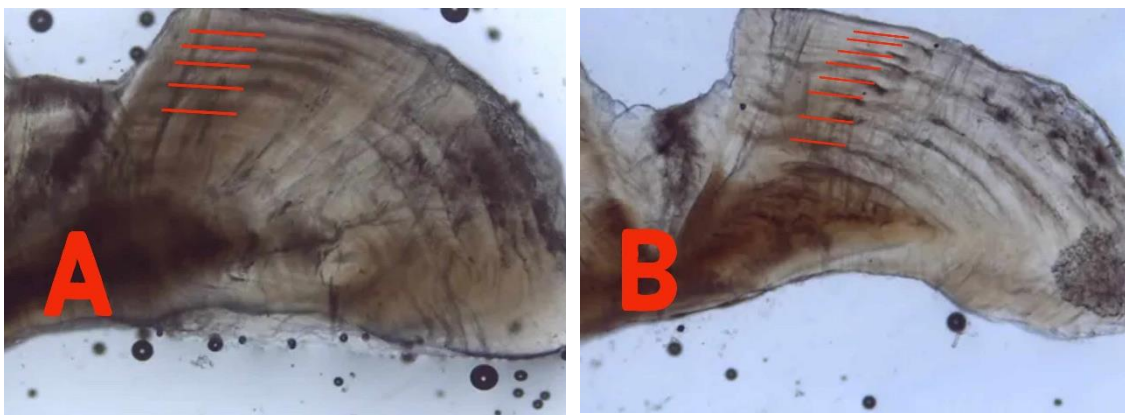

Figure 4. Sectioned sagittal otoliths. Accumulation of material around a core create opaque annual bands (highlighted by red lines) display the incremental growth (A = Ctenochaetus striatus, B = Acanthurus achilles).

3.4.1 Sagittal otoliths

The examined sectioned sagittal otoliths of *C. striatus* displayed regular growth increments expressed by opaque bands within the otolith matrix like descriptions according to Choat and Axe (1996). However, *A. achilles* displayed generally deeper sulcal grooves than *C. striatus*. The sulcal grooves and alternating opaque bands within the otolith matrices can is displayed in Figure 4. A regression portrayed a strong positive linear relationship between sagittal weight and age in both species indicated by moderately high R^2 values which is typical of acanthurid growth (Choat & Axe, 1996; Trip et al., 2014) (Figure 5). The regression of *C. striatus* comparatively shows a lower R^2 value which may be due to the heavier concentration of younger samples resulting in an age-bias and creating variability. However, the noticeable lack of late teens and early 20s specimens will have skewed the R^2 value, with the two oldest outliers estimated to be 27 years old. By contrast, the oldest individuals within the *A. achilles* population are estimated to be 9 years old.

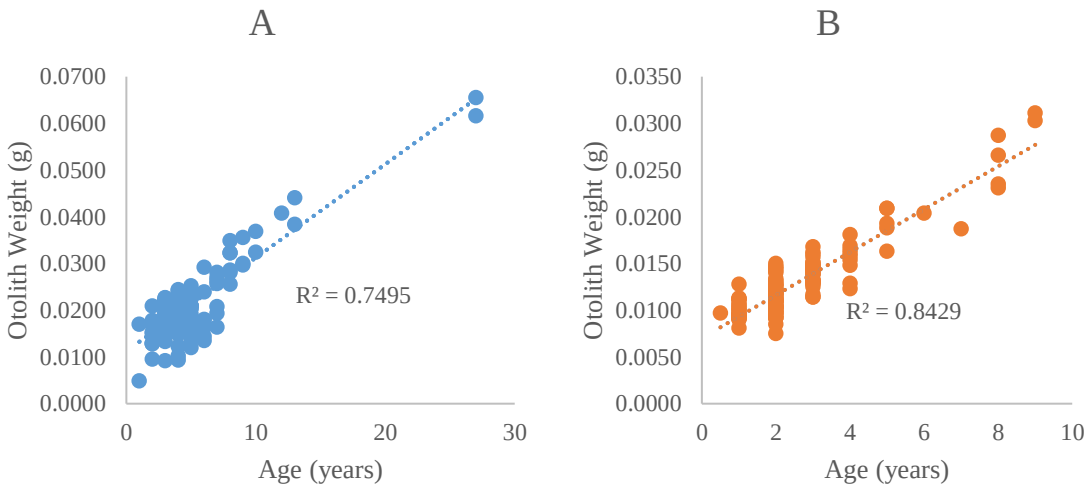

Figure 5. Sagittal otolith weight-age least squares regressions of (A) Ctenochaetus striatus: Y = 0.002x + 0.0113, n = 138; (B) Acanthurus achilles: Y = 0.0023x + 0.007, n = 131.

3.4.2 Length-weight relationship

The length-weight distributions in this study follow the criteria noted in Kamikawa et al. (2015) which include minimum sample size of 50, R^2 value above 0.8, and data covering more than 30% of the full-length range. ANCOVA did not detect any significant differences in LWR between males and females for *C. striatus* (F = 1.8, DF = 1, P = 0.18) and *A. achilles* (F = 1.28, DF = 1, P = 0.26). *C. striatus* and *A. achilles* exhibited strong length-weight relationships (Figure 6). Across both sexes and the overall populations, total body weight (W) for both

acanthurids roughly displayed a cubic function of length (FL) - *C. striatus* (b = 2.8016 – 2.8838); *A. achilles* (b = 2.9652 – 3.0869).

The condition factor (K) is displayed over time showing relatively stable fluctuations between 2.4-2.9 for *C. striatus* (Figure 7). The K value also has a stable range for *A. achilles* ranging between 2.8-3.3 (Figure 8). Some months display a lack of data due to in-situ sampling limitations. The stable characteristics of the condition factors for both species resemble the expectations for species with isometric growth as shown by the LWRs.

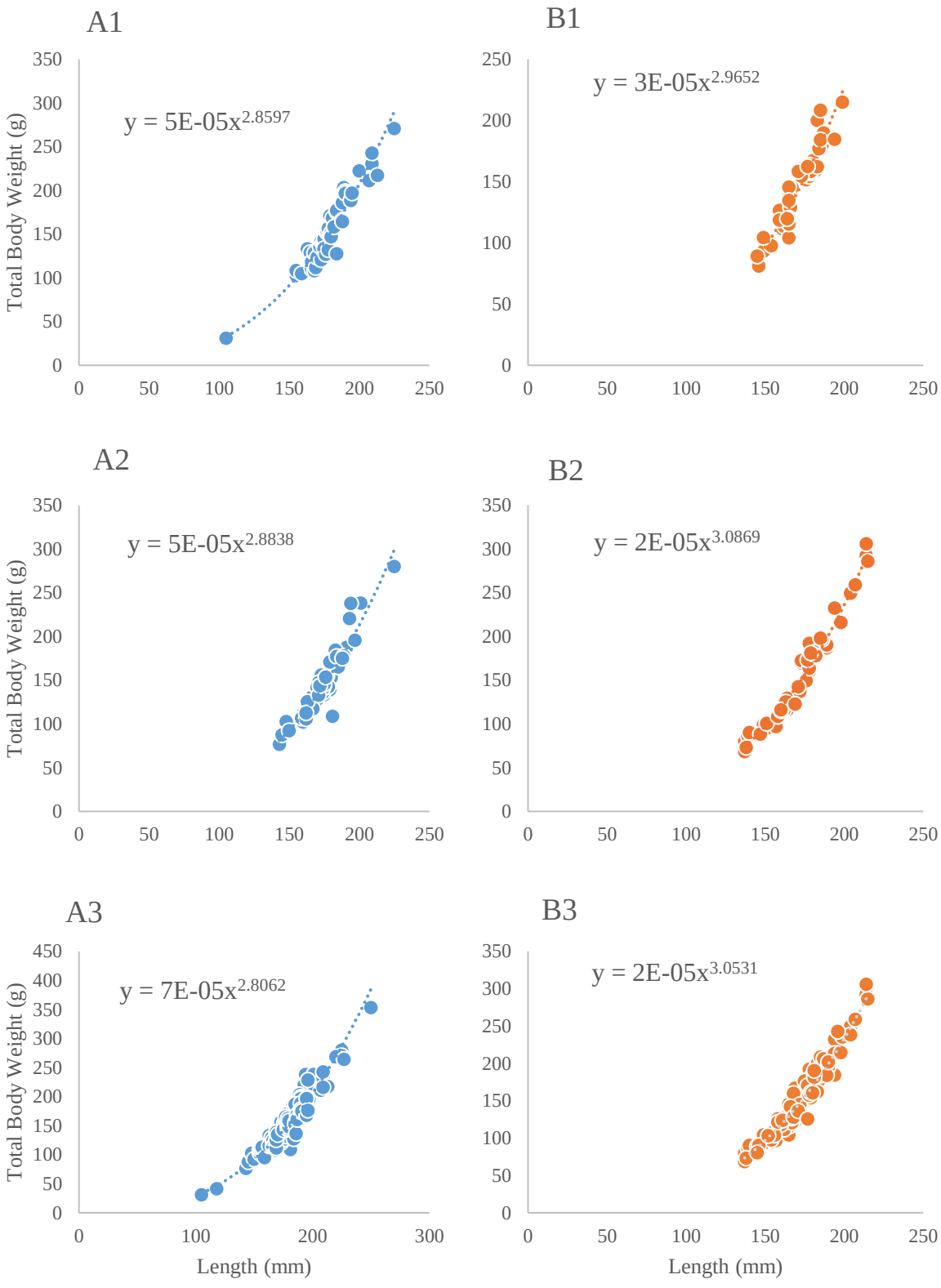

Figure 6. Weight- at-length distribution for Mitiaro populations of Ctenochaetus striatus (A) and Acanthurus achilles (B). 1) Male population; 2) female population; 3) total population (including unidentified sexes). The fitted regression lines are power curves for each species.

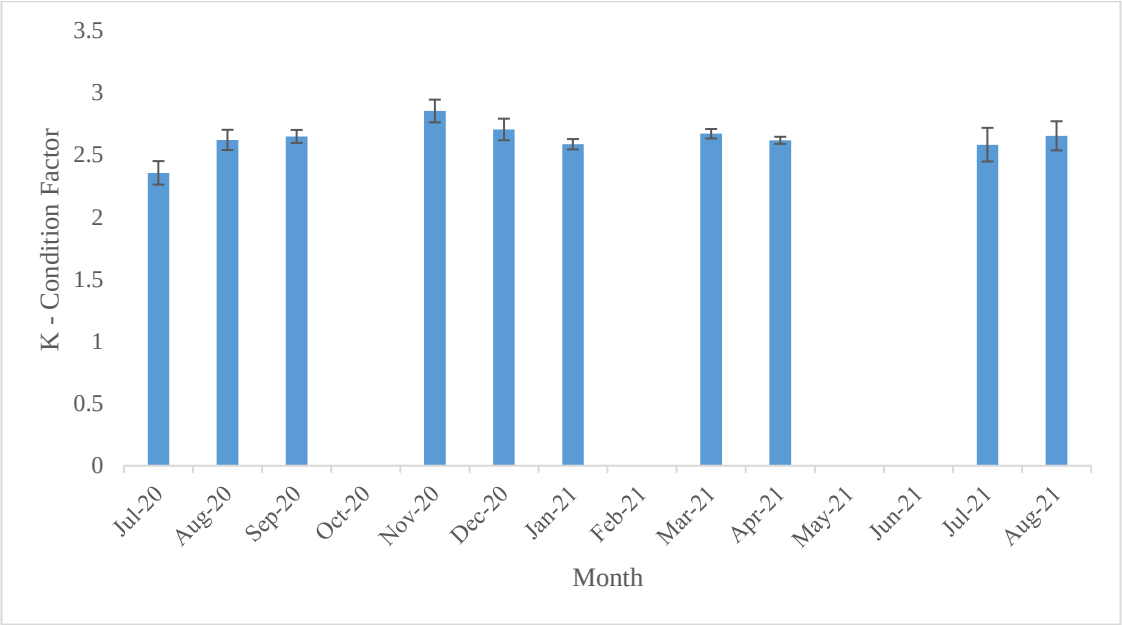

Figure 7. Mean monthly Fulton's Condition Factor (K) values for Mitiaro Ctenochaetus striatus populations on Mitiaro (Cook Islands). Overall mean and standard error (2.63 ± 0.08)

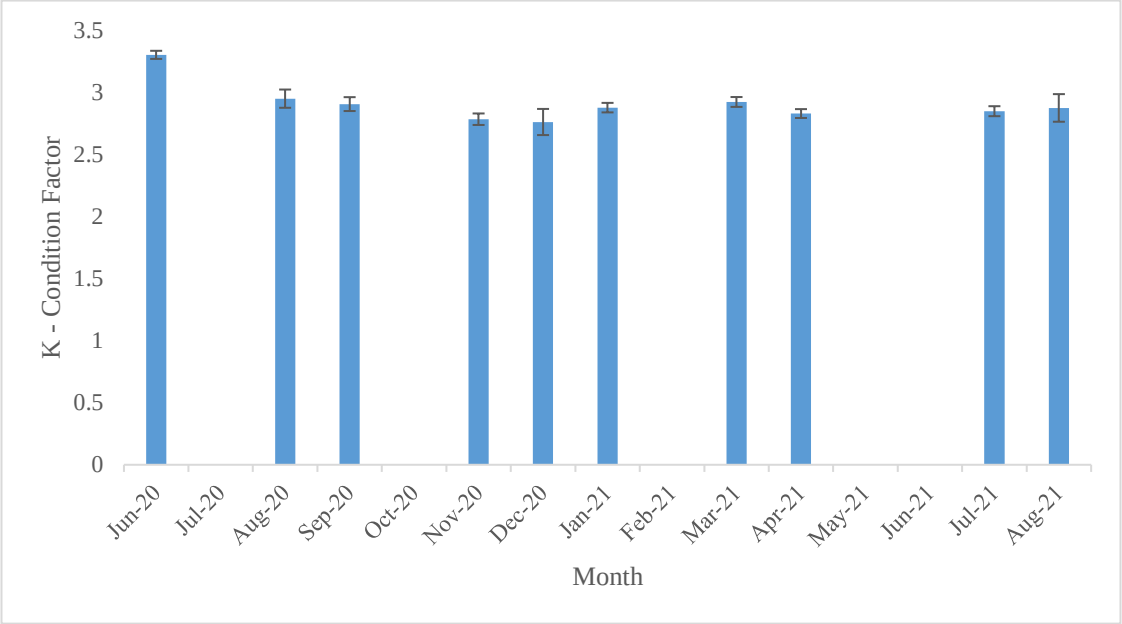

Figure 8. Mean monthly Fulton's Condition Factor (K) for Mitiaro Acanthurus achilles populations on Mitiaro (Cook Islands). Overall mean and standard error (2.90 ± 0.06).

Table 1. Demographic information on male and female populations of Ctenochaetus striatus and Acanthurus achilles within Mitiaro. Sample size, size range (FL, mm), standard VBGF and reparameterised VBGF (rVBGF) are presented here, displaying sex-specific and overall populations. Overall populations include samples of individuals with unidentified sexes. Longevity Estimates: the mean age of the oldest 10% within each population was used to estimate mean Tmax (mean maximum age) as done in Trip et al. (2008).

Species	**n**	**Size range**	**VBGF parameters**			**rVBGF parameters**		**Longevity**	
		(FL, mm)	**L∞**	**K**	**T_0**	**L1**	**L5**	**Mean T_{max}**	**Max Age**
C. striatus (m)	50	105-225	186.44	0.87	-0.33	128.28	184.67	12.6	27
C. striatus (f)	46	143-225	177.17	1.15	-0.26	136.35	176.77	10.75	13
Total C. striatus	138	105-250	185.18	0.87	-0.33	127.48	183.43	12.53	27
A. achilles (m)	40	145-199	177.32	1.56	-0.19	150.21	177.20	5.75	8
A. achilles (f)	45	137-215	191.24	1.04	-0.27	140.26	190.44	7.75	8
Total A. achilles	131	137-215	183.11	1.26	-0.23	144.85	182.87	6.76	9

3.4.3 Growth

The demographic summaries displaying the vBGF and rvBGF parameters of both species distinguished by sex and overall population (including unidentified sex) is provided in Table 1. The maximum recorded sizes for both sexes of *C. striatus* were 225 mm, while minimum recorded sizes for male and female was 105mm and 143mm respectively. Females of *A. achilles* reached a larger maximum size (137-215 mm) than males (145-199 mm). Size-at-age plots of all populations revealed rapid initial growth in the first few years and plateauing as age increased, which is a typical characteristic in acanthurid growth (Trip et al., 2008; Choat & Axe, 1996), and displayed consistent asymptotic growth patterns, all reaching asymptotic sizes within the first 3 years (Figure 9 - Figure 12). The growth trajectories differed slightly between male and female populations of either species. There is a noticeable age gap in the *C. striatus* populations showing a lack of mid-range ages. However, it can be assumed that both sexes display similar rapid growth patterns in the early life stages, even though they achieve different asymptotic lengths; with males reaching larger sizes. Conversely, the age distribution of samples partitioned by sex is more balanced in *A. achilles*, where females achieve higher asymptotic sizes over their male counterparts. Comparing the growth curves of both species shows that the populations with sharper, more rapid initial growth results in shorter asymptotic sizes. By constraining lengths at the average T_0 between male and female populations, 95% confidence regions were generated for growth coefficient K and L∞, mean asymptotic length. Comparing the 95% confidence ellipses between males and females indicated that there were no significant differences within the respective *C. striatus* and *A. achilles* populations (Figure 13 and Figure 14) shown by the overlapping K and L∞.

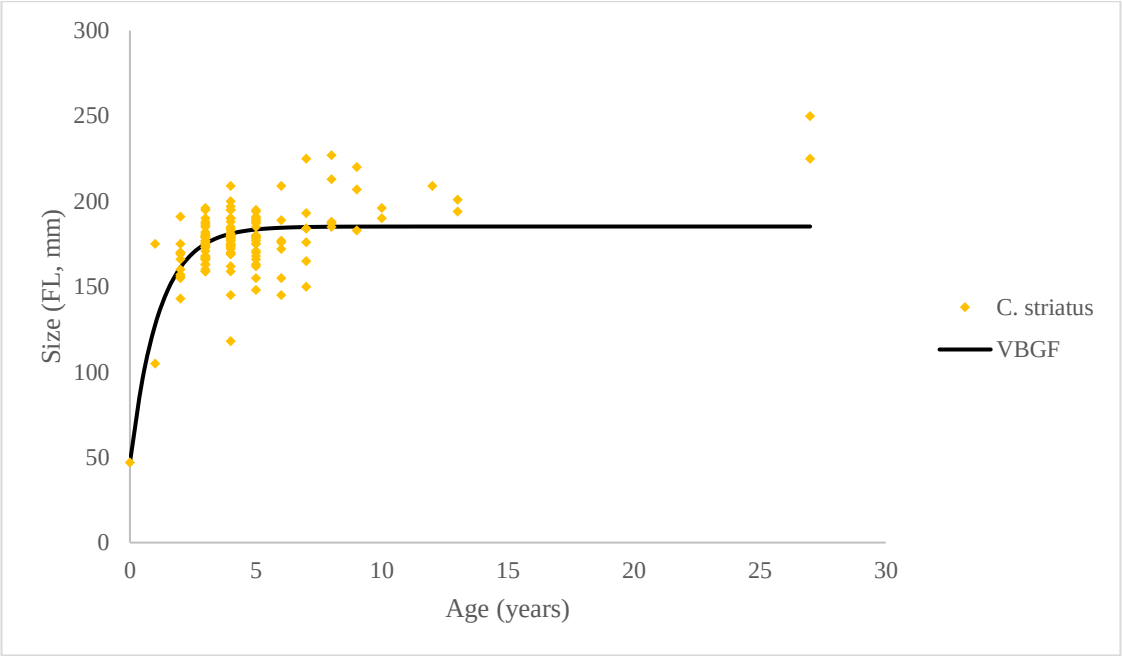

Figure 9. Growth of overall population (including unidentified sex) of Ctenochaetus striatus in Mitiaro (Cook Islands). Size-at-age of individuals (points) is shown with best-fit vBGF (n = 138, K = 0.87, L∞ = 185.18, T_0 = -0.3).

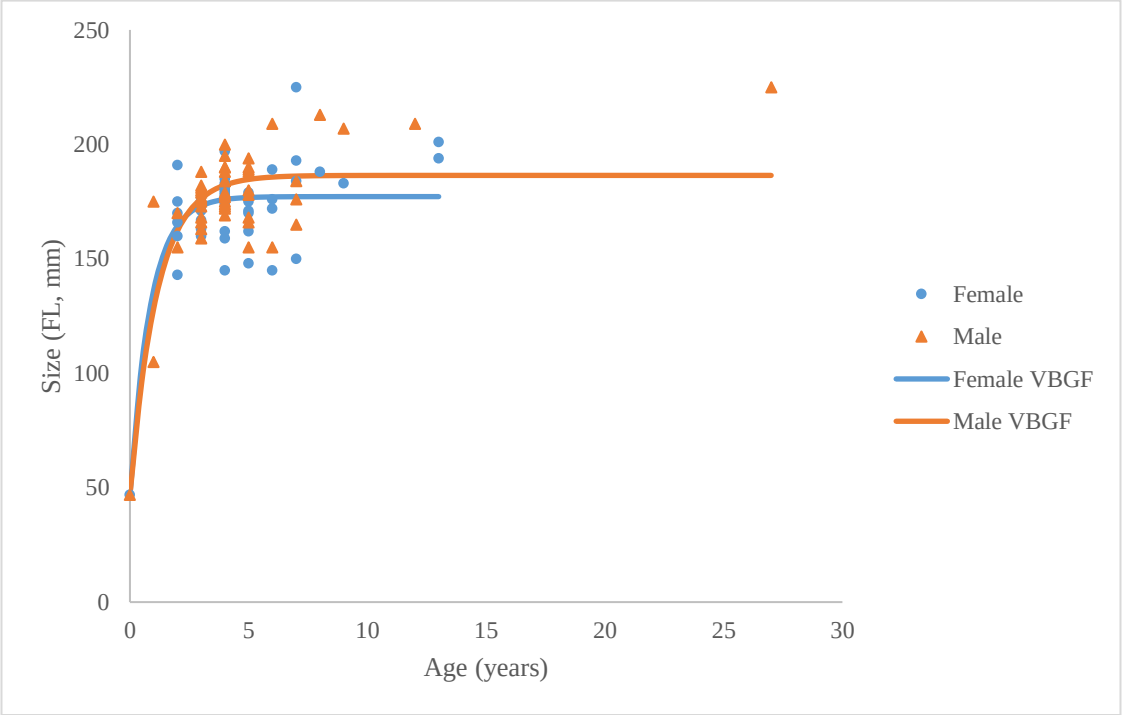

Figure 10. Growth of Ctenochaetus striatus in Mitiaro partitioned by sex. Sex-specific size-at-age of female individuals (circles) and males (triangles) is shown with best-fit vBGF for each sex, and both sexes (dotted). Female vBGF (n = 46, K = 1.15, L∞ = 177.17, T_0 = -0.26). Male vBGF (n = 50, K = 0.87, L∞ = 186.44, T_0 = -0.33).

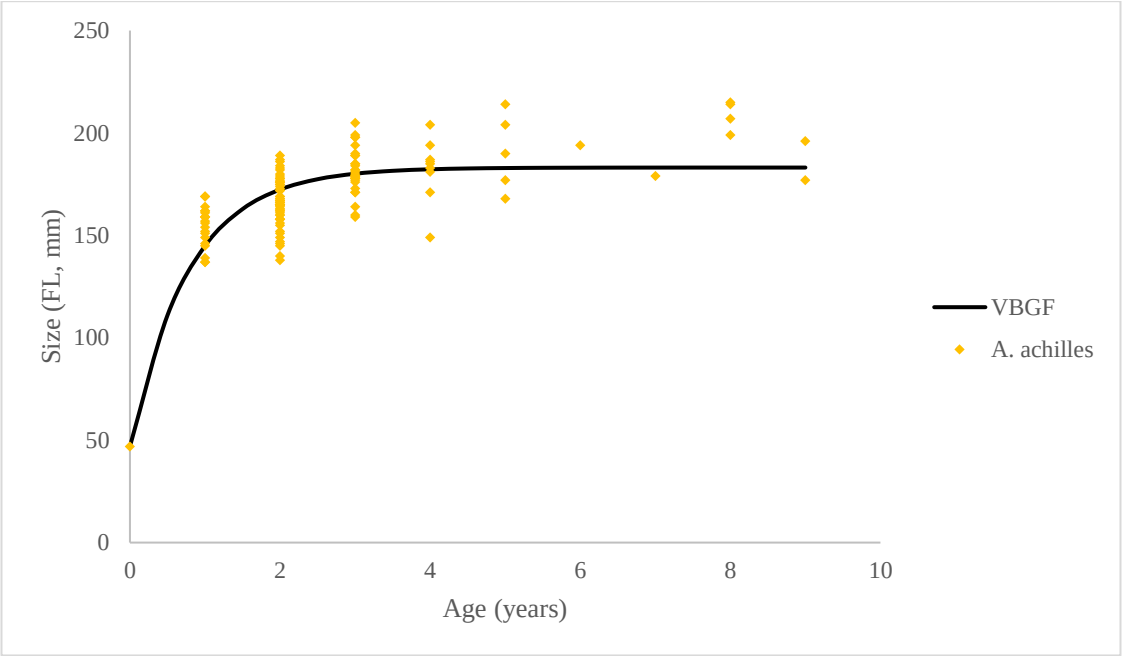

Figure 11. Growth of overall population (including unidentified sex) of Acanthurus achilles in Mitiaro (Cook Islands). Size-at-age of individuals (points) is shown with best-fit vBGF (n = 131, K = 1.26, $L\infty$ = 183.11, T_0 = -0.2).

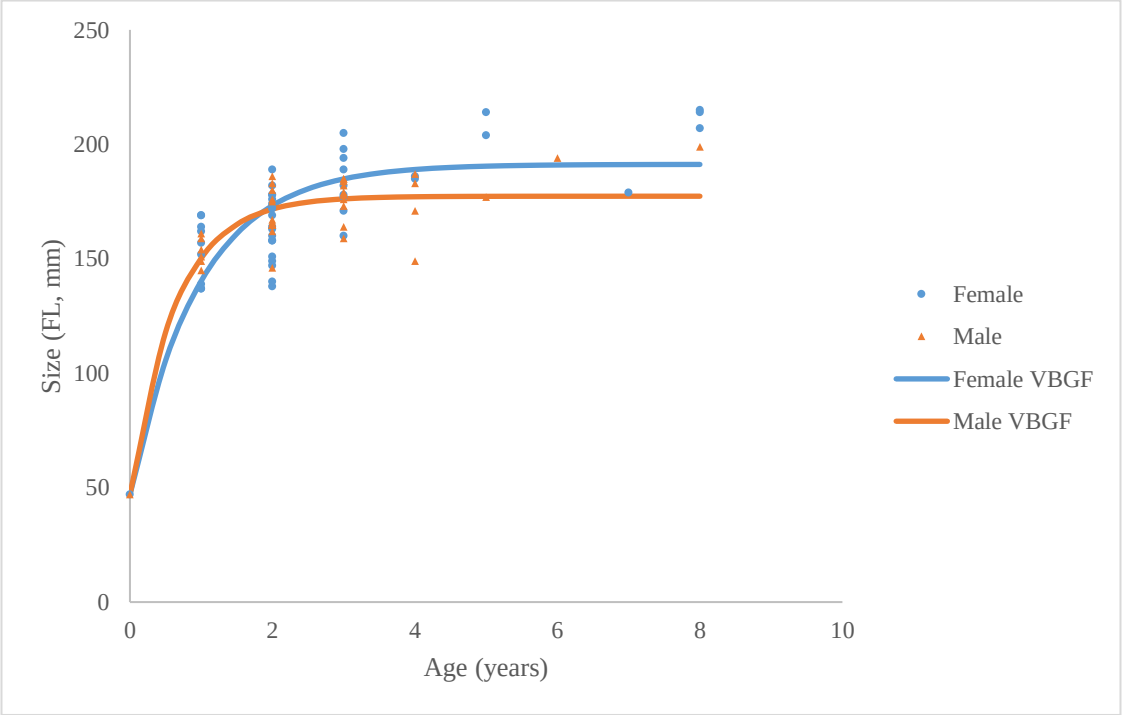

Figure 12. Growth of Acanthurus achilles in Mitiaro partitioned by sex. Sex-specific size-at-age of female individuals (circles) and males (triangles) is shown with best-fit vBGF for each sex, and both sexes (dotted). Female vBGF (n = 45, K = 1.04, $L\infty$ = 191.24, T_0 = -0.27). Male vBGF (n = 40, K = 1.56, $L\infty$ = 177.32, T_0 = -0.19).

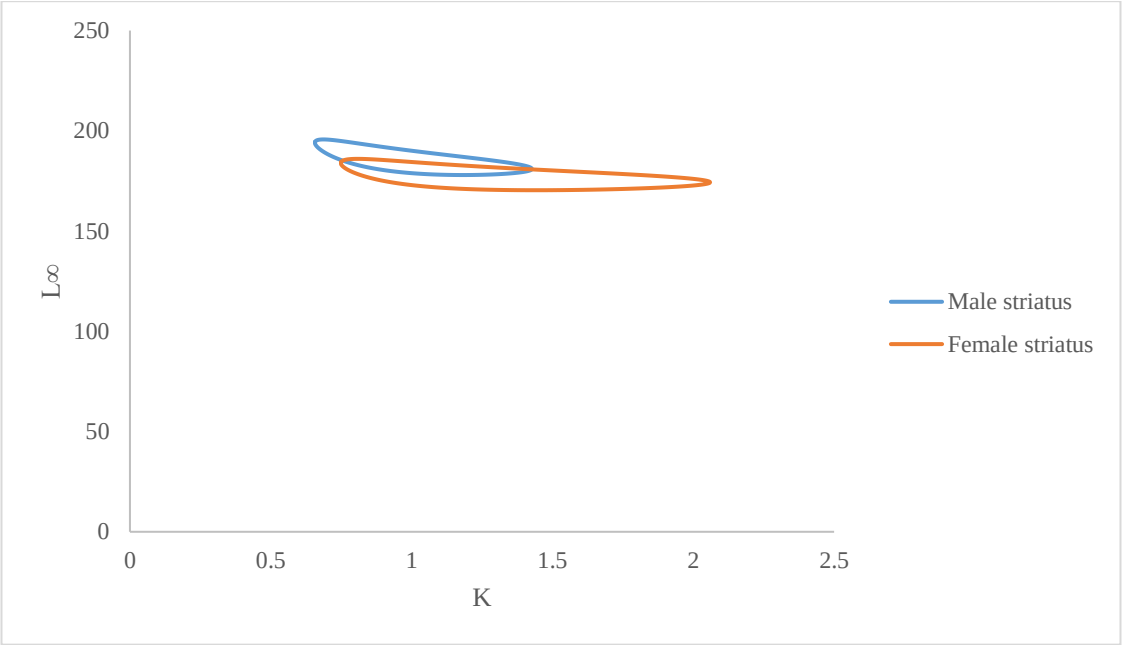

Figure 13. vBGF comparison across male and female populations of Ctenochaetus striatus with 95% confidence ellipses around the least square estimates of L∞ and K. t0 was constrained to -0.299 for both populations.

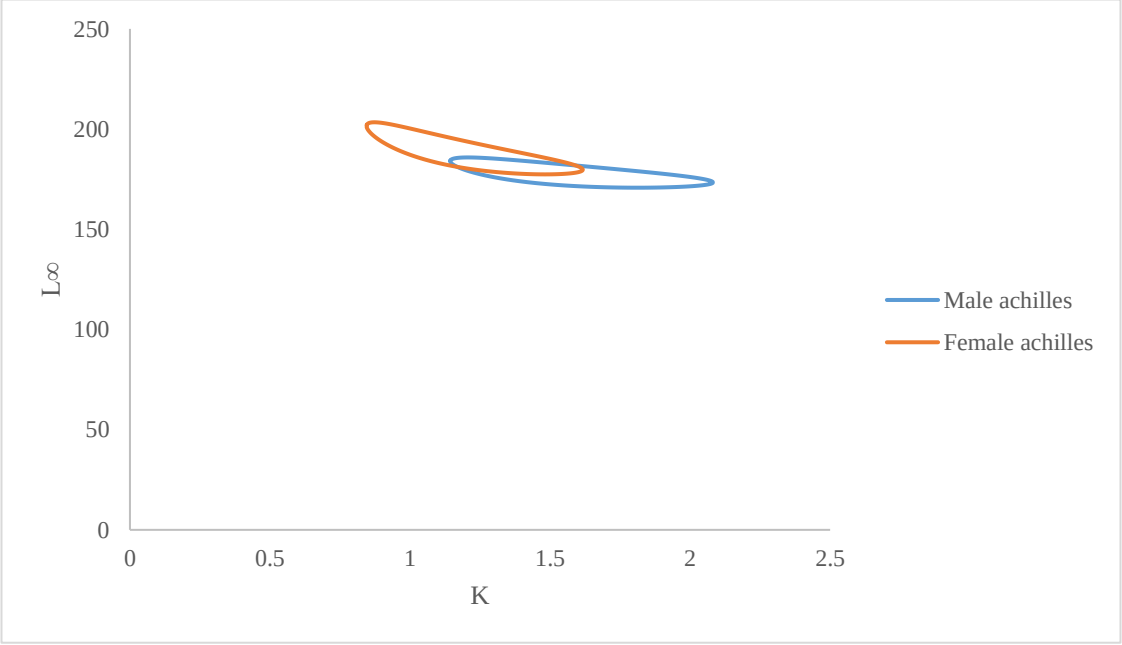

Figure 14. vBGF comparison across male and female populations of Acanthurus achilles with 95% confidence ellipses around the least square estimates of L∞ and K. t0 was constrained to -0.233 for both populations.

3.4.4 Gonadosomatic Index

Spawning seasonality obtained from the GSI (gonadosomatic index) indicated peaks of mean gonadal weight during the last third of the year from September with a gradual decline towards December for both *C. striatus* (Figure 15) and *A. achilles* (Figure 16). The GSI plots provided here do not account for sexual differentiation as it is assumed that spawning periodicity is synonymous between sexes. The lack of samples in certain months are due to two factors; lack of donated fish by local fishers and also lack of discernible gonadal tissue.

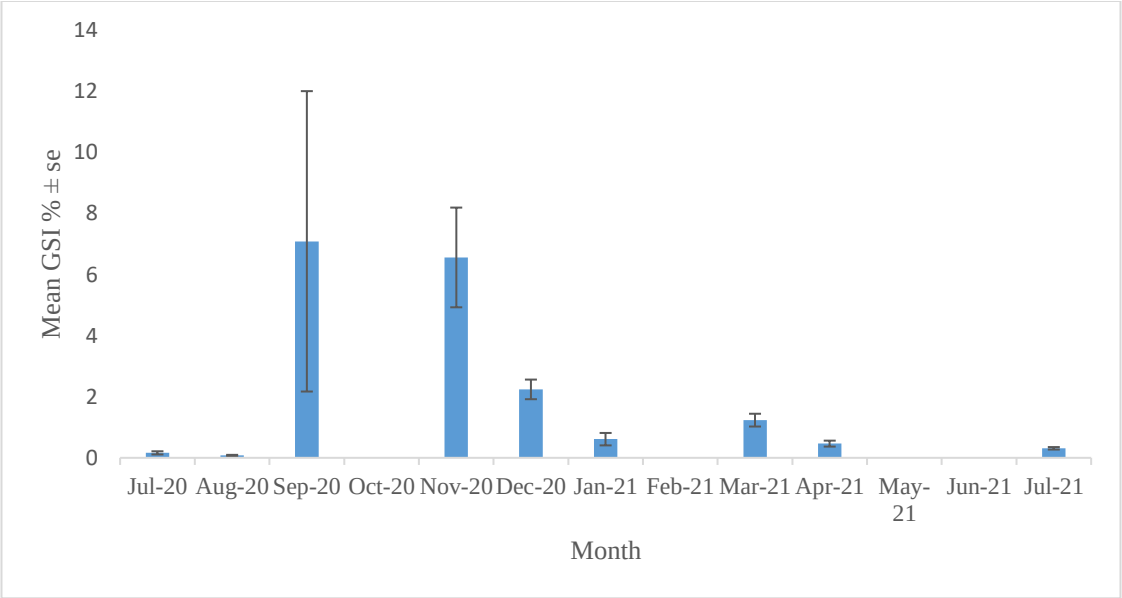

Figure 15. Mean monthly gonadosomatic index (GSI) for Mitiaro population of Ctenochaetus striatus.

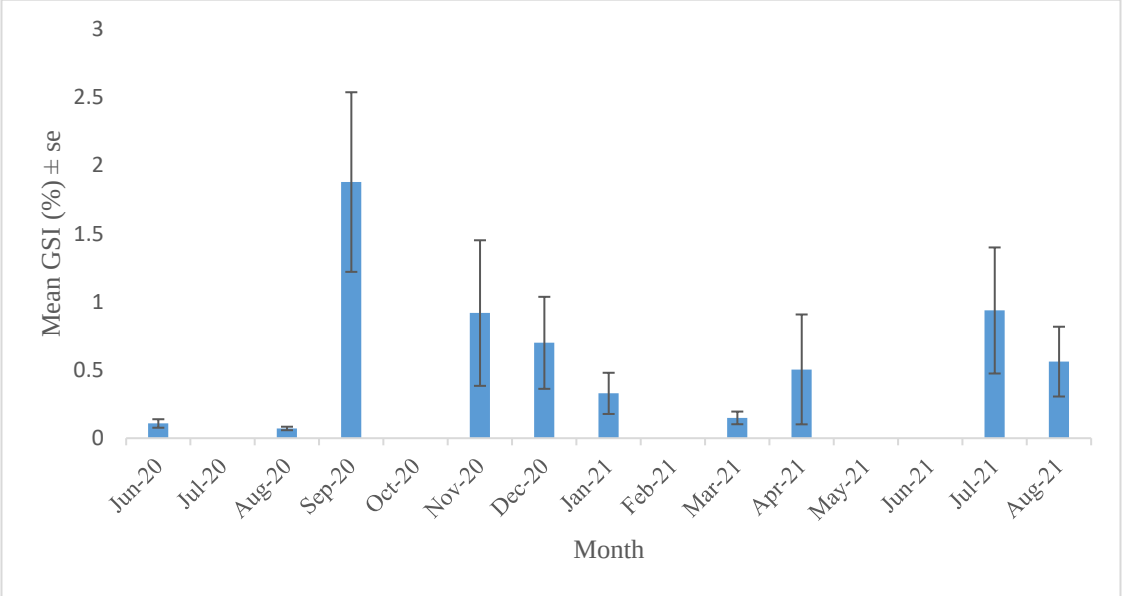

Figure 16. Mean monthly gonadosomatic index (GSI) for Mitiaro populations of Acanthurus achilles.

3.4.5 Length and age distributions

Considering the sampling procedure having an innate size bias, the mode age and length class for *C. striatus* was 4 years and 175-184 mm for both sexes (Figure 17). Maximum longevity ranged from 13 years (female) to 27 years (male) for *C. striatus* population. Both sexes also reached the maximum length class 225-234 mm. On the other hand, *A. achilles* had a mode age of 2 years and had bimodal length classes of 157-166 mm and 177-186 mm for both sexes. Frequency of females were more abundant in upper length classes reaching a maximum age class of 207-216 mm, while males reached 197-206 mm. Both sexes of *A. achilles* displayed a maximum longevity of 8 years. However, looking at the overall populations, *A. achilles* had two individuals of unidentified sex reaching a maximum longevity of 9 years (Figure 18). Furthermore, an individual of unidentified sex within the *C. striatus* population reached a maximum size class of 245-254 mm.

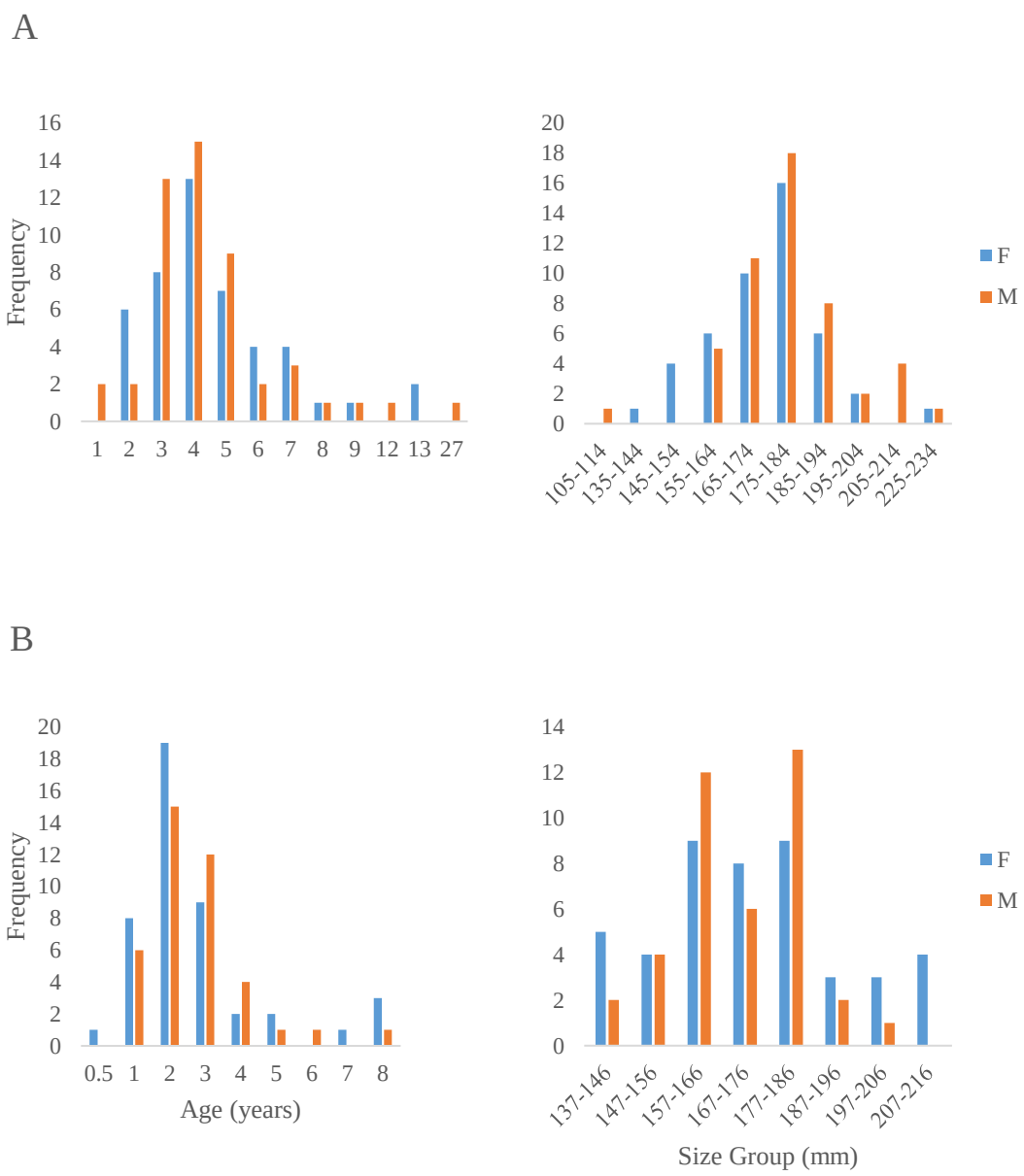

Figure 17. Length and age frequency distributions of Ctenochaetus striatus and Acanthurus achilles distinguished by sex. C. striatus (A): male (n = 50) and female (n = 46). A. achilles (B): male (n = 40) and female (n = 45).

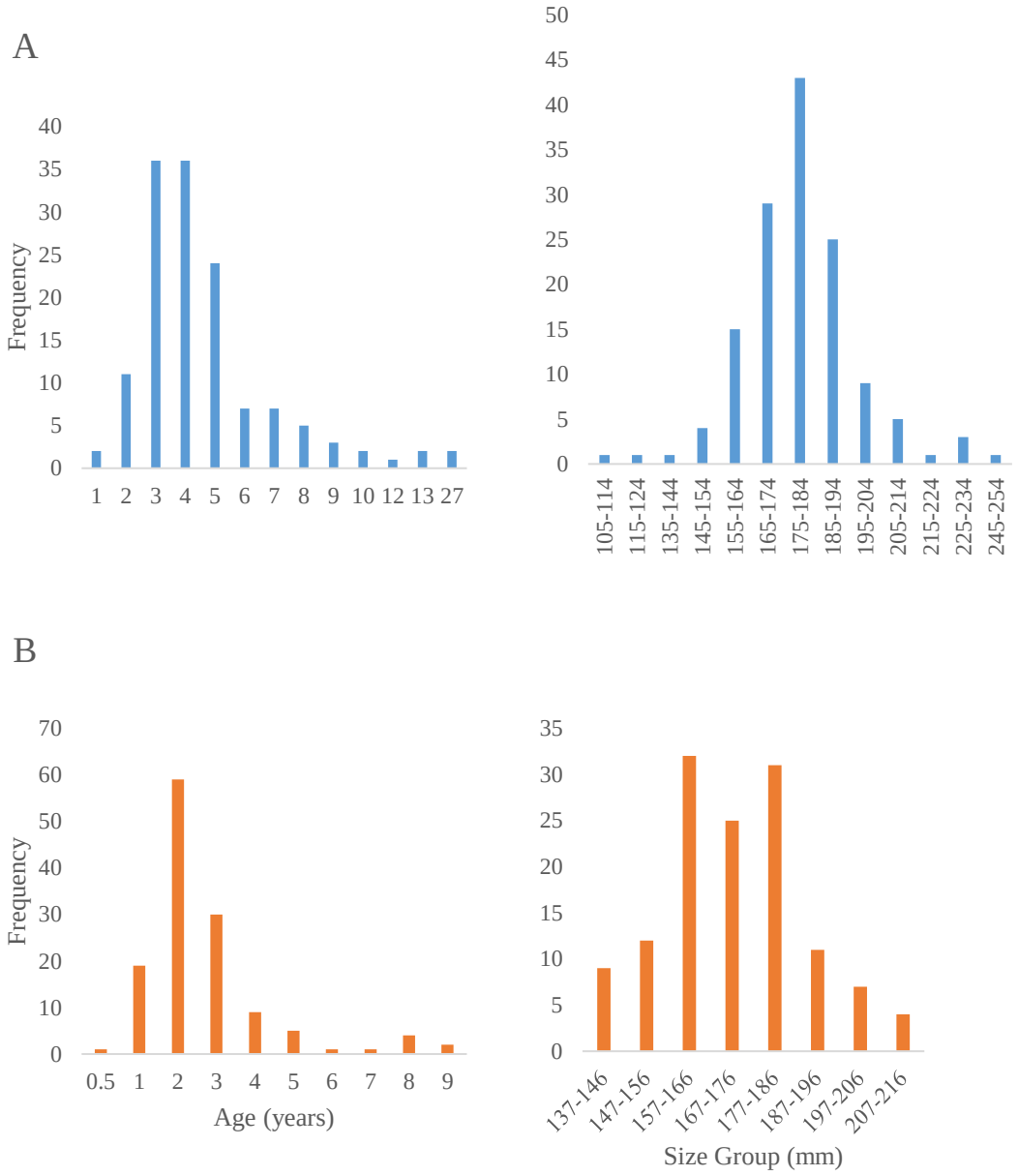

Figure 18. Length and age frequency distributions of the overall populations for C striatus (A) and A. achilles (B) including unidentified sex specimens.

3.4.6 Mortality

The age frequency distribution was used to obtain mortality estimates from a regression of age-based catch curves. The catch curves show *C. striatus* and *A. achilles* having very similar rates of mortality (Figure 19). Individuals of *C. striatus* and *A. achilles* younger than three and two years respectively were removed from the analysis as they were considered not fully recruited based on the age-frequency distribution.

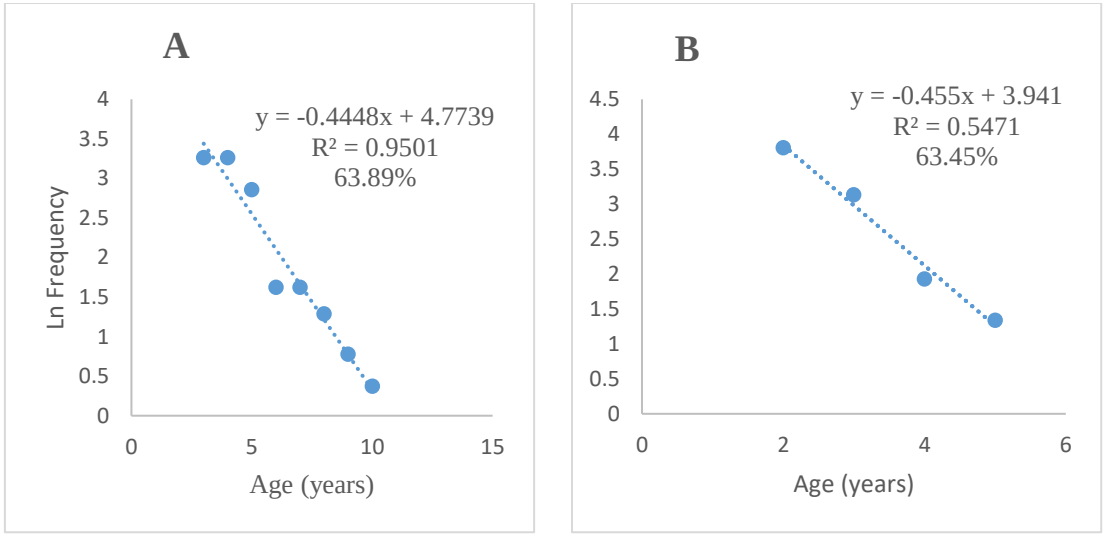

Figure 19. Catch curve and estimated mortality for Ctenochaetus striatus and Acanthurus achilles populations in Mitiaro. Estimates of mortality per year are: C. striatus, 0.35; A. achilles, 0.34.

3.5 Discussion

Information on age-based demography of important coral reef fish species provide valuable insight for environmental and fisheries management. On a global scale acanthurids are often highly exploited within artisanal and subsistence fisheries (Craig et al., 2008; Craig et al., 1997; Ford et al., 2016; Nañola et al., 2011; Rhodes et al., 2008; Tebbett et al., 2022), some of which are considered the most commercially valuable in the insular Pacific (B. M. Taylor, 2019). In Mitiaro, acanthurids are a popular choice for the local subsistence-based fishery.

The baseline results in this chapter provide a practical contribution to the limited knowledge-base on the population dynamics of important Cook Islands coral reef fishes. This study highlighted two specific life-history parameter traits for *C. striatus* and *A. achilles* on Mitiaro that are consistent with the literature on acanthurids: early rapid growth and sexual maturation. In the context of Mitiaro Island's reef fisheries, life-history parameters are critical to determine productivity and fisheries impacts and estimating sustainable fishing yields (Ault et al., 2008; Gough et al., 2020). These findings of rapid growth provide a critical step towards assessing whether population turnover is occurring at sustainable rates in response to local subsistence fisheries efforts or wider environmental variables. Between 2020 and 2021, acanthurids accounted for the second highest catch (22%) of the entire coral reef-associated fishery, of which *A. achillies* and *C. striatus* contributed 51% and 41% respectively (see chapter 3). With no previous life-history information on *A. achilles*, this study represents a baseline after which comparative investigations can be conducted.

To date, only a single age- and size-based investigation has been conducted on acanthurids in the Cook Islands; *C. striatus* in Rarotonga (Manarangi-Trott, 2000). Comparisons of size and age estimates from this study to the Rarotonga population (~264km southwest of Mitiaro) indicate that *C. striatus* in Mitiaro attain larger sizes and a higher maximum age. Furthermore, Mitiaro populations tend to reach asymptotic size sooner than their Rarotongan counterparts.

Comparisons with other South Pacific *C. striatus* populations indicate that our L_∞ (185 mm) are generally lower to those reported in Arias-Gonzalez et al. (1987) in Mo'orea, Tahiti to the east of the Cook Islands (L_∞ = 241 mm). However, a more recent account of Mo'orea suggests shorter asymptotic lengths (L_∞ = 178 mm) (Trip et al., 2008b). The results presented in this study fit within the age (17-37 years) and size ranges (L_∞ ranging from 128-232 mm) of *C. striatus* populations distributed throughout the Indo-Pacific region (Trip et al., 2008). Older longevity is not without precedence as studies have reported that acanthurids have an average lifespan of 30 – 40 years (Choat & Axe, 1996). In comparison to the fifteen Indo-Pacific studies cited in Trip et al. (2008), Mitiaro's populations of *C. striatus* ranks as the third largest

maximum size, eighth highest maximum age and seventh fastest growth rate based on the estimated L_1 rvBGF parameters.

Across the upper size classes, males tended to be more prominent than the female counterparts in *C. striatus*. This was not the case for *A. achilles* as females were more abundant within the upper size class range. Furthermore, a bimodal size-frequency of *A. achilles* was apparent for both sexes which seems rather uncommon among acanthurid life-history papers. Bimodal distributions have been posited towards complex ontogenetic and mortality responses to biotic and abiotic mechanisms (Huston & Deangelis, 1987). Sampling procedure bias has been suggested to cause bimodal distributions (Finstad et al., 2003). However, other plausible reasons could include migratory movements for potential development or breeding purposes (Furness et al., 2021; Warburton et al., 2023). Considering that the bimodal trend was present in both sexes for *A. achilles*, it seems rational to consider possible spawning-related migrations in less targeted areas of the forereef. It is also speculated that age and growth would also reflect unusual patterns considering that life-history parameters are compromised in relation to each other, instigating a need for further study.

C. striatus were observed within the shallow reef flat and forereef habitats of Mitiaro (pers. Obs., A. Vavia), which aligns with this species being found in similar habitats across the Indian and Pacific Oceans (Meekan & Choat, 1997; Robertson, 1983; Tebbett et al., 2022). However, this study did not investigate life-history stages and the associated habitat types or locality as found in other studies (Choat & Axe, 1996; Gust et al., 2002; Manarangi-Trott, 2000; Trip et al., 2008b). Cases for the size and age distribution of *C. striatus* have been hypothesised to respond to local habitat conditions more than other variables, particularly on body size (Ochavillo et al., 2011). Therefore, local investigations could provide additional information on size structures.

The vBGF growth curves for both species were typical of acanthurids displaying a "square" pattern whereby the fish undergo rapid initial growth within the first couple of years of life followed by a sudden plateau (Trip, Craig, et al., 2014) even though the species are long-lived. This displays the growth in what resembles a curved right-angle. Sagittal otolith weight also met expectations displaying a strong positive relationship with increasing age in *C. striatus* (R_2 = 0.7495) and *A. achilles* (R_2 = 0.8429).

In terms of growth rates and asymptotic sizes, slower growth rates have been associated with larger asymptotic sizes (Morais & Bellwood, 2018; Trip, Clements, et al., 2014). However, this can vary among different species whereby faster growth results in larger asymptotic sizes (Claisse et al., 2009). This is the case for Mitiaro populations of *C. striatus* and *A. achilles* presented here whereby slower growing populations achieved larger asymptotes. The vBGF results revealed that the female population of *C. striatus* achieved faster growth rates (L_1 =

136.35 mm) than their male counterparts (L_1 = 128.28 mm) resulting in larger males. Conversely, the *A. achilles* male population achieved faster growth rates (L_1 = 150.21 mm) than their female counterparts (L_1 = 140.26 mm). Sexual size dimorphism has shown *C. striatus* males to achieve higher faster growth rates than that of females at early life stages in the Indo-Pacific region (E. Trip, 2004). Assessing growth rates at the juvenile stages of life-history may explain the sexual dimorphism observed here.

Likelihood ratio tests were not used to compare the growth parameters between sexes within each species as there were no detected differences (X_2 = 4.15; df = 3; p = 0.25). This is further supported in the 95% confidence intervals for both species suggesting that there is no significant difference in the growth curves for male and female populations in *C. striatus* and *A. achilles*.

Growth rates are exchanged for other life-history parameters (Pardo et al., 2013; Ruttenberg et al., 2005), making life-history and overall population dynamics complex investigations. This is further exacerbated by the magnitude of variables at play across temporal, spatial and biological factors (Ruttenberg et al., 2005; Trip et al., 2008b).

In terms of spawning periodicity, *A. achilles* tends to resemble similar spawning seasons to *C. striatus* with September showcasing peaks in the monthly gonadosomatic index (GSI) and experiencing a gradual decline towards December/January. Increases in GSI in March/April may indicate the potential for a second spawning season. However, the limited data here fails to confirm such a claim or determine which sex, if not both, is causing the spike. Obtaining more samples and sexual identifications could have assisted in elucidating the trends presented here, particularly during months where data are missing and to closely address GSI differences between sexes. Variations of spawning periodicity months have also been displayed for other species of acanthurids including multiple GSI spikes and behaviour (DeMartini et al., 2014; Kilarski & Everson, 2008; Robertson, 1983).

There were no observed immature specimens collected, which prohibited conducting age- or size-at-maturity analyses. This was due to lack of very small or young specimens, which is to be expected as our samples came from local fishers who tend to target larger specimens for food (Barbosa et al., 2021). It is also possible that some immature specimens went undetected as the identification of sexual morphologies were often challenging, particularly during out of spawning seasons when gonadal development appeared inconspicuous. With only mature samples identified in this study, it may suggest that the population turnover is occurring at a rate that can withstand existing levels of exploitation (Taylor et al., 2019). This is whereby newly recruited or juvenile, immature individuals are not targeted suggesting that Mitiaro populations of *C. striatus* and *A. achilles* could mature from as early as year one of life. Very early sexual maturity in coral reef fish is not that uncommon. Sabetian (2010) showed the parrotfish *Scarus*

ghobban from the Solomon Islands was sexually mature soon after its first year of life. Results from histological analyses of Tutuila, America Samoa populations of *C. striatus* suggested that 50% of males and females were mature between two and three years of age (Ochavillo et al., 2011). Mature individuals in Tutuila also ranged between 150-210 mm (FL), compared to that of *C. striatus* in Mitiaro being 105-250 mm (FL). Based on the rvBGF values tau (L1) and omega (L5) presented here, Mitiaro populations would appear to have a faster growth rate and a larger mean maximum size but achieves a lower level of longevity compared to Tutuila (Trip et al., 2008b). This relatively faster growth and larger maximum size is also observed between North Reef and Granite Bluffs populations (Choat & Axe, 1996). Another study shows that Papua New Guinea populations of *C. striatus* reach an estimated 50% maturity at 80 mm (Longenecker et al., 2017). Overall, the faster growth rates align with achieving maturity sooner than those with slower growth rates (Berrigan & Charnov, 1994). These factors are known to be linked with the general temperature-size rule (Kingsolver & Huey, 2008) described below.

Life-history traits and fish population dynamics often exhibit paradoxical relationships (Angilletta et al., 2004). Latitudinal variation in growth and longevity has been well documented across large geographic scales where there is substantial evidence of life-history trait differences across regions based on metabolic theory in response to sea surface temperatures in both tropical and non-tropical reef fishes (Lowe et al., 2021; Robertson et al., 2005; Taylor et al., 2019; Trip et al., 2008b). These differences can be seen across relatively small geographical latitudinal distances like Mo'orea and Mitiaro, for example. Despite variation in life-history across fish species, the general response due to metabolic theory is that warmer waters yield shorter lifespans and smaller sizes (Kingsolver & Huey, 2008; Robertson et al., 2005).

Localised growth and size structure variation has also been more closely associated with habitat structure (Trip et al., 2008b). For example, (Gust et al., 2002) detected significant differences in growth between mid- and outer-shelf reefs across four coral fish species. These can be further complicated by the influence of local fisheries. In certain populations the influence of fishing pressure limits understanding environmental drivers for life-history traits (Rutterford et al., 2023). In addition to growth variations being influenced by complex ecological density dependence relationships, additional information on the roles of recruitment and mortality is needed (Ford et al., 2016; Trip, Craig, et al., 2014), as most models assume constant levels of recruitment and mortality across age classes.

Given the localised geographic scale of this study, the generality of the findings may be problematic if applied to wider management of coastal reef fisheries. However, there is also a strength in this approach as far as managing and conserving the local fishery is concerned. While the geographical nature of Mitiaro may not be typical of the majority of fringing tropical

coral reef habitats and fisheries, it offers a unique study of a stand-alone oceanic island subsistence-based fishery.

With subsistence fisheries accounting for primary food sources, the lack of long-term catch compositions, particularly with respect to acanthurids promotes further need for monitoring and documentation. Despite the paucity of data, local residents have reported that *C. striatus* and *A. achilles* are a popular coral reef fish. Evidence of current fishing pressure in Mitiaro is uncertain. High turnover rates and phenotypic plasticity have been linked to fishing mortality (Sabetian et al., 2015; Trip et al., 2008b) which may drive populations towards increased growth rates, earlier maturity, but decreased maximum size (Berrigan & Charnov, 1994; Craig et al., 1997). In terms of aging, anthropogenic pressure has not been strongly linked with levels of longevity (Robertson et al., 2005; Taylor et al., 2019; Trip et al., 2008b). However, fisher selectivity and pressure for larger (older) individuals are theorised to drive the evolution towards smaller body sizes (Birkeland & Dayton, 2005). Current survival rates of *C. striatus* and *A. achilles* are moderate (~64% per year) which suggests challenges to making inferences without long-term trends. Furthermore, the absence of older aged *A. achilles* compared to other long-lived acanthurids is compelling, where additional life-history studies for other populations would benefit understanding this popular coral reef species. This study is the first ever to establish any age-based analysis of A. achilles. I will also have to acknowledge that local fishers have observed size, behavioural and effort changes over the past decades (explored more in Chapter 3). In spite of that, given the uncertain attributes of these observations, the role of fishing pressure remains unclear on whether there is a significant impact on the demographics of *C. striatus* and *A. achilles* (or other fish). Under the context of fisheries management, it would prove beneficial to assess more local and national geographic variation on the environmental and ecological factors that may influence the demography and life-history relevant fisheries for stock assessments in the future (Caselle et al., 2011; Taylor et al., 2019). For the purpose of utilising life-history data within fisheries science, whether across broad geographic scales and populations, inferences should be made based on the respective localised trends. Applying the best models that suit localised fish populations would prove to be locally effective. For example, applying the best models for LWR or condition factors (Froese et al., 2011). Additionally, incorrect use of geographically-sensitive life-history information within fisheries management models may lead to over- or underestimating factors such as recruitment, mortality, and maturity rates, which could exhibit an unanticipated response based on current research (Dwyer et al., 2003).

3.6 Conclusion

In summary, this is the first demographic study for *C. striatus* on Mitiaro, and *A. achilles* in the world. In fact, this is the first ever age-based demographic investigation on any reef fish species on Mitiaro. The life-history traits here describing age, size and growth parameters of two common surgeonfish species provide both a baseline, and also additional information on these geographically widespread coral reef fishes. Data on the population structures of these two locally important species may play a key role in understanding subsistence and artisanal fisheries impacts, as well as understanding the overall ecological functional roles that each species play. The results presented here provide baseline reproductive and growth information that can be utilised for comparative analyses, and broader fisheries management decisions. Future studies based in the Cook Islands would benefit by considering further investigations across other outer islands to develop a nationwide database of fishery-relevant coral reef fishes. By applying similar survey methods, I suggest integrating methods that investigate earlier life-history stages such as recruitment and trends within local fisheries. Associating life-history stages with habitat types may also provide valuable insight into fish assemblages and movements which may also serve well in designing potential marine management plans and fishing regulations that align with local custom.

Chapter 4

Mitiaro: a case study of a remote Cook Islands fishery

Chapter Four addresses a large-scale research approach to understanding the Mitiaro fishery. In this chapter, I achieve the second objective of this thesis by documenting catch data of coral reef and nearshore pelagic fish in Mitiaro of local fishers, including counts, weights, and lengths of fish, and information on time spent fishing, the number of fishers, and locations. This investigation also provides the family and species catch ratios, and the techniques employed for catching fish which is used to calculate the catch-per-unit-effort (CPUE) values for different fish families and across the different fishing techniques. Coral reef fish counts were estimated using underwater visual censuses along randomly selected line-transects. Semi-structured interviews were conducted with Mitiaro fishery experts to provide anecdotal accounts of significant events or observed changes pertaining to Mitiaro marine resources. These discussions suggested ongoing changes within the Mitiaro fishery whereby nearshore pelagic fish have become increasingly difficult to harvest over time and highlighted the local strategies to preserve marine resources through traditional practices. This study of the fishery and knowledge through local actors reveals that nearshore pelagic fish primarily account for marine resources in Mitiaro, but coral reef fish continue to have significant importance. It also underlines the challenges with ongoing changes within the fishery which requires long-term monitoring to overcome potential concerns with local food security.

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4.1 Abstract

Coral reef and nearshore pelagic fisheries are crucial for subsistence and artisanal fishers by providing food security and supplementing livelihoods on the remote island of Mitiaro, Cook Islands. However, information and data on remote coastal communities and fisheries remain underrepresented. Standardised catch-per-unit-effort (CPUE) was calculated for the multispecies fishery in Mitiaro based on species caught, fishing techniques employed, and fishing vessels using catch data over 598 fishing trips accounting for 1949 combined fishing hours. The catch survey revealed that the pelagic fishes accounted for 88% of the documented fishery by weight (4.5-tonnes) and achieving an overall higher CPUE rate than coral reef fisheries. Carangidae and Acanthuridae formed over 50% of the coral reef fishery. Furthermore, acanthurids appeared to be the dominant family based on the underwater visual census. Bottom fishing and spearfishing formed the most preferred fishing methods to target reef fish. Whereas the traditional drop-stone and trolling were most popular and successful for catching pelagic fish. Semi-structured interviews revealed a gradual decline in catch and fish size over years, suggesting an increase in effort is required. The results of the catch data and semi-structured interviews suggest that long-term monitoring of CPUE accounting for fishing techniques, vessels and targeted fish are necessary to assess changes in Mitiaro's fishery to determine whether sustainability measures are required to minimise threats to food security.

4.2 Introduction

Ongoing exploitation of small-scale fisheries (SSF) account for the households and livelihoods of coastal communities supporting millions of people worldwide (Kittinger et al., 2013; Teh & Sumaila, 2013; Wabnitz et al., 2018). Across 99 countries' coastal communities, there is estimated to be around 6 million reef fishers (Teh et al., 2013). In indigenous and other developing nations, fisheries are a primary source of accessible and affordable protein (Islam & Berkes, 2016; Pauly & Zeller, 2016; Wabnitz et al., 2018). However, it is becoming increasingly well known that these fisheries are threatened by unprecedented oceanic changes involving climate change, ocean acidification, illegal, unreported, and unregulated fishing, and poor management resulting in negative impacts threatening the health, food security, and livelihoods of coastal communities. Small Island Developing States (SIDS) in the Pacific are noted to be the most vulnerable to such negative impacts (Blasiak et al., 2017). If left unmonitored, these issues can be further exacerbated by continuous overexploitation of marine

resources, influenced by subsistence- and artisanal-based fishing, unregulated capital motives, and inappropriate governance measures (McClanahan et al., 2009).

Due to the remote and often isolated circumstances of many of these SSF in the Pacific, coastal fisheries are generally quantitatively data poor creating a potential for misleading statistics. Pacific Island communities with a significant dependence on marine resources are evidenced to have difficulty collecting data, for the most part, due to four identified reasons: (1) logistical and political limitations; (2) insufficient local researchers and resources; (3) exclusive research access to locations that may be enforced by customary rights; and (4) poor research mechanisms between scientists and local knowledge holders (Chuenpadgee, 2012; Dalzell et al., 1996; Teh & Sumaila, 2013). Moreover, historically, both national and international industries have neglected SSF as the catches or socioeconomic factors are often viewed as negligible when compared to large industrial fisheries (Chuenpagdee et al., 2006). This marginalisation is further amplified by the misperception that SSF are small actors on the global podium represented by the inadequate levels of data, thus, generating a loophole of information deficits (Dalzell et al., 1996). Despite the high value of these SSF throughout the Pacific region to livelihoods and food security, it is believed that SSF reports have been highly underrepresented (Zeller et al., 2021). Furthermore, Pauly and Zeller (2016), estimate worldwide fisheries catch decline to be underestimated and demands improved monitoring efforts in industrial and SSF.

There has been increasing effort in quantifying fisheries catch data in smaller localities in response to the alarming information gaps. Where there is information, particularly in recreational fisheries, analyses have indicated overexploitation of reef species by low densities of targeted species and higher densities of non-target species (Pinheiro et al., 2010). Composition of catch and Catch Per Unit Effort (CPUE) can also be influenced by different fishing methods (Frisch et al., 2008; Guabiroba et al., 2020). Not all quantitative investigations document the totality of their fisheries involving gear or fishery distributions i.e., artisanal, subsistence etc. as information might be achieved by adopting interdisciplinary methods (Teh et al., 2007).

In order to improve SSF management regimes we need to develop our understandings of resource use and sustainability drivers (Cinner et al., 2013). Many fisheries management systems are commonly designed with a top-down approach driven by quantitative science or political measures that neglect local community stakeholders and knowledge holders (Lavoie et al., 2019; Salas et al., 2007). Social dynamics including local knowledge systems have a critical role by possessing an understanding of locally relevant environmental knowledge – information that could prove pivotal for successful marine environmental management (Cinner & David, 2011; Johannes, 1998; Kittinger, 2013; Matera, 2020; Sabetian & Foale, 2006). Kittinger et al. (2015) provide an elaborate study on a community-based approach that assesses the socio-

ecological dynamics of SSF economically and in terms of food security along with catch data and ecological surveys.

Engagement with local community members of a given environmental society is known to prove valuable in fisheries research particularly for data-less locations (Johannes, 1998). Mclean and Forrester (2018) suggests that there are some links between the scientific and local knowledge of fishers, but more work needs to be done to improve collaborative efforts. The complex relationship between local stakeholders, particularly those with customary resource rights and external governing agencies has long been identified (Hviding, 1998, 2006). Cultural anthropological approaches to fisheries research and engagements with fisheries stakeholder's are increasingly becoming more recognised for effective fisheries planning with stakeholder interests (Albert et al., 2015; Aswani & Ruddle, 2013; Hind, 2014). In the Pacific, these qualitative aspects can revolve around a complex body of local social, political, economic, cultural, and spiritual constitutions which can directly and indirectly influence fishery outcomes (Kittinger et al., 2013). Therefore, there is a need to find and create synergies across the differences in knowledge systems to address the declining state of the ocean and its resources (Tengö et al., 2014; Thaman et al., 2013).

In the Cook Islands, the marine industry is the nation's second largest economic revenue contributor following tourism (Cook Islands Government, 2015; Kumar et al., 2020; Solomona, 2009); both of which have a strong reliance on the wellbeing of local marine ecosystems. Additionally, at a local community level within the Cook Islands, there is a significant dependence on small-scale artisanal and subsistence fishing. According to the 2021 Cook Islands Census, 90.6% and 78.7% of fishers in the Cook Islands practiced reef and ocean fishing for subsistence purposes, respectively. Estimates of the Cook Islands' coastal subsistence fisheries produced 276 tonnes of catch in 2014 valued at $2,000,000NZD (Gillett, 2016). Overall, the revenue estimated from fisheries accounted for 2.4% i.e., coastal commercial, offshore sectors, freshwater, and aquaculture.

In 2017, the Cook Islands established a multi-use marine park covering the entirety of the nation's EEZ, called 'Marae Moana' in efforts to improve sustainable development and the integrity of marine health. This paper will not outline the deeper details of Marae Moana's inception, but rather describe that its motivation in response to Pacific-wide Ocean challenges has brought forward more conversations about the economic, ecological and cultural values of marine resources (Durbin, 2018). Part of those discussions have addressed monitoring efforts of local marine resources and livelihoods for the outer islands and the need to confront data paucity and engaging with local ecological knowledge holders (also see (Rongo et al., 2013; Rongo and Dyer, 2015).

4.2.1 Aim and Objectives

To address the paucity of small-scale fisheries data in the Cook Islands, this case study aims to approach the knowledge gaps that can improve marine resource governance (national and local), which will then allow for optimised subsistence and artisanal fisheries, food security and economic opportunity. My specific objectives were to document and quantify the Mitiaro SSF via a detailed fishery survey, as part of a wider investigation of fisher behaviour, knowledge, and connection to the marine environment (see chapter 4).

Catch data is critical in assessing trends in stock status in relation to ongoing fisheries practices. The significance of catch data in this study is four-fold. Firstly, the catch data shows the ratio of each family of fish caught by fishers by weight, secondly it shows which specific species contributed significantly to catch landings, thirdly it provides baseline data against which a variety of factors such as seasonality can be compared, and lastly it documents the fishing activity and behaviour of local fishers across temporal and spatial scales. Moreover, it can provide a quantitative angle which can be triangulated with qualitative data obtained from local informants (also see Mclean and Forrester (2018). According to Kittinger et al. (2015), this type of survey is time-intensive and labourious but is also the most effective method to employ, particularly in fisheries that are data-poor. It is also an important method for understanding possible long-term trends in food security.

Semi-structured interviews were designed using ethnographic observations and working alongside local informants of Mitiaro Island to provide insight into the local worldview and to address marine environmental changes overtime. Overall, the goal of this study was to understand and deconstruct a local island coastal fishery using quantitative and qualitative information. The hope is that in describing the dynamics of a small island Cook Islands fishery, we may be able to gain insight that can be used to better understand the challenges of coral reef fisheries.

4.3 Material and Methods

4.3.1 Location

Mitiaro is the fourth largest (22 km^2) of 15 islands which make up the Cook Islands, located 264km north-east of the country's capital island, Rarotonga (Figure 20). Unlike Rarotonga, Mitiaro is a low lying raised volcanic island (12 m elevation) with substantially limited access to fertile soil, and the terrain primarily consists of limestone and volcanic rock known as "*makatea*". In contrast to neighbouring islands and atolls in the Cook Islands, the centre of Mitiaro hosts a large brackish lake housing certain freshwater fauna. The uplifted reef flat is

commonly patrolled for shellfish gleaning, and crayfish and slipper lobster harvesting. To a lesser extent the reef flat is used for line fishing or targeting conger eels. Most fishing activity occurs within the forereef either by line fishing from the reef flat, canoe, or boat. Pelagic and deep-sea species are targeted beyond the forereef region. The common area for canoe and boat departure and fish landing is from the Mitiaro Harbour (Te Ao Omutu).

Mitiaro is one of three islands in the Cook Islands that remains to have traditional sovereignty as opposed to the nation's government in free association with New Zealand. With a small population of 155 (Cook Islands Statistics Office, 2022), Mitiaro residents account for roughly 1% of the Cook Islands' total population. The primary economy is provided through Cook Islands government work, and to a lesser degree logistics, ecotourism and services run by a few families. On a monthly basis cargo is shipped in from Rarotonga delivering building materials, household supplies and a wide variety of imported foods. Furthermore, there exists a strong subsistence- and artisanal-based lifestyle shown by the effort and dependence on local root vegetable and fruit plantations, hunting/growing livestock, and diverse fishing activities.

Fisheries management in Mitiaro includes the traditional customary marine tenure system called *ra'ui*. Historically, the *ra'ui* used to be instigated by the island chiefs but in more recent times the local island council is responsible deciding when to open and close ra'ui, what species or habitats to protect, and gear restrictions. A popular practice of marine tenure is the fishing methods for flying fish during their spawning seasons throughout the second half of the year. During these aggregations, the use of outboard motors, sale of spawning flying fish and gender-specific restrictions apply. Additionally, in many parts of the Cook Islands, fishing prohibitions are in place for Sunday's due to religious systems. The Cook Islands Ministry for Marine Resources (MMR) also provides technical expertise with reef surveys and resource monitoring to document environmental health and any ecological changes. Currently, there are no licencing measures in place for fishing in Mitiaro as the resource-harvest practices relies on both pre- and post-colonial management processes. Resource abstinence in protected areas is monitored and enforced via the Mitiaro community and council. The pricing for fish sales is arbitrary based on the local economy, whereas Rarotonga prices could be up to six times higher.

4.3.2 Catch Survey

Fishers were opportunistically intercepted for surveying following fishing activity. Data was primarily recorded between 0630 hours and 1700 hours from April 2020 to August 2021. If circumstances permitted, fish were counted, fork lengths measured (pelagic = to the nearest cm, reefs = to the nearest mm) and weighed (pelagic = to the nearest kilogram, reef = to the nearest gram). If measurements and weights were unobtainable due to fisher hesitancy or uncooperativeness, counts were recorded. Each fish was identified to the lowest taxonomic level

where possible. The type of vessel used (if any) was documented along with the fishing gear used, number of fishers, time spent fishing (effort) and fishing locations around the island. Additional data was documented on the fishers' dynamics including age range and sex. The analysis of catch rates/CPUE (Catch Per Unit Effort) in this case study is used to estimate catch landing across fishing methods and gears. It was also used to estimate the catch rates of different fish families/species. CPUE cannot solely be used to determine stock status as there is not necessarily a linear relationship between CPUE and stock size. Furthermore, catch data will also differ according to different methods and gears. This phenomenon is partly due to the fishery characteristics. For example, a species may experience a decline in stock size, but its CPUE may remain high or consistent if effective fishing pressure and gears are increasingly used in areas where stocks remain high. Therefore, we want to use these data as an index of relative abundance that covers as much of the population as we can (Maunder et al., 2006).

4.3.3 Underwater Visual Census

Coral reef fish count estimates were collected using underwater visual census (UVC) surveys along 32 randomly selected strip transect lines (50 x 10 m). These were conducted using snorkel as scuba apparatus was unavailable on Mitiaro. As a fishery-independent assessment of fish density, UVCs are a non-damaging method that can provide relative abundances, size compositions, and rates of population change (Aswani & Sabetian, 2010; Bacheler et al., 2017; Samoilys & Carlos, 2000). Estimates from UVCs are subject to biases by observer abilities, and the behaviour of certain species that can lead to poor estimations (MacClanahan et al., 2007). However, it remains a popular inexpensive and quick method for data collection, and issues of observer bias can be reduced if the same observer conducts the entire survey (as in this case). Abundance estimates can also be triangulated with CPUE and catch data to assess their relative accuracy (Aswani & Sabetian, 2010). All transects were conducted by a single diver to minimise potential interobserver biases in recording counts and identifications of coral reef fishes. Transects were done on the Western side mid-forereef (half-way between reef crest and reef slope), north- and southward to Te Ao Omutu Harbour at estimated depths ranging between 5-15 meters. Fishes were identified at the family level, and to the species if possible. Size estimates were not collected.

4.3.4 Semi-structured Interviews and Korero

Through an ethnographic participatory approach, observations were made over a continuous period of 18-months fieldwork (December 2019 to September 2021) of local customs, spiritual affiliations, societal relationships and hierarchies, and labour professions of the Mitiaro

population. This embedded approach enabled a researcher-participant relationships and insight into indigenous worldviews. In total, 13 local fishing experts were identified for interviews pertaining to fishing history and local knowledge of marine ecosystems. Semi-structured interviews were instigated with open questions about when participants first started fishing, who were their teachers, and what motivated them to develop their skill. The interviews were allowed in way that naturally flowed into a *korero*, a free-flowing informal atmosphere for knowledge sharing through story telling in local Cook Islands contexts that is not restricted to linear methods of inquisition. This allowed knowledge to be shared that reflects the participants realities; akin to the Pasifika methodology of *talanoa* (Vaioleti, 2006). Interviews were conducted in Cook Islands Māori language and English.

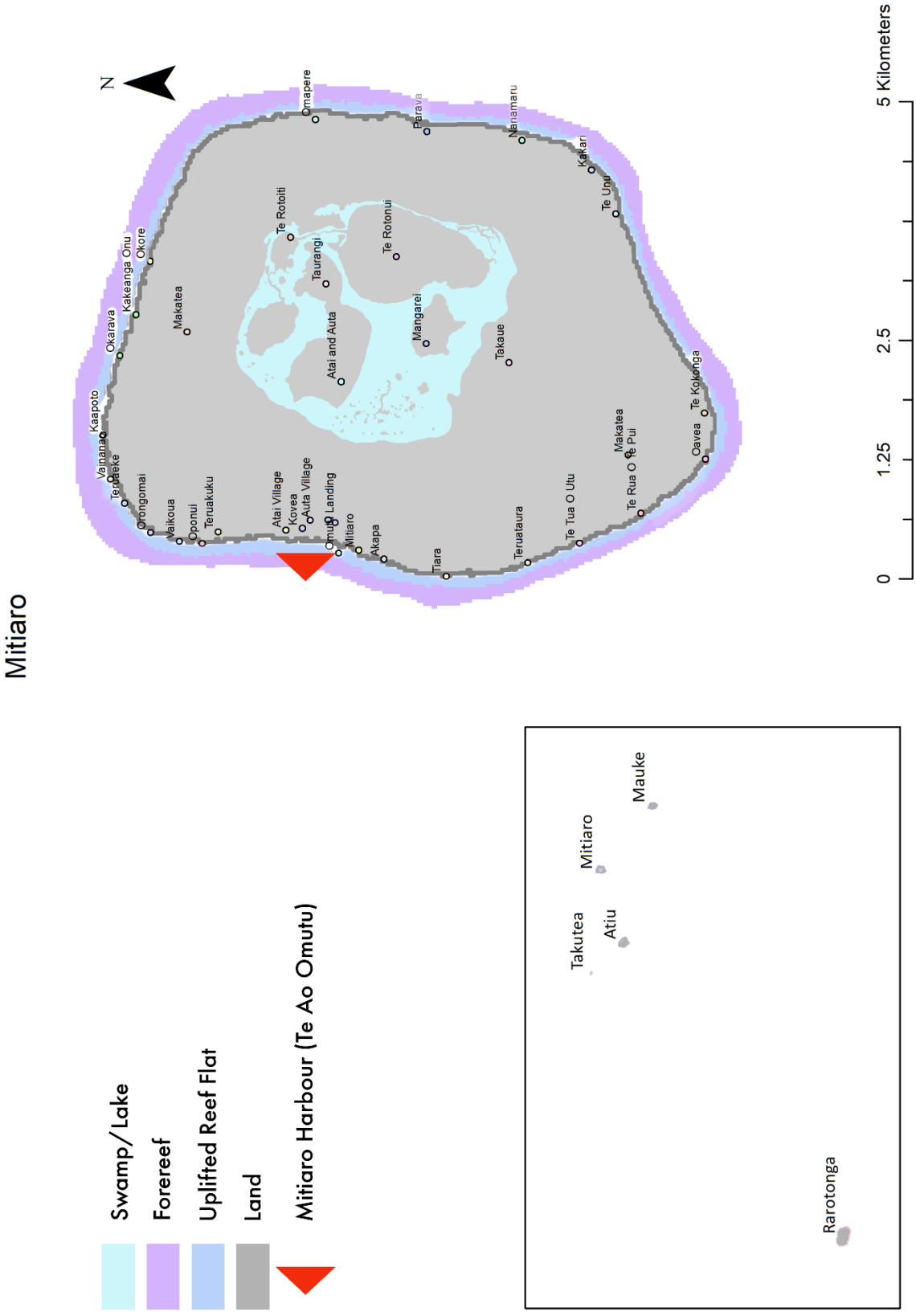

Figure 20. Map of Mitiaro and neighbouring islands Atiu, and Mauke (called 'Ngaputoru' as a collective), and Takutea – Northeast of mainland, Rarotonga.

4.4 Results

For analytical purposes, the total fishing effort for Mitiaro fishers was estimated by quantifying the hours spent fishing per fisher. This data along with the catch rates, composition, vessel, and gear type across reef and pelagic fishes are used here to compare CPUE rates across the different factors.

4.4.1 Catch Survey

4.4.1.1 Catch Composition and Catch-Per-Unit-Effort

Catch data from 598 fishing trips were collected representing a total 1949 hours of combined fishing time and a yield of 4563 kg. Landed catch consisted of a wide variety of coral reef fishes and several pelagic fish types, namely, tunas, flying fish and barracuda. Reef-associate fish catch are portrayed in order by weight distinguished across a family level (Table 2). Carangidae proved to be the highest return of catch by weight, accounting for over 30% of total reef fish catches followed by Acanthuridae (22%) and Serranidae (17%). Across all reef fish families, total weight reached 562kg. Only three pelagic families were identified during the catch surveys (Table 3). Scombridae accounted for a significant portion of all pelagic fish caught (84%) with over 3-tonnes of fish caught. Exocoetidae and Sphyraenidae accounted for 13% and 2% respectively of all pelagic fish caught with an overall total of just over 4-tonnes of fish.

Geographically, most reef fish were targeted along the forereef. Of the reef fish, most were caught on the western side (80.7%) of Mitiaro Island, followed by Eastern (5.3%), Northern (4.9%) and while circulating the circumference of the island (3%). 6.2% of reef fish were geographically unaccounted for. Like the reef fish, most pelagics were caught from the West (60.9%), East (9.9%), North (2.7%), and South (0.9%). Furthermore, 25.6% of pelagics were reported to be caught while trolling the circumference of the island.

*Table 2. Reef fish catch by total weight distinguished by family. *Nine other families were also noted but weights were not recorded (including a row for unidentified family's).*

Family	Common name	Total Weight (kg)	Percentage
Carangidae	Trevally	173.1	30.8
Acanthuridae	Surgeon and Unicornfish	125.9	22.4
Serranidae	Grouper	96.4	17.1
Kyphosidae	Chubs	74.5	13.2
Scarinae (sub)	Parrotfish	26.4	4.7
Lutjanidae	Snapper	17.6	3.1
Mullidae	Goatfish	15.0	2.7
Holocentridae	Soldier and Squirrelfish	14.6	2.6
Balistidae	Triggerfish	9.3	1.7
Labridae	Wrasse	8.6	1.5
Belonidae	Needlefish	1.1	0.2
Total*		**562.5**	100

Table 3. Pelagic fish catch by total weight distinguished by family. Only three families were identified across all pelagic fish caught in Mitiaro.

Family	Common name	Total Weight (kg)	Percentage
Scombridae	Tuna	3370.1	84.2
Exocoetidae	Flying Fish	523.5	13.1
Sphyraenidae	Barracuda	107.1	2.7
Total		**4000.7**	100

For the top three weighed reef fish families, the top five species were also identified by weight within each respected family (Table 4). *C. orthogrammus* had the highest CPUE rate overall, followed by *C. melampygus*. It is important to note that island trevally only accounted for under 6% of the total Carangidae catch within a short period of time. Therefore, the CPUE may be misleading for this rare species which explains its position being the lowest in its category. This may also be assumed across other species that have relatively high to low CPUE/total weight ratios. Unlike a singular species within Carangidae and Serranidae, two species accounted for a significant portion of Acanthuridae's catch. *A. achilles* and *C. striatus* was the most popular species within Acanthuridae considering their total catch and relatively high CPUE rates compared to other species within their family besides *A. olivaceus*.

All pelagic species are presented separately in Table 5. *Thunnus albacares* accounted for over 84% of the Scombridae fish caught, but only had the third highest CPUE rate following *A. solandri* and *T. alalunga*. Flying fish weight was gained from averages within the literature. It is important to note that the flying fish are count in this study is known to be significantly underestimated due to documenting/sampling challenges as they are fished during late hours at night. They also provide a unique opportunity within the Mitiaro fishery as Mitiaro undergoes 'special' flying fish spawning events at certain times of the year around the island, bringing

large aggregations of flying fish at which locals target. This is explored more in the semi-structured interviews.

Table 4. Top five species caught (by weight) across the top three reef fish families caught. Catch-per-unit-effort for top five reef fish species of the top three reef fish families by weight. The average CPUE for each family (Carangidae = 4.24kg/hr, Acanthuridae = 0.88kg/hr, Serranidae = 0.97kg/hr. Species are ranked from highest catch (not by CPUE).

Carangidae	**Species**	**Common name**	**Total Weight (kg)**	**Percentage**	**CPUE (kg/hr)**
	C. melampygus	Bluefin trevally	123.22	71.18	2.37
	C. lugubris	Black jack	10.11	5.84	0.63
	S. rivoliana	Almaco jack	10	5.78	0.92
	D. macarellus	Mackeral scad	9.79	5.66	1.25
	C. orthogrammus	Island trevally	8	4.62	16.00
Total			161.12	93	
Acanthuridae					
	A. achilles	Achilles tang	65.28	51.86	1.59
	C. striatus	Lined bristletooth	52.42	41.64	0.95
	N. lituratus	Orangespine unicorn	2.87	2.28	0.39
	A. Olivaceus	Orangeband surgeon	2.79	2.22	1.10
	A. guttatus	Whitespotted surgeon	2.04	1.62	0.37
Total			125.41	99.62	
Serranidae					
	E. melanostigma	One-blotch grouper	59.35	61.59	1.27
	C. argus	Peacock hind	12.09	12.55	0.75
	C. urodeta	Flagtail grouper	10.74	11.15	1.08
	P. maculatus	Spotted coral grouper	7.9	8.20	0.77
	S powelli	Golden grouper	4.2	4.36	1.00
Total			94.29	97.84	

Table 5. Top species caught (by weight) across the three pelagic fish families caught.

Scombridae	Species	Common name	Total Weight (kg)	Percentage	CPUE (kg/hr)
	T. albacares	Yellowfin tuna	2851.5	84.61	4.62
	A. solandri	Wahoo	350.6	10.40	7.09
	T. alalunga	Albacore tuna	83	2.46	6.75
	K. pelamis	Skipjack tuna	75	2.23	2.97
	G. unicolor	Dogtooth tuna	10	0.30	0.80
Total			3370.1	100	
Exocoetidae					
	C. poecilopterus	Flying fish	523.5	100	10.00
Total			523.5	100	
Sphyraenidae					
	S. barracuda	Barracuda	107.1	100	2.89
	S. qenie	Blackfin barracuda	N/A	N/A	N/A
Total			107.1	100	

4.4.1.2 Fishing Techniques

The various fishing methods employed are documented in Table 6 and Table 7. In terms of CPUE, these methods can be compared across different vessels used (including land-based fishing). Eight different methods were used for targeting reef fish species. Methods such as drop-stone were mostly used while fishing from canoes. However, for the pelagic fisheries, using the drop-stone method from motorised boats was also observed, but not as often as canoe fishing. Across all vessels within reef fish, baited lines accrued the highest number of hours (295 hours), followed by spearing (173 hours) and jigging (60 hours). Whereas trolling had the highest time spent (378 hours), drop-stone method (336 hours) and baited lines (38 hours) for targeting pelagic species.

Table 6. CPUE distinguished by fishing method and vessel used (including land-based fishing) across all reef fish caught over the study period. Note: this table also considers time spent targeting reef fish but returning zero catch.

Method	Time (hrs)	Weight (kg)	CPUE (kg/hr)
Boat	**82.27**	**80.36**	**0.98**
Jig	54.23	52.67	0.97
Spear	15.00	8.95	0.60
Baited Line	11.71	9.78	0.83
Trolling	1.33	8.97	6.73
Canoe	**105.88**	**110.92**	**1.05**
Baited Line	56.90	62.50	1.10
Drop-stone	25.44	20.33	0.80
Lure	12.20	10.15	0.83
Spear	11.00	16.14	1.47
Jig	0.33	1.79	5.38
Land-based	**451.87**	**371.25**	**0.82**
Baited Line	263.03	179.75	0.68
Spear	150.63	152.87	1.01
Plastic Bait	16.03	8.49	0.53
Jig	10.42	25.29	2.43
Lure	10.02	4.85	0.48
Grand Total	**640.01**	**562.53**	**0.48**

Table 7. CPUE distinguished by fishing method and vessel used (including land-based fishing) across all pelagic fish caught over the study period. Note: this table also considers time spent targeting pelagic fish but returning with zero catch.

Method	Time (hrs)	Weight (kg)	CPUE (kg/hr)
Boat	**644.98**	**2694.70**	**4.18**
Trolling	506.03	1948.60	3.85
Net (flying fish)	52.38	523.50	10.00
Baited Line	38.75	161.50	4.17
Patara (barracuda)	26.50	0.00	0.00
Drop-stone	20.33	36.10	1.78
Plastic Bait	1.00	25.00	25.00
Canoe	**652.28**	**1306.00**	**2.00**
Drop-stone	646.95	1306.00	2.02
Patara (barracuda)	5.33	0.00	0.00
Total	**1297.27**	**4000.70**	**3.08**

Table 8. CPUE rates across fishing methods, top three reef fish families, and vessels used. CPUE rates are based on times spent successfully catching fish and not the time spent targeting fish.

Method	Time (hrs)	Weight (kg)	CPUE (kg/hr)
Boat	**40.97**	**38.82**	0.95
Acanthuridae	**12.84**	**5.15**	0.40
Jig	2.03	N/A	0.00
Spear	10.80	5.15	0.48
Carangidae	**11.16**	**16.66**	1.49
Baited Line	0.29	1.40	4.90
Jig	8.92	6.29	0.71
Spear	0.63	0.00	0.00
Trolling	1.33	8.97	6.73
Serranidae	**16.97**	**17.01**	1.00
Baited Line	4.63	4.73	1.02
Jig	12.34	12.28	0.99
Canoe	**76.02**	**77.17**	1.02
Acanthuridae	**8.38**	**10.04**	1.20
Baited Line	3.50	0.16	0.04
Spear	4.88	9.88	2.03
Carangidae	**25.98**	**26.58**	1.02
Baited Line	10.78	14.88	1.38
Drop-stone	14.98	10.33	0.69
Jig	0.22	1.37	6.16
Serranidae	**41.66**	**40.55**	0.97
Baited Line	31.73	35.00	1.10
Drop-stone	7.92	4.00	0.51
Jig	0.06	0.17	3.12
Spear	1.96	1.38	0.70
Land-based	**189.02**	**279.40**	1.48
Acanthuridae	**94.52**	**110.70**	1.17
Baited Line	9.40	6.32	0.67
Spear	85.12	104.38	1.23
Carangidae	**57.29**	**129.88**	2.27
Baited Line	42.41	88.78	2.09
Jig	6.00	25.29	4.22
Lure	3.27	4.85	1.48
Plastic Bait	3.03	8.49	2.80
Spear	2.59	2.47	0.96
Serranidae	**37.22**	**38.81**	1.04
Baited Line	29.59	33.57	1.13
Spear	7.63	5.24	0.69
Total	**306.01***	**395.38***	1.29

Table 9. CPUE rates across fishing methods, top three pelagic fish families, and vessels used. CPUE rates are based on times spent successfully catching fish and not the time spent targeting fish.

Method	Time (hrs)	Weight (kg)	CPUE (kg/hr)
Boat	**508.61**	**2694.70**	5.30
Scombridae	**396.65**	**2064.10**	5.20
Trolling	356.24	1866.70	5.24
Baited Line	23.75	136.30	5.74
Drop-stone	15.67	36.10	2.30
Plastic Bait	1.00	25.00	25.00
Sphyraenidae	**59.58**	**107.10**	1.80
Patara	22.50	N/A	N/A
Trolling	22.08	81.90	3.71
Baited Line	15.00	25.20	1.68
Exocoetidae	**52.38**	**523.50**	10.00
Net (flying fish)	52.38	523.50	10.00
Canoe	**325.80**	**1306.00**	4.01
Scombridae	**320.47**	**1306.00**	4.08
Drop-stone	320.47	1306.00	4.08
Sphyraenidae	**5.33**	N/A	N/A
Patara	5.33	N/A	N/A
Total	**834.41**	**4000.70**	4.79

The top three families show the differences in CPUE between fishing methods used across the different vessels for reef and pelagic fishes (Table 8 and Table 9). These families, shown as their catch rates, indicate where CPUE estimates might need to receive further attention to assess fishing pressure. It is expected that some families are more susceptible to certain methods based on diet. Moreover, CPUE rates may be influences by fisher behaviour and expertise.

According to total times spent, land-based reef fisheries was the most popular option for fishers which was over three and two-and-a-half times higher than the time spent on boats and canoes respectively. The different CPUE rates across fishing techniques shows the various levels of efficiency for targeting specific families. However, across all results there are four relatively outstandingly high CPUE rates (see Carangidae across different vessels - Table 8) due to the time:weight ratios which could possibly be misleading based on the short times.

Geographically, the Western side of Mitiaro Island (see Figure 20) was the most productive in terms of catch landing by weight in both reef (80.7%) and pelagic (60.9%) fisheries (Table 10). These are largely due to the use of baited lines and spearing within the reef fishery and the use of the drop-stone method and trolling for pelagic species. The Southern part of the island is the least reported side for successful catches followed by the Northern end.

Table 10. Catch weight (%) by location and fishing technique. Location and weights are ranked in order from highest to lowest. NOTE: This does not account for effort spent at each location.

Reef			Pelagic		
Location	**Weight to Location (%)**	**Weight to Fishery (%)**	**Location**	**Weight to Location (%)**	**Weight to Fishery (%)**
West		**80.7**	**West**		**60.9**
Baited Line	55.8	40.5	Drop-stone	55.1	33.5
Spear	31.6	22.9	Trolling	29.3	17.8
Jig	11.1	8.0	Net	14.6	8.9
Drop-stone	5.0	3.6	Plastic Bait	1.0	0.6
Lure	3.7	2.7	**Round Trip**		**25.6**
Plastic Bait	2.1	1.5	Trolling	70.1	18.0
Trolling	2.0	1.4	Baited Line	15.8	4.0
East		**5.3**	Net	14.1	3.6
Jig	0.6	3.4	**East**		**9.9**
Baited Line	0.4	1.9	Trolling	100.0	9.9
North		**4.9**	**North**		**2.7**
Spear	0.9	4.3	Trolling	100.0	2.7
Baited Line	0.1	0.6	**South**		**0.9**
Round Trip		**3.0**	Net	64.9	0.6
Jig	0.9	2.8	Trolling	35.1	0.3
Trolling	0.1	0.2			

4.4.1.3 Monthly Averages

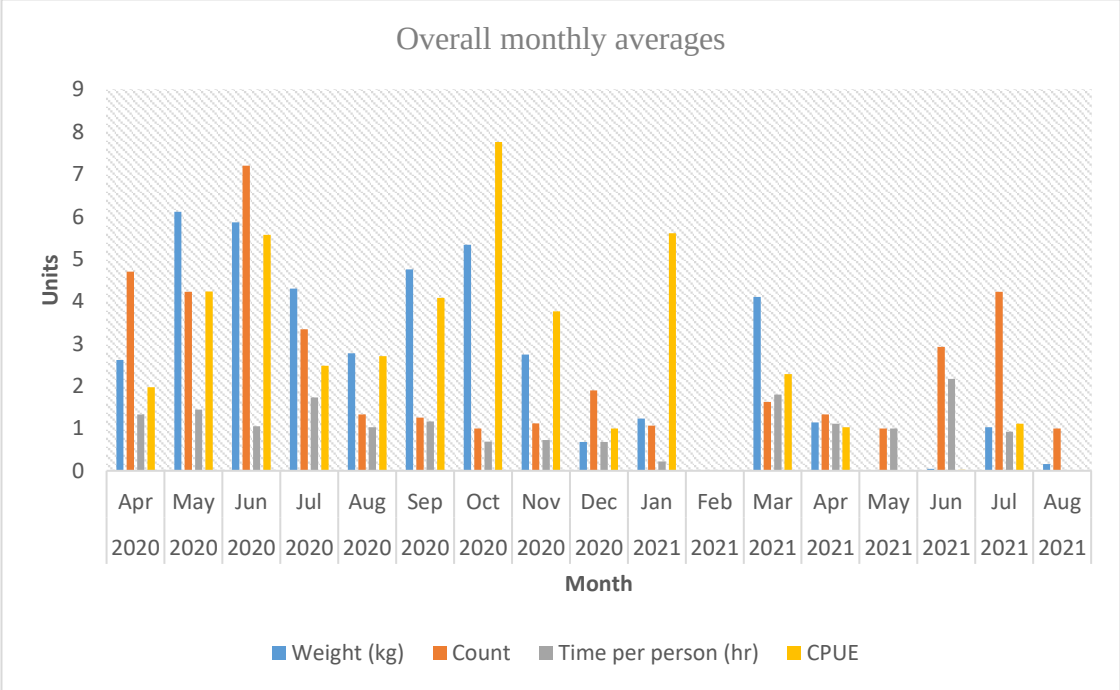

Figure 21. The overall monthly averages of weight (kg), count of fish, and time spent per person fishing (hour) between April 2020 and August 2021. This includes the reef and pelagic fisheries and does not distinguish across fishing methods or vessels.

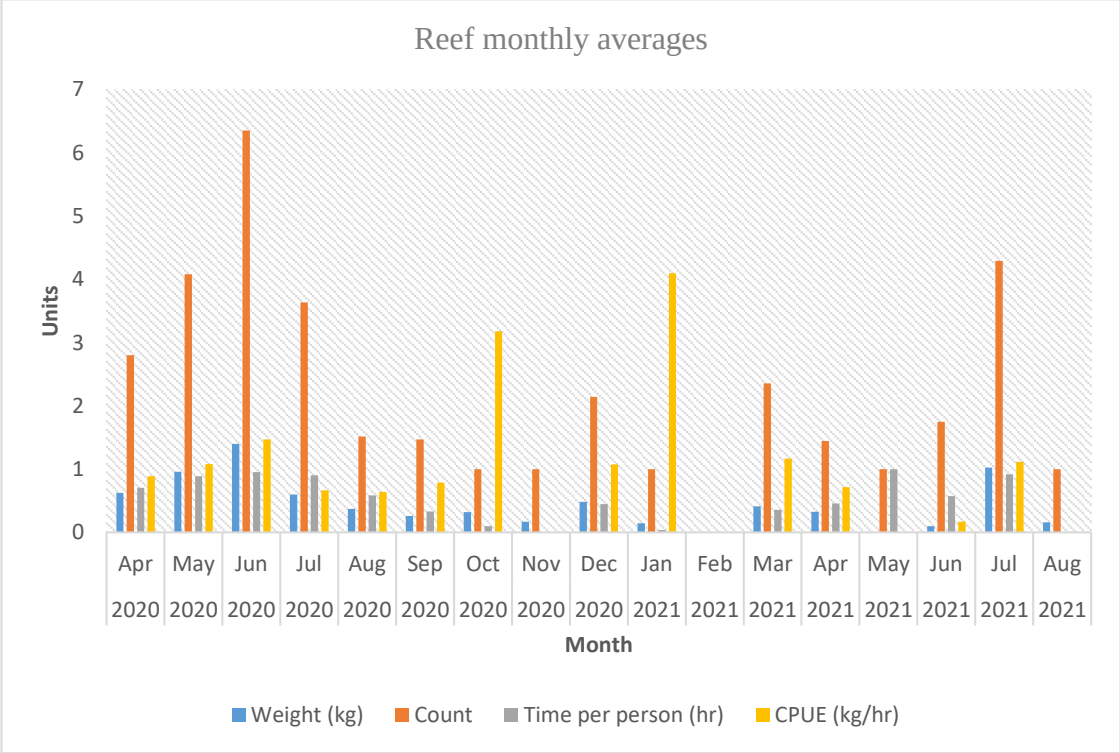

Figure 22. The monthly averages of reef fish caught by weight (kg), count, and time spent fishing per person (hour).

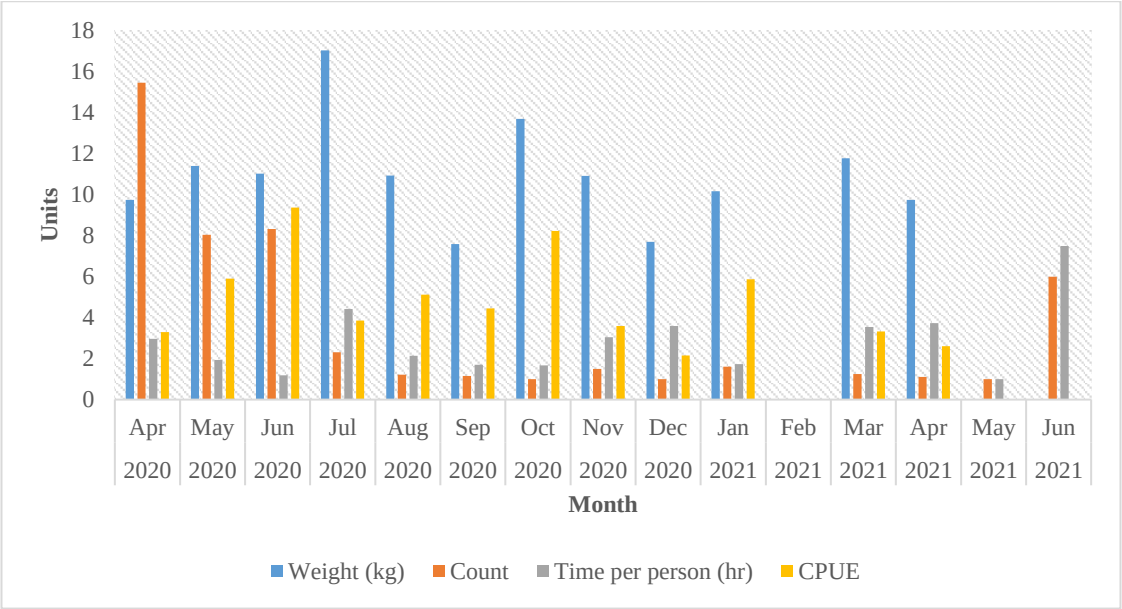

Figure 23. The monthly averages of pelagic fish caught by weight (kg), count, and time spent fishing per person (hour).

Fishing activity took place during all quarters of the year (Figure 21, Figure 22 and Figure 23). As expected, some months were more active than others. Even though fishing information was collected for over a year, it is still difficult to deconstruct some monthly differences. For example, the 2021 July and August results exhibit no pelagic species. Additionally, it is important to note April 2020's abnormally high pelagic count would be a result from the annual fishing competition where fishers targeted fish for with motivations other than subsistence purposes (Figure 23). Conversely, the same cannot be said regarding the reef fishery (Figure 22).

4.4.1.4 Fisher Demography

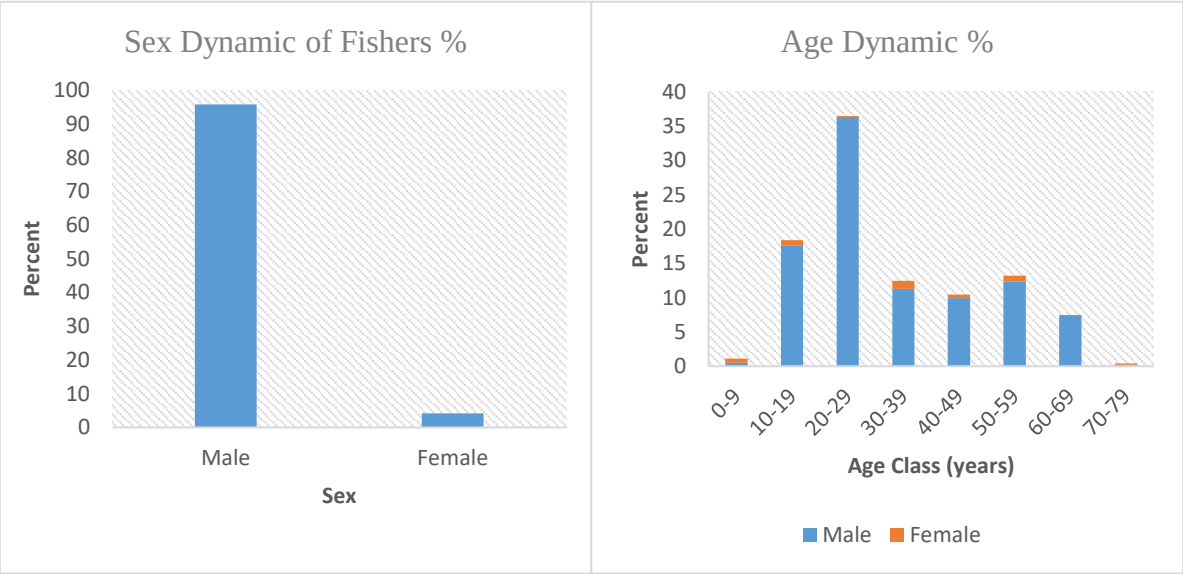

Figure 24. Sex and age dynamics of all fishers recorded during time of study. Note: the figures presented here represent the proportion of fisher time spent (2015 hours of fishing).

There is a marked difference in time spent fishing partitioned by sex (Figure 24). 95.8% of fishers recorded during the study period were males (1930 hours), meanwhile females attributed to 4.2% of the total time spent fishing (84 hours).

The overall age range extends quite broadly from fishers below the age of 10 years old to above 70 years old. As expected, the extreme age classes have the lowest fishing activity. The most active age range are fishers between 20 and 30 years of age accounting for 36% of documented fishers. Although females account for the lowest fishing activity time, they are however active across all age classes, except for between 60 and 70 years old.

4.4.2 Underwater Visual Census

Underwater visual surveys on the western Mitiaro mid-forereef provided abundance estimates from the thirty-two strip line transects. This UVC documented fourteen families and thirty-two species across 1815 fish counted. Surgeonfishes (acanthurids) were by far the most abundant and widespread family (Figure 25). Average surgeonfish density was around 43.8/500m^2 (±5.4 SE) which is over twenty times greater density than the following subsequent families – Labridae 2.6/500m^2 (±0.5 SE) and Balistidae 2.2/500m^2 (±0.4 SE).

Individuals identified at a species level within Acanthuridae are shown in Figure 26 highlighting average densities across nine species. *C. striatus* accounted for around 80% of surgeonfishes with an average density of 36.2/500m^2 (±05.0 SE) followed by *A. guttatus* 4.2/500m^2 (±2.2 SE). and *N. lituratus* 1.5/500m^2 (±0.3 SE).

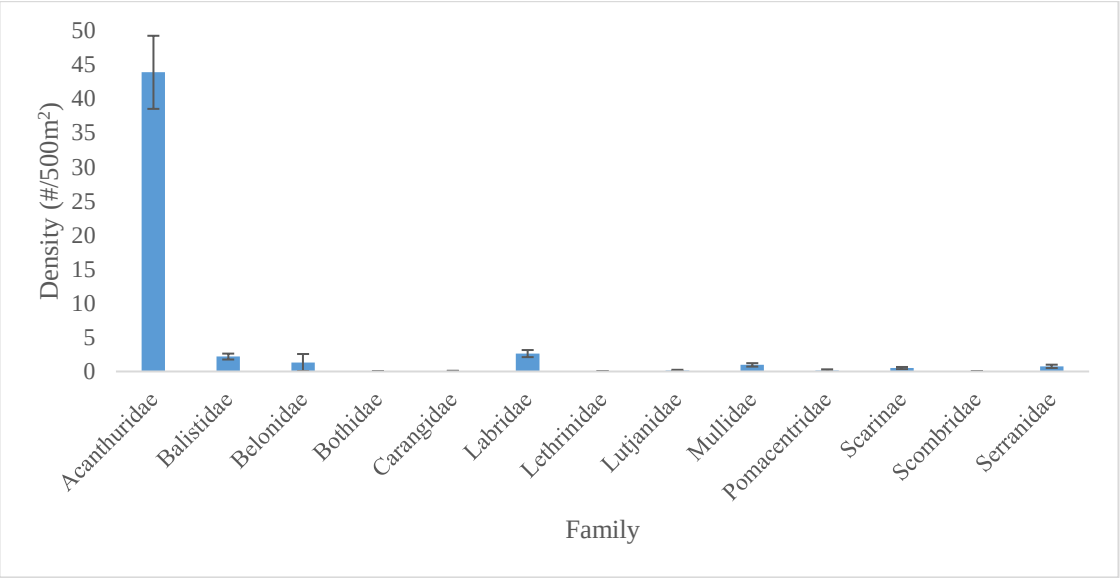

Figure 25. Average density estimates of coral reef fish families per 500 square meters on the western mid-forereef of Mitiaro from the UVC analyses.

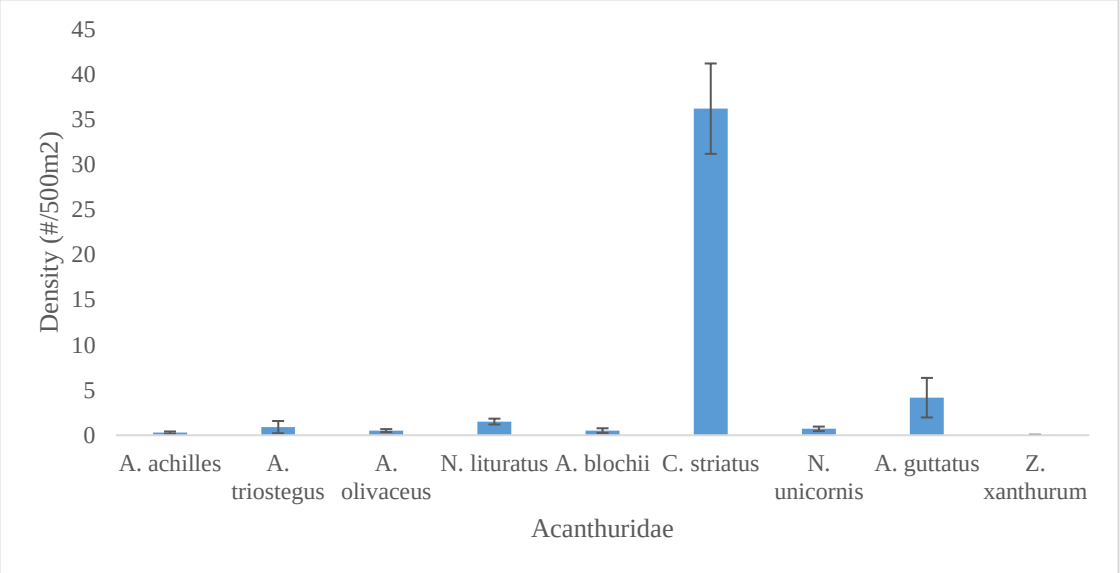

Figure 26. Average density estimates for family, Acanthuridae showing the nine identified species detected within the UVC surveys.

4.4.3 Semi-structured Interviews and Korero

In the context of Mitiaro's fisheries and overall food security, the majority of interviewees (9 out of 13) emphasised the high and fundamental values of fish being a primary source of sustenance in their day-to-day lives both historically and at present (see Table 11). Nine participants also shared that the practice and methods around marine resource harvesting were important lessons to educate the next generation. Together with the skill of being an efficient fisher to hunt for ocean resources, the ability to preserve both marine and terrestrial foods have always been critical for sustaining the community across a shared effort of resource partitioning. However, when asked about the local Mitiaro convenience (Pa's Store) and its role and influence on food security, seven of the participants stated that marine resources are considered more important than food purchased from the store. Moreover, in recent times, food from the shop is claimed to be just a back-up during times of challenging weather conditions that prohibit the community to go fishing safely. The same number of participants also claimed that the readily available foods that are imported from the capital (Rarotonga) is rather a popular preference among the children in the community (<18 years of age). One interviewee further explained that regular access to a shop only became viable around the 1960s and 70s for goods such as flour, rice, cabin bread and tins of corned beef, which slowly started to supplement the traditional school lunches of fish, uto (mature coconut) and nu (immature coconut). This coincided with the gradual increase in employment and government work. Furthermore, six participants described food from the shop as a "luxury".

The topic of various fishing methods employed was also discussed. Five participants spoke of the evolution of fishing methods from their respective times of youth ~30 to 60 years ago. Historically, methods ranged from using iron pole spears (*pata*), handlines and canoes with no outboard motors, nets, wooden hooks crafted with feathers to create lures, and wooden boxes and glass fashioned to a device used to view the reef from above the water (e.g., aqua scope) to target specific fish. However, with the development of the Cook Islands and technological advances, outboard motors became more accessible, the variety of plastic fishing lures and game rods and reels were introduced but were, and still are expensive methods. Although it wasn't as popular as other fishing methods, spearguns also became an effective method for targeting reef fish yet it never completely replaced the iron pole spears. When participants were asked about their fishing method preferences, the consensus was that there is not a particular favoured technique per se, but rather the fishing methods alternated depending on three circumstances: 1) age and health, 2) weather, and 3) targeting specific fish (either during seasonal times, or simply for preference).

Without historical documentation of Mitiaro's fishery catches, several fishing experts shared lived experiences and provided insight into the marine resource trends over time. Over the past 30 to 40 years that they had observed changes within the Mitiaro fishery in multiple

ways. For example, 8 of the 13 participants of the semi-structured interviews shared concerns that fish in general, but with particular reference to two pelagic species, *T. albacares* and *A. solandri* ("'*a'ai*" and "*pa'ara*" in Māori, respectively) are relatively smaller (in size and less fatty) and are fewer in numbers than previously caught. Another informant claimed that it required less effort (less time and bait supply) to achieve an abundant catch that would sustain multiple family households. Furthermore, two local spearers described that reef fish behaviour has also shifted towards being less "tame" and required more effort to catch at present as the reef fish developed fleeing responses to spearers. Another phenomenon spoken about by 12 of the participants, was the *ika tauira*, which is when a large aggregation of juvenile reef fish happens within Mitiaro's reef flats (< 3 inches – suspected to be a mix of surgeonfish, unicornfish and groupers). According to six participants, the *ika tauira* used to occur during the cyclone season (December – April) but it has not happened for the last 20 years. Cyclone season was also mentioned by several participants to be the season for other fish migrations including juvenile goatfish (*koma*), bluefin trevally (*tapa'uru*), and blackjacks (*ru'i*).

The *māroro tu* (flying fish spawning event) was spoken about by nine of the participants. *Māroro tu* is a significant event when a flying fish spawning aggregation occurs close to the coast and can occur multiple times between the months of June and December, but only during the first quarter moon phase. The Māori lunar calendar known as "*Arāpō*", and tides are widely utilised indicators by locals to determine optimal times of fishing or crop planting/harvesting. During the *māroro tu*, there are strict cultural and spiritual rules in place that govern the fishing activities such as the restriction of no motors to be used, and women are prohibited from being at the wharf or on the coast while the men are netting the māroro from their canoes. Another point of interest from five participants were the reports of increased shark encounters. Fishers have found that over the years, shark encounters while fishing has increased and are coming closer to the reef more frequently, leading to losses of gear and catches. However, this has not been linked to any ecological trend or activity.

Cook Islands *ra'ui* are traditional Māori systems of marine (and terrestrial) resource management. Historically, *ra'ui* were put in place and enforced by the *ariki* (chiefs) of the island but are now managed through the island's council. When participants were asked about the purpose of *ra'ui*, six participants said that they are put in place to ensure sustenance. Additionally, five participants specifically shared that *ra'ui* are created for the purpose of preserving fish for people to eat, and not for the purpose of conservation and biodiversity. Therefore, a periodic resource or area closure could take place for an agreed time to allow stocks to regenerate that would eventually reopen to catch and distribute fish among the community or other people. Conversations on *ra'ui* also evolved into investigating to whom they were designed for. Nine people responded that they are commonly for hosting *tere pati* ("traveling party" - visiting groups of people from other islands). One person, however, did not

agree with the notion of constantly reserving resources for *tere pati* groups, as they believed that since *ra'ui* are a result of the local community's abstinence to the closed resource, then the local community should have priority to being fed from the *ra'ui*. Several participants had also disclaimed their observations of community member's breaching *ra'ui* protocol – an indication that everyone does not share the same opinion for certain regulations. It is also believed by some participants that the breaching of *ra'ui* is a cause towards the declining number of fish over the years.

Table 11. Thematic areas raised in semi-structured interviews and korero sessions with expert fishers.

Theme	Topics Shared	Responders (out of 13)
Values/Priorities	Sustenance: marine resources are critical for sharing and feeding the community. Marine harvest education. Imported goods have shifted community diet.	9 (69%) 9 (69%) 7 (53%)
History	Evolution of fishing techniques Smaller and fewer fish. Fish behaviour changes. No more juvenile reef fish aggregations (*ika tauira*).	6 (46%) 8 (61%) 2 (15%) 12 (92%)
Management	*Ra'ui* preserves resources for the people, not the resources themselves. Decline due to abuse e.g., *ra'ui* breach, *ora papua* (poisoning). *Ra'ui* are primarily for guests rather than locals.	5 (38%) 6 (46%) 9 (69%)
Local Knowledge	Cyclone season fish aggregations Flying fish spawning (*māroro tu*) Lunar cycle (*Arāpō*)	6 (46%) 9 (69%) 8 (61%)
Culture/Spirituality	Resources are available as a gift from God. Resources are to be shared with everyone.	1 (7%) 4 (30%)

4.5 Discussion

Pacific Islands small-scale fisheries (SSF) are known to be under-documented. While government-led ecological surveys have been conducted, this study is the first comprehensive coastal fisheries investigation conducted in Mitiaro, Cook Islands integrating detailed CPUE data for both pelagic and reef fisheries, UVCs and semi-structured interviews. The findings in this chapter provide a broad baseline on Mitiaro's subsistence and artisanal SSF, which in turn provide insight to the local marine resources, their management and use. Given the wide array of non-standardised global fishing effort investigations, comparative analysis of temporal and spatial trends was not the overall aim of this study. In fact, my aim as mentioned was, for the first time, to document information of Mitiaro's local fishery and its fishers, which could in time be used as a baseline to understand challenges and solutions unique to Mitiaro. I hope that the findings of this study can also be used to inform baselines of other small island fisheries across the Pacific Islands.

The findings in this study were put together by standardising catch data against the various gear/methods employed for fishing, the types of vessels used, and it highlights the top species caught in which catch-per-unit-effort has been extracted from. Furthermore, the results provide insight into the social dynamics of Mitiaro fisheries including gender roles, age ranges, and anecdotal accounts of historical changes and phenomena in that outline the biological and societal evolution over time. Thus, the results of this study provide empirical evidence necessary for local community leaders and Ministries to make informed decisions on fisheries management that consider subsistence and artisanal livelihoods.

The overall catch landings in Mitiaro proved to be diverse across 22 identified families, with a far wider range of species. However, some species clearly have either preference or viable targetability by local fishers. Reviewing the catch data revealed the reef fisheries accounted for 14% of the overall catch from April 2020 to August 2021 with a total estimated catch weight of around 526kg. The remaining 86% of catch comprised of pelagic species, totalling to around an estimated 4-tonnes. Considering that the average weight of reef fishes is considerably lower than that of pelagic catches, this highlights that the count for targeted reef fish is high, underlining the fundamental importance of Mitiaro's reef fisheries as a source of the island's population's nutrition and livelihood.

Within the Mitiaro reef fisheries, the top three families Carangidae, Acanthuridae and Serranidae (e.g., trevallies, surgeonfishes, and groupers respectively) accounted for over 70% of all fish caught across a total of 19 identified families. With the addition to the top three families, Kyphosidae and Scarinae account for 88% of the reef fish caught. Some of these top families are seen in other Pacific fisheries also. For example, in a Palauan fishery, acanthurids, serranids and scarids along with 3 other families not noted here also contributed to around 90% of total

reef fish catches (Wabnitz et al., 2018). Serranids have also been identified as a popular targeted family within the Great Barrier Reef (Frisch et al., 2008). The results of this paper suggest that there could be varied preferences for reef fishes across different trophic levels shown by the high levels of carangids and acanthurids. However, there is a much higher catch of Carangids despite less time spent fishing compared to acanthurids. A comprehensive assessment of catch from an America Samoan outer island reef, also showed Carangids to account for the highest catch but across both reef and pelagic fisheries (P. Craig et al., 2008). Species that are targeted tend to vary across different coastal communities depending on reef fish assemblages, methods employed and fishing pressure history as well as post-harvest opportunities (Pavlowich & Kapuscinski, 2017) making SSF a complex topic. Interestingly, Scarinae ranked the fifth highest in catch (4.7%) which has shown to be higher or most targeted across other Pacific Island nations and coastal communities (Aswani & Sabetian, 2010; Barbosa et al., 2021; Pavlowich & Kapuscinski, 2017).

Pelagic fisheries catch consisted of three families, Scombridae (84%), Exocoetidae (13%), and Sphyraenidae (2%). Five species within Scombridae were identified, *T. albacares* accounting for 84% of the catch followed by *A. solandri* (10%). This is no surprise as tuna fisheries have a vital role in the economy and food security of many Pacific Island nations (Bell et al., 2015). *C. poecilopterus* was the only specie identified within Exocoetidae and two species of barracuda were identified within family Sphyraenidae, *S. barracuda* and *S. qenie*. *S. qenie* was a poorly documented species as they were typically targeted between the hours 2100 and 0600. Therefore, they are highly underrepresented. Similarly, it is important to note that Exocoetidae (flying fish) is also considered to be highly underrepresented due to sampling limitations. There are two reasons that influence the statistics: 1) flying fish are normally targeted between the hours 2100 and 0000 which is beyond the sampling procedure. Opportune scenarios were undertaken in which flying fish count could be estimated based on their sales the following morning after being caught. Weights were estimated using (FFA, 1993). The second reason, 2) currently, unlike any other outer island in the Cook Islands, Mitiaro experiences unique aggregations of spawning flying fish during the second half of the year during the first quarter moon phases. At these times, hundreds, or maybe thousands of flying fish may be caught using nets. This event is not always guaranteed each month and there are brief windows of time to harvest the spawning stock. Due to these reasons, it was difficult to record samples.

This catch survey approach lacked (for the most part) night-time data collection as it was primarily focused on daytime where most fishers were active. It is important to acknowledge that there was a considerable amount of harbour and boat fishing (flying fish and barracuda) at night, but surveying circumstances did not allow night fishing catch documentation. Another limitation was that catch surveys primarily targeted vessel and shore-based catches at a single location – Mitiaro Harbour. This location was key for surveying most

of the fishing activities. However, it resulted in being unable to assess shore-based fishers that may have travelled to other reef flats to fish. Based on the participatory observation, it is also important to note that there was a considerable number of shore-based fishers around the island during the survey times. In some instances, community members made efforts to declare their catches in passing in which these data were documented but not first-hand observed.

This standardised catch-per-unit-effort (CPUE) data is not to be used independently to determine stock status due to the disproportional relationship between CPUE and abundance (Maunder et al., 2006). In other words, fishery-independent data is advocated to provide better indices for stock assessments. However, such data comes with greater difficulty and at greater costs leaving CPUE to be used to generate a relative abundance index (Okamura et al., 2018). For example, over time stock size may show a decline, but CPUE can remain high or consistent depending on the fishing gear selectivity and effectiveness within a given environment which is addressed here. It is also important to note some results show relatively high CPUE rates which is likely due to the short amount of time spent fishing using specific methods for fishes. The chances of catching large fish biomass within short timeframes have resulted in high CPUE rates which are likely to be misleading and would require more documentation of such scenarios.

Due to the practice and nature of the pelagic fisheries in Mitiaro requiring canoes and boats, fishers are likely to land their catches at the Mitiaro harbour. Therefore, pelagic fishes are more viable and likely accessible for monitoring and documentation within a given area. On the other hand, reef fish species are caught from vessels as well as surf casting along the reef flats around the entirety of Mitiaro's circumference. By documenting most of the catch at the Mitiaro harbour, this indicates the projected extent at which the reef fisheries may result in being underestimated, potentially skewing perceptions of the overall fishery and when distinguishing efforts between reef and pelagic fisheries. Furthermore, the estimated 4-tonnes of pelagic catch in this study are substantial compared to previous unpublished government reported catches for Mitiaro based on the catch, fishing hours and CPUE. Estimates showed that the total artisanal catch (likely to be limited to pelagic species) in Mitiaro was 15 mt in 2017, a major decline from 39 mt in 2015 (OFD, 2015, 2018). However, 2016's catch statistics in the 2016 report, differs to 2016's catch statistics reported in the 2017 report (OFD, 2016). This indicates inconsistent data reporting standards which can be misleading. It is also unclear how the catch estimates are generated based on the reported catches. Estimates for the Cook Islands' coastal fisheries has also been questioned whether some information could be casual speculation (Gillett & Tauati, 2018). This sort of assessment would be required to be conducted for each island community. Due to the differences in reef structure, number of fishing community members and socio-ecological behaviours, assessments are required to be undertaken within each unique location. For example, Bruckner (2014) highlighted key differences between other

islands in the Cook Islands, such as Rarotonga, Aitutaki and Palmerston islands in taxa, fish sizes, and abundance and diversity levels. On an economic front, the improvement of coastal fisheries monitoring would provide necessary assistance in assessing the opportunities available that advance economic avenues in the private sector through the development of sustainable small-scale local export, while maintaining local cultural values and traditions.

Applying the CPUE directly to fish families shows the relative outcomes of 'success' when targeting specific fish. The CPUE rates of the top three reef fish species across fishing methods vary widely but may indicate changes over time within populations when considered alongside other fishing variables in Mitiaro. However, these results demonstrate the difficulties in generalising CPUE as identified in other studies due to the variability of factors including mixed species, gear, vessels, decentralisation of post-harvest processes, and ecology (Castello et al., 2013; Chuenpagdee et al., 2006; Salas et al., 2007). It is also possible that the differences in CPUE can be influenced by the skill level of fishers (Frisch et al., 2008) which is not considered in this paper. Therefore, to assist overcoming SSF heterogeneity particularly in unregulated fisheries, perhaps localised efforts in centralising fishing activity may contribute to more precise fishery information.

Besides the fluctuating levels of CPUE in the overall fishery (figure 1), effort proved to be relatively consistent over the study period. This may reflect adaptive fishing behaviours that still achieved acceptable harvests for sustenance (or income) by targeting different species (Butler, 2001; Salas et al., 2004), or changing fishing locations and methods (S. Albert et al., 2015). Alternatively, the 'prey return fishing strategy' introduced in (Butler, 2001), describes reduced catches of specific fish species leads to targeting other species as opposed to needing to shift or increase fishing effort. Monitoring these responses (the need to adjust fishing range/methods/effort) to ecological and resource change may help local Cook Islands communities and institutes to improve fisheries management strategies.

Nine different fishing methods were documented across three mobile methods (canoe, boat, surfcasting). It is evident that different fishing methods/gear types serve different purposes for targeting certain fish. Overall, addressing the top three reef species, land-based fishing achieved the highest CPUE rate for the top three families. CPUE rates for spearing targeting acanthurids from a canoe was interestingly higher than land-based spearing. Spearers targeting fish when accompanied by a manned canoe, extra time and effort would be allocated to returning each fish to the canoe for storage and minimise shark attractions. Whereas land-based spearers would carry a wire around their waist that they would skewer fish for storage, allowing for a quicker recovery to target the next fish. When comparing spearing to line-fishing Frisch et al. (2008) relates this to "good" fishing sessions whereby if fish are abundant then line-fishers may achieve a higher CPUE. On the other hand, spearers become "gear saturated" meaning that shooting, retrieving, and storing fish can result in lower CPUE rates.

Land-based fishing methods proved to be the most popular method for targeting reef fish (451 hours). This is likely due to the more viable access to fishing activity. For example, not every fisher owned a canoe, and the price of fuel for the boat outboard motors was a considerable financial factor. Additionally, inshore waters can be exposed to different weather conditions that limit vessel use. Across all modes of transport in the reef fisheries, using baited lines was the most popular fishing method (331 hours) followed by spear (176 hours). In terms of biomass caught, baited lines caught 252kg while speared fish biomass accumulated to 177kg (75kg difference). This differs to (Frisch et al., 2008), whereby line- and spearfishing achieved similar results of exploitation in fish count and biomass. Additionally, they suggested that line- and spear fishers overlapped in species composition. In this study, it is quite possible for overlap too; albeit it may be a one-way overlap. For example, using a baited line for herbivores or detritivores (e.g., acanthurids, scarids) is considered less effective than using spear (Table 8). Spearing, on the other hand allows for targeting specific fish which can include species caught efficiently with a line (Mann et al., 1997). Targeting specific species also minimises bycatch of non-target species which makes it efficient, therefore if mismanaged, can be considered destructive (Barbosa et al., 2021; Frisch et al., 2012).

This drop-stone method is described in (Moarii & Leproux, 1996) can only be deployed from vessels. It was primarily used from canoes to target pelagic species and had the greatest fisher effort (667 hours). Considering that canoes are limited to a singular fisher, the results indicate that canoes are the favourable vessel compared to the use of boats that can host several fishers (higher fisher hours per fishing session). The pelagic CPUE levels of drop-stone 1.70_{boat} and 2.02_{canoe} (kg/hr) are like those found in (Albert et al., 2014) however, it does not distinguish between vessel type. According to Gillett and Tauati (2018) use of traditional methods of tuna fishing (i.e., drop-stone) are declining by being replaced by trolling in the Pacific. Oceanic currents are also deemed to be impacting drop-stone use in the Cook Islands (Rongo & Dyer, 2015). This might be supported by the contrast in this study, whereby despite a higher overall effort for drop-stone, trolling resulted in noticeably higher fish biomass and CPUE rate.

The underwater visual censuses (UVC) aimed to provide a fishery-independent scope to estimate the overall fish assemblages of thirteen identified taxa at the family level. Acanthuridae represented highest average density, followed by Labridae, and Balistidae, respectively. However, Acanthuridae were significantly dominant on the mid-forereef area by a considerable margin (Figure 25) accounting for around 74% of total fish count and represents a higher average density than Labridae by 20-fold. Consistent with other surveys, acanthurids are known herbivores to dominate reefs throughout the Indo-Pacific and Caribbean (A. Friedlander & DeMartini, 2002; Roff & Mumby, 2012). Their high presence is attributed to their high grazing ability as a critical role within coral reef ecology (Bellwood et al., 2014; Marshell & Mumby,

2015). So much so, that acanthurid decline is linked to negative trophic cascade and ecosystem changes (Hughes, 1994; O'leary & Mcclanahan, 2010).

With respect to fisheries at a global scale, subsistence and artisanal fishers heavily exploit acanthurids (Craig et al., 2008; Craig et al., 1997; Ford et al., 2016; Tebbett et al., 2022). In the insular Pacific, they are also considered the most commercially valuable (B. M. Taylor, 2019). Compared to the coral reef catch survey (Table 2), acanthurids accounted for the second highest catch (22%) following Carangidae (30%). Similar patterns were also observed in Russ et al. (2004). However, it is important to note that by accounting for other identified fish families as detected from the line transects, they fail to align with the information presented in the catch dataset. When comparing the two methods to estimate abundance it is also worth considering that the catchability of fishes is likely to create bias in the CPUE estimates (Bacheler et al., 2017; Connell et al., 1998). However, this study did not aim to validate the relationship between the visual counts and CPUE, but it does indicate a relative proportionality – or in this case, the lack of. Thus, more detailed surveys are required that also consider fish size, biomass, and multiple habitat types.

At a species level, *Ctenochaetus striatus* constituted for 86% of the observed acanthurids across the thirty-two transects, which is a noticeably higher representation than other species of acanthurids identified in this study. *C. striatus* was also frequently observed in Mitiaro across ten sites including the site in this study (Kora et al., 2018). The low counts of *Acanthurus achilles* in relation to the catch data also prompts inquiries. The fact that they form the highest caught acanthurid, it would be anticipated that these values would reflect the data derived from the UVC more closely. Currently, the meaning behind this is unclear, though it is plausible to consider that the data may reflect habitat preferences, food availability, and the strategies employed by fishers. With the contrast abundances of high targeted *C. striatus* (brushers) and *A. achilles* (croppers), the different feeding strategies evident from tooth morphology and alimentary tract point towards food availability with habitat type variation being a suspected corollary (Tebbett et al., 2022). High herbivore biomass has been associated with reef crests as opposed to the deeper mid- and outer-shelf parts of the forereef correlated to macroalgal cover (Wismer et al., 2009), which also correlates with spear fisher location preferences for targeting surgeonfishes as seen in the catch data (pers. Obs., A. Vavia). However, to make further general inferences for surgeonfish distribution in Mitiaro, would require a more robust survey.

Information collected from the semi-structured interviews and korero with expert fishers provided valuable insight into the Mitiaro fisheries and the perceptions that have shaped fishing activities. There were no full-time fishers on Mitiaro as most participants had jobs and other livelihood commitments. However, fishing occurred when circumstances permitted (weather conditions, commitments etc.) and has been a long practice as a source of sustenance.

This information is explored in further detail used to describe Mitiaro philosophies that influence marine resource use (see chapter 5).

Local ecological knowledge (commonly used interchangeably with 'traditional ecological knowledge') played a key role in Mitiaro's community that influenced both fishing and planting activity. The primary example described here is the aggregation of flying fish in Mitiaro for spawning during the first quarter moon phases during the second half of the year. Following these aggregations, particularly in the later part of the year in the lead up to the cyclone season (December – April), the presence of other fish species such as *A. solandri* become abundant and are noticeably heavier and have enlarged gonads. Along with other local knowledge reports on the cyclone season, it appears to be a period with abundant juvenile reef fish species suggesting that the latter half of the year may be a critical moment for mass fish spawning across multiple species. This would also coincide with the no longer occurring *ika tauira* event.

The concerns around pelagic species being smaller in size and numbers over the past 40 years observed by the fishers suggests that there is a decline in Mitiaro's SSF over a large temporal scale. This aligns with the observed changes over the last 3 to 5 decades in the wider Cook Islands (Rongo & Dyer, 2015). If the generalised notion that the level of reliance on local fisheries has decreased as imported goods have increased over that same period, this would suggest that the fisheries decline may be more significant than it appears. Despite poor statistical documentation, this decline is also indicated in the government reports (OFD, 2015, 2016, 2018), however the degree of decline remains unclear. Additionally, like other neighbouring islands, the nation has undergone a population decline due to economic limitations within places such as Mitiaro resulting in emigration to New Zealand or Australia. This might suggest that with population declines, excessive fishing might still be occurring, or other factors are influencing a decline in local fisheries.

A reason that could explain the decline is the improved access to advanced fishing equipment increasing overall fishing efficiency. Other introduced technological advances over the past four decades include refrigerating systems enabling food storage in preparation for seasons of poor weather conditions and limited fishing opportunities. These advances also support within the context of the Cook Islands' artisanal fisher economy allowing the sale and distribution of Mitiaro fish to the Mitiaro community or the more lucrative Rarotongan market. Considering that the employment opportunities are limited on Mitiaro, artisanal fisheries may be on a gradual increase. If left unmanaged, such developments leaves the fisheries prone to potential binge activity which could contribute to excessive fishing.

Discussions and anecdotal accounts on Mitiaro reef fisheries were critical in that they are poorly statistically documented. However, there was no mention of a decline within the reef

fisheries besides the cease of the '*ika tauira*' event consisting of aggregations of juvenile reef fish, namely, surgeonfish, unicornfish, and groupers for the past two decades. Interviewees described bulk harvests during these events but did not allude to impacts on mature populations of reef fish.

The behaviour of reef fish species has also been described to have developed an increased awareness of fisher presence in certain parts of the reef that had made spearfishing activity difficult. Thus, some parts of the reef may result in lesser CPUE. Through personal observation, the fish in commonly accessed reefs (Western Mitiaro) tend to be markedly more difficult to catch than less frequented reefs (Eastern Mitiaro) due to more rapid fleeing responses (compare to Table 10). Learning mechanisms including induced timidity has been detected in target species more than non-target species. Fisher's apply pressure and tend to target "bolder" fish could influence a higher presence of timid fish in excessively fished areas (Sbragaglia et al., 2018). Other studies have also highlighted greater fleeing responses in unprotected areas compared to protected areas (Cohen & Alexander, 2013; Côté et al., 2014; Januchowski-Hartley et al., 2011). Further studies would benefit from integrating spatial components to address any variation in fishing effort and CPUE which may also underline the impacts of fishing pressure.

Considering the importance of fisheries to food security in Mitiaro, the practice of local *ra'ui* closures is a testament to that fact. However, it's important to note that the conditions that a ra'ui constitutes may vary within and across island communities as they are designed to meet the purpose of local needs and ecology (e.g., *ra'ui* in Mitiaro could significantly differ in multiple aspects of marine resource management to neighbouring islands). The undocumented but observed ecological responses to marine exploitation over time involves continuous adaptations to *ra'ui* (and other customary marine tenure) regulations to achieve desired resource results (Chambers, 2016; Hviding, 1998). This is possible since *ra'ui* are governed through traditional leadership and community instead of governmental legal enforcement (Hoffmann, 2002; Tiraa, 2006) like their unsuccessful counterparts; Western marine protected areas (Cinner & Aswani, 2007; Drumm, 2004). Nevertheless, there are challenges synonymous to Western MPA's including cases of lack of compliance. This could be due to disagreements on *ra'ui* locations and access rights, or possibly being driven by negative fish assemblage changes in response to concentrated fishing pressures in open areas.

4.6 Conclusion

The findings in this study brings about the following insights into Mitiaro's coastal fisheries:

1) The estimated overall yield (4.5-tonnes) for Mitiaro fisheries provides a detailed snapshot of the contributions to the local livelihood. Here, it demonstrates the importance of marine resources to the Mitiaro diet in terms of nutrition and subsidy to living costs. This can also be observed by the overall constant fishing effort over the study period. However, the observed gradual decline over the past four decades in pelagic fish and the potential pressure shift towards reef species should be better monitored.

2) CPUE rates should also consider fishers' targeting intent to account for the time spent on unsuccessful fishing sessions. This would provide more accurate estimates of CPUE rates for each species.

3) Acanthurids appear to dominate the western forereef but is the only family that closely resembles relativity to the catch data. This is suspected to be due to transect survey sampling location bias.

4) Taking into account that there are mixed views on ra'ui spatial placement and purpose, it is worth examining multi-faceted options to locally led marine resource management. This could be spatial and temporal plans that consider gear sensitivity, spawning seasonality, species selection or size quota as opposed to overall periodic closures in a location. This may achieve greater levels of compliance, and easing fishing pressure by diversifying locations in which certain fish are targeted e.g., eastern Mitiaro.

5) The influence of the nation's commercial fisheries could be investigated closer in conjunction with small scale fisheries to determine whether there are impacts on local catch rates of pelagic species.

6) The findings presented here for Mitiaro can be improved with regular and long term catch and effort monitoring for both reef and pelagic fisheries that include spatial components. This can also be applied to neighbouring islands.

Chapter 5

Marara te tai: Towards a Mitiaro marine ecology

In this chapter, I explore aspects of the Mitiaro worldview of marine resources to address my third objective. In order to understand the socio-ecological relationship between Mitiaro people and the marine environment, it was critical to become cognisant of the local values, practices and knowledge within Mitiaro. To achieve this, I used ethnography as a participant observer. I use a multiple narrative analysis as a holistic approach to underline the stories involving experiences of key interview participants that relate to marine resources and food security. I show that the use and management of marine resources are influenced by the physical, cultural, and spiritual Mitiaro values, that centre on the wellbeing of the Mitiaro community. Furthermore, I demonstrate the importance of embracing local and traditional knowledge systems as an effective tool to understanding diverse values of conservation. In terms of marine management and conservation, developing strategies that align with local worldviews, history, tradition, and knowledge is critical to management success. Moreover, integrating local values and practices may reveal opportunities for further research and development for wellbeing and food security.

5.1 Abstract

This paper presents an introduction to fishing-related concepts and practices of the people of Mitiaro, a remote island in the Cook Islands nation in the South Pacific. I spent 18 months living in the Mitiaro community as an embedded participatory researcher, and conducted conversational interviews with 13 local fishing experts. In this research I am drawing on a range of sources, including my own experiences and observations, as well as the interview data and literature. The purpose of this paper is to begin to delineate an Indigenous account of marine ecology through a Mitiaro worldview and philosophy.

5.2 Keywords

Human ecology, Indigenous, Marine ecology, Mitiaro, Ra'ui

5.3 Introduction

Mitiaro (traditionally called Nukuroa) is an island in the Cook Islands nation, located 264 km northeast of the country's capital island of Rarotonga – see Figure 27. Mitiaro is one of the smallest islands with a continuous history of inhabitation and its own sense of identity, and hence sub-culture. The people of Mitiaro refer to themselves as Māori, which is a traditional word originally meaning ordinary or normal.

Mitiaro is a small volcanic raised island with its widest diameter being 6 km across and a land area of approximately 22 km^2 surrounded by a fringing reef flat, with makatea (volcanic rock) and limestone making up a significant portion of its land area, and limited fertile soil within the island's interior. The volcanic geography displays fossils of corals and invertebrates that can be found engraved in the makatea inland, pointing to the island's ancient subaquatic past. Significant to Mitiaro are the two central brackish lakes, Rotonui (Big Lake) and Rotoiti (Small Lake), and the myriad freshwater caves around the island.

Atai, Auta, Mangarei, and Takaue are the four tapere (villages) that make up Mitiaro society. Before the arrival of Christianity in the 1800s, these tapere were located in central parts of the island, as indicated in Figure 27. Since then, they have migrated to the western leeward coast, forming a larger settlement near the Te Ao Omutu harbour area, where the entire population now resides (Figure 28. Centre of the Mitiaro township on the western side of the island.The original inland sites of the tapere are reserved for plantations. There are also two are 'uipā'anga (meeting houses) that are used as community halls for events and functions, dancing

and singing practices and performances, and welcoming and hosting manu'iri (visitors) to the community.

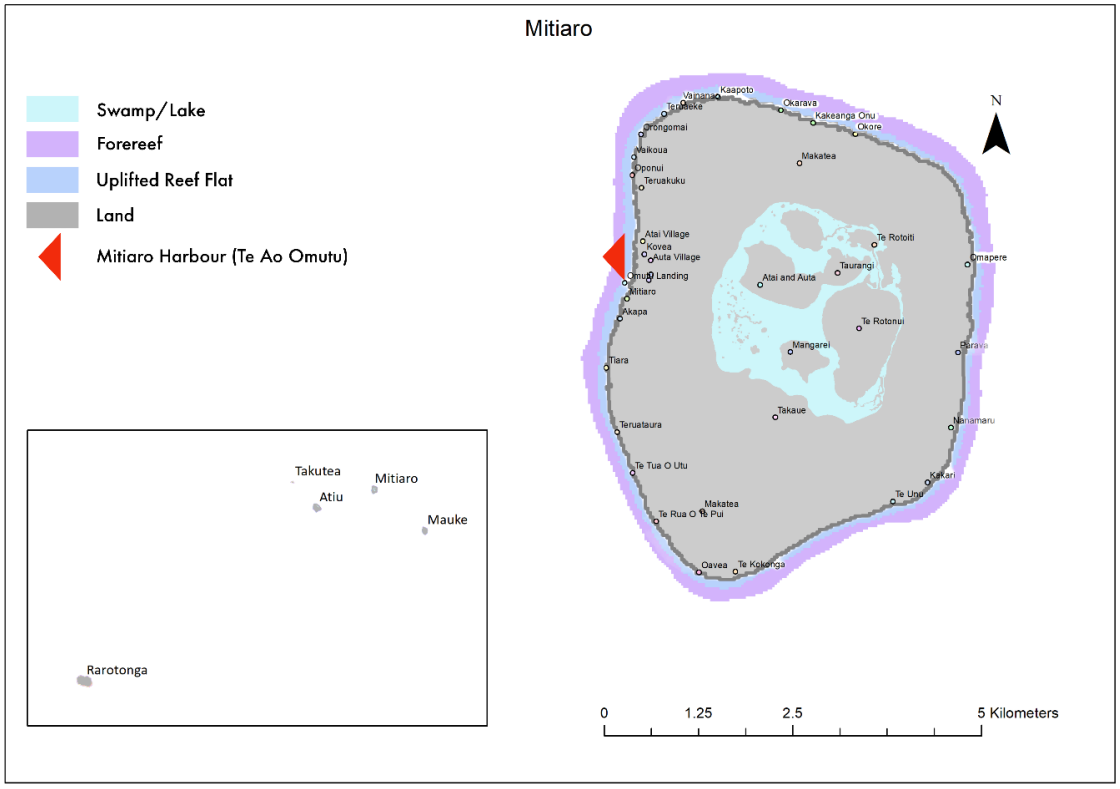

Figure 27: Map of Mitiaro

The population of Mitiaro consists of 155 people (Cook Islands Statistics Office, 2022), accounting for about 1% of the total Cook Islands' population. The government sector is the predominant employer in the cash economy, with very few private sector businesses (tourism provider, accommodation, retail). Some households are supported by cash 'remittances' received from younger adults working overseas in New Zealand or Australia. A significant portion of living 'expenses' for Mitiaro families, however, are provided by subsistence-based activities that make up the basis of the primary diet. These include working inland plantations producing for local root crops (taro, arrowroot), fruit plantations, and home gardens for leafy vegetables. These plantations are communal, the crops shared with all. Livestock in the form of feral goats, pigs and chickens roaming the island may be hunted, or caught for farming, but the main protein source in the diet of the Mitiaro people comes from various species of reef and pelagic finfish (see Figure 29 on page 96 below).

Figure 28. Centre of the Mitiaro township on the western side of the island.

Religion and spirituality are important influences on the people of Mitiaro. Christianity has become strongly embedded throughout Cook Islands culture; on Mitiaro both Catholic and Protestant churches are well patronised and held in the highest regard. Church influence is interwoven with traditional culture in the everyday lives of the people. Christianity arrived in Mitiaro in 1823 with Rev. John Williams of the London Missionary Society (LMS), who was accompanied by Ngaka'ara, the high chief Rongomatane Ariki of Atiu. The people of Mitiaro were converted to Christianity and their old ways were extinguished. Indigenous gods were forgotten; carvings and other iconography were burned and the marae were destroyed. The church influenced the people of Mitiaro to abolish their traditional customs and behaviours that were seen as adultery, promiscuity and cannibalism, and end warfare out of loyalty to their new religion. The influence of Christianity led to the cessation of traditional ongoing battles between Mitiaro and their neighbouring islands of Atiu and Mauke.

The ready acceptance of Christianity in Mitiaro is suggested to be due to parallels between the gospel and traditional Mitiaro spiritual beliefs (Tumu-Makara, 2016). These parallels include the belief in gods as supernatural deities, and in places of ultimate spiritual significance, such as 'Avaiki (underworld). Both Christian and Māori forms of belief include a wider spiritual element that extends beyond the self, and which conceivably influences the knowledge passed down on Mitiaro. Intergenerational oral exchanges concerning ecological phenomena contribute to building the traditional ecological knowledge (TEK) of Mitiaro, which has existed since long before the arrival of the first Christian missionaries. As explored in the sections below, religious beliefs intersect with certain traditional knowledges in their influence

on the cultural concepts and behaviours that constitute local equivalents of aspects of marine ecology.

TEK is often seen as the antithesis of science, owing to its lack of measurability, and thus perceived lack of objectivity. Scientific studies of fisheries and marine ecology typically focus on empirical research methodologies, removing humans from the ecological matrix. But such studies thereby fail to engage with one of the key drivers of marine ecological change, namely people. Those who engage with the marine environments are often neglected as key actors in research potentially disregarding valuable information (Jentoft et al., 1998; Lavoie et al., 2019). Therefore, scientific approaches overlook local and traditional knowledge systems, a problem recognised in the Pacific (Aswani & Hamilton, 2004; Cinner & Aswani, 2007; Hviding, 2006; Johannes et al., 2000). These systems which are built up from countless generations of detailed observations and trial and error through experience in and of the local environment, as well as political ecology and overall socioecological relationships (Berkes et al., 2000).

This dilemma is embodied in the concept of *ethnoscience*, a term from the social sciences used to denote a knowledge system that enables a cultural group to survive and thrive in their homelands (Stewart, 2015). In these terms, the traditional knowledge of Mitiaro or any other indigenous culture can legitimately be regarded as an ethnoscience. On the other hand, the word 'science,' whilst originating in an ancient word meaning 'knowledge' in general, today refers to a worldwide set of systems and structures based on empirical research according to scientific method that have generated unprecedented levels of access to and power over knowledge of all manner of natural phenomena. Yet because of its hard boundaries, science, in its generally-accepted sense, cannot study the essence of being human, and what people know and value about the natural world, including fish, fishing and marine ecology.

Work such as this, which attempts to take TEK seriously, pushes against the boundaries of science and its disciplines, including the young discipline of ecology that became prominent only since about 1950, when it became clear that (Western) human activity was damaging the environment. Human ecology recognises humans as an ecological factor, and in scientific terms, this research could be classed as contributing to an Indigenous or 'kincentric' form of human ecology (Salmón, 2000). Since the paradigms and methods in which I have trained as a marine scientist cannot explore TEK, specifically the TEK of Mitiaro, I have opted in this research to enlarge my purview using an Indigenous Studies approach (Andersen & O'Brien, 2016; Hokowhitu et al., 2020). This approach centres the Indigenous viewpoint, examining knowledge, language and culture from the inside, whereby Indigenous knowledge, language, culture and people are regarded as valid and ethically-significant, capable of holding and generating valuable insights about people and the environment.

5.3.1 Introducing the researcher

I am a Māori Cook Islands male who akapapa'anga (has genealogical connections) to Mitiaro and Mangaia through my ancestry, as well as to Fiji. I have always considered my ethnicity to be Māori Cook Islands, but I was born and raised in New Zealand. As I was growing up, I was taken on several visits over the years to Rarotonga, and a few trips to Mitiaro. Though my upbringing was physically remote from Mitiaro, my Māori Cook Islands extended family in New Zealand exposed me to cultural customs, arts and performance. I was inducted into a watered-down form of Māori culture, with limits imposed by the harsh realities and obligations of New Zealand lifestyles. As a known grandchild of Mitiaro, however, I benefited from family relationships and support networks that enabled my time living and researching in the Mitiaro community.

Before going to live in Mitiaro, I held a romantic notion of ra'ui as an Indigenous way to care for the fish and the sea. Talking with an older marine scientist who had spent decades researching in the Pacific and was a fluent speaker of Cook Islands Māori, I mentioned wanting to learn more about how ra'ui works. He replied, "That's good. But it's not what you think. I'm not telling you, you go there and you learn from the people. It's not what you think." I contradicted him, "Nah, I think I already know."

Later, when I was living in Mitiaro and July came, the ra'ui was opened. Suddenly we were told to go and harvest. Harvest? I asked myself - surely not? Yet two days of intense harvesting followed, taking large quantities of all kinds of fish, which was then shared out amongst everyone in the community. This experience forced me to re-examine everything I thought I knew about ra'ui, thinking more deeply, until I finally understood. What I learned is outlined in the section about ra'ui on page 106, below.

This research explores the holistic nature of the Mitiaro community: language, history, values and cultural concepts associated with local marine ecology. Through a unique insider perspective, this paper offers an introduction to traditional customs and concepts relating to how marine resources are managed, exploited and conserved in Mitiaro.

5.4 Methodology

The overall approach taken in presenting this research is to use Mitiaro as the frame of reference, through which to examine and write about traditional knowledge relating to fishing and marine ecology. This approach attempts to reverse the usual yardstick of scientific research in an Indigenous community by centring and normalising Mitiaro knowledge and perspectives.

Information was collected from a range of sources, including interviews with 13 local expert fishers. Prior to the interviews, I lived in the community for 18 months, immersed in my research context and participating in daily life. My family connections and ancestry from Mitiaro smoothed the way for me to undertake this embedded research.

My methods enabled me to continuously and opportunistically document a wide array of daily rituals of the Mitiaro community, and write detailed accounts of the physical, social, spiritual, and cultural interactions between people and their surroundings. This immersion in the Mitiaro culture gave me direct access to the diverse worldviews of the Mitiaro people, so that I could capture not only what was spoken or physically conveyed, but also the intricate subtleties of messages from things left unsaid, or at least interpret these nuances according to my degree of understanding.

5.4.1 Exploratory visit

I was determined to do my empirical research on Mitiaro since it is my ancestral home, and I wanted to help and serve my people. Soon after enrolling, my supervisor and I travelled to Mitiaro for 10 days for an exploratory visit to assess the feasibility of basing my study there (Figure 28). Through a family connection, we were provided with a house to stay in. During this visit, we met with the Mitiaro Island Council so that I could outline my research plans to them, and seek their approval. Another aim of this trip was to establish which fish species to study that were relevant to the local people, which I achieved by talking to people and watching what they were catching. By coincidence, we were there when the first-ever Mitiaro fishing competition took place. It was a snapshot of the centrality of fishing in the local social calendar, as the whole population of the island turned out to participate or watch.

The paragraphs below describe the strands of data collection and analysis woven like kikau (coconut fronds) into this paper, noting that in this approach, ‘data collection’ and ‘data analysis’ are merged within a holistic practice of writing. These kikau strands are: participant ethnography, interviews, autoethnography (AE), narratives, and writing as a method of inquiry.

5.4.2 Participant Ethnography

The term ‘embedded observation’ is apt to describe my approach to participant ethnography (Lewis & Russell, 2011), reflecting the fact that I lived as part of the Mitiaro people and lifestyle for an extended period, from December 2019 to September 2021. I shared local commitments: responsibilities to cater for, pigs to feed and butcher when needed, taro plantations to maintain, arrowroot fields to plant and tend. I participated in church, helped with

island formalities and festivities, led visitors on island tours, performed at cultural arts events, engaged in island political exchanges, made loving allies, and formed non-hostile adversaries. This embeddedness into Mitiaro society enabled me to form genuine kinship relationships and become, to some extent, no longer a 'researcher' but, instead, just another Mitiaroan. Mitiaro was no longer just my subject; my entire personal existence within 'everything-Mitiaro' became the subject.

5.4.3 Interviews

Prior to going to live in Mitiaro, my grasp of Māori Cook Islands language was at novice level. Much of my knowledge was of the Rarotongan dialect rather than Mitiaroan, which although very similar, has some distinguishable differences. Living on the island for 18 months before conducting any interviews enabled me to develop and advance my ability to speak and understand Māori with the Mitiaro-specific nuances. Over time, I became able to pick up fundamentals of the Māori language that allowed me to follow what was being said in conversations, especially those regarding the ocean. I gained a level of fluency in Māori that enabled me to, firstly, conduct the interviews, and, secondly, transcribe the audio files to produce the interview data drawn on below.

Before travelling to Mitiaro to begin data collection, I obtained formal ethics approval from my university to conduct semi-structured individual interviews, which involved providing information sheets to potential participants, and collecting a signed consent form from each person I interviewed. Using such forms seemed unnatural in the context of Mitiaro society, and I worried they would compromise the flow of kōrero that I wanted to encourage. Another advantage of prolonging my initial observation period before initiating any interviews was that it enabled me to reduce such risks.

I began each interview by speaking in Māori to communicate my wish to listen to the person's stories about their experiences as fishers from throughout their lifetimes. I offered for them to speak in Māori or English, or both. I audio recorded all the interviews, and personally completed all of the transcribing. I promised to protect their privacy by not revealing any identifying details. While honouring that undertaking, below is a thumbnail sketch of the participants as a group, giving a glimpse of the people behind the data.

5.4.4 Interview Participants: Fishers of Mitiaro

I held 11 individual conversational interviews and one with two participants, giving a total number of 13 people who contributed their information to this research. All were born and grew

up on Mitiaro, and they comprised 12 men and one woman. Most of them were married with children and grandchildren. At the time of the interview, the youngest was in their 30s, most were aged between 40 and 69, and three were 70 or older. All were either still actively fishing, or had fished all their lives until they were too old.

Most of these people had left Mitiaro in their teens or 20s, going to Rarotonga, New Zealand or Australia for high school, tertiary study, or work. Some had spent decades overseas, then later (often at around 60) moved back to live on Mitiaro. Most were still working for wages, mostly in government jobs such as infrastructure and maintenance: roading, water, waste, airport and public facilities. About five participants hold positions of aronga mana (social leader) as oro metua (priest), pā metua (elders), ariki (high chief) or mata'iapo (sub-chief). In these roles, they are called upon to represent their people, speak on their behalf, and settle disputes, especially over land.

Life for the fishers of Mitiaro revolves around food. Fishing is a major food-gathering activity, so fishing is closely associated with life in the sense of survival, as well as a culture, or way of life. Mitiaro has a community solar plant that provides electricity to all the homes, but not all homes have potable water on tap. Homes are usually multi-generational. Most of the participants grow their own leafy greens at home, and also eat from the communal plantations of taro and maniota (arrowroot).

5.4.5 Autoethnography (AE)

Autoethnography (AE) comes into this research as a result of my ancestral connections to Mitiaro; as a grandchild of Mitiaro in the diaspora, to carry out research into the traditional knowledge of my people has more than a professional significance. AE is the most well-known of the methodologies that capitalise on the auto-turn in research, whereby the researcher's own life and experiences are used as a source of data (Ellis & Bochner, 2000). Auto-research has resulted in changes to research practice that enable the use of the first-person voice in research. In this research, AE is a contributing strand, rather than the overarching method of collecting and analysing information. AE is visible in the snippets of my own experiences, such as in the final sub-section below, *The 'akamea scientist.'*

5.4.6 Narratives and writing as a method

Narrative research capitalises on the power of stories as a universal human way of organising and passing on complex arrays of information, and on the centrality of stories to the essence of being human (King, 2003). Narrative genres are inherent in AE research since writing about one's own life and experiences naturally involves stories (Stewart, 2023b). Narrative research is

recognised as important by Indigenous researchers (Archibald, 2008) and linked to writing as a method of inquiry (Richardson & St Pierre, 2018). Writing as a method of inquiry is a useful qualitative approach for unifying my kikau strands of research to write in a coherent, holistic way about Mitiaro, including vignettes written from my own experiences and as recounted by my interview participants.

5.4.7 Ethical considerations

As noted prior, I obtained formal ethics approval from my university for the interviews involving the standard ethical considerations of informed consent and protection of privacy of the participants. More importantly, during my exploratory visit I met formally with the Mitiaro Island Council to discuss my research proposal and seek their approval on behalf of the community. An ethical issue regarding the inequity of knowledge transfer was raised in that meeting. Other researchers before me had conducted research in Mitiaro, and the council explained they had frequently faced situations in which knowledge transfer was a one-way relationship in favour of the researcher. Such behaviour breaches the intellectual property rights of the Mitiaro people. Included in my agreement with the council were commitments about how the intellectual property and outputs of this research will be disseminated appropriately with the Mitiaro community.

In addition, in order to formally conduct this research, I first required to obtain a research permit from the Cook Islands Office of the Prime Minister, supported by a letter from the Mitiaro Island Council, and also one obtained from the Ministry of Marine Resources.

Completing this section on methodology, the following vignette demonstrates the use of narrative writing to convey some of the complexity of the research in a personal and immediate way.

5.4.8 The ‘akamea scientist’

As I planned and prepared for my extended sojourn living in Mitiaro, I worried about being socially accepted within the Mitiaro community, aware that I had been raised in a far wealthier country, with access to higher education and careers. Maybe I would be seen by the local people as a lucky one, perhaps the spoilt one, who returns home to Mitiaro to show off his knowledge or money.

In my early days living in Mitiaro, going to the island’s only public bar was one of my strategies for meeting and getting to know people. On the second or third time I walked in, I was called over by a man I had seen before, which raised my spirits and made me feel good.

“I want to ask you something. How does rock and coral become sand?”

I was surprised by the question, since we had not yet even been introduced, and began to reply, “Well, firstly with a lot of wave action...” but he interrupted me, “No. You’re not listening” and repeated his question. This went on for a few minutes until I decided to agree with him that God made the sand.

“You’re the researcher. You should know this.”

This exchange was a direct confrontation with the derogatory attitudes held throughout the whole Cook Islands towards the word ‘scientist’ that is used as a label for someone who is a know-it-all. Such attitudes chime with those of indigenous peoples throughout the Pacific and around the world, whereby ‘research’ is a dirty word (Smith, 2021). To call someone an ‘akamea scientist’ is to address them as someone with a lot of ideas that are not often understood by common people, accusing them of being a ‘wannabe scientist.’

At first, some of the Mitiaro locals used my ignorance of this local meaning as an opportunity for humour by introducing me to others as a scientist while I was standing there, oblivious to the insult. Taking this joke at my expense on the chin and partaking in the humorous banter seemed to quickly elevate my social status. Soon after, the jokes stopped. Today, I still use these terms in exchanges as friendly banter.

Being selective about my social behaviour and disputes acted as a catalyst in starting from the ground up and building authentic, rich relationships that eventually displaced any preconceived ideas of my being a threat to the Mitiaro ethos. Just as my time spent on Mitiaro was significant in my life, so in return my presence there becomes a tiny part of the larger story of Mitiaro. Through my unique and genuine relationships with the island and its people, I can report from an insider standpoint on the knowledges relating to fish and the sea held by the people of Mitiaro, with far more depth and richness, and hence with more accuracy, compared to studies conducted by almost any other marine scientist.

While not turning my back on my scientific training, as already noted above, in this paper I am enlarging my research perspective by investigating the TEK of the people of Mitiaro. To do so in a way that respects the nature of Mitiaro society and knowledge, it is appropriate to embrace qualitative methods of research, in which the meaning is found in the whole text, and the precision of science is supplemented by the richness of detail and affective power of narrative (Stewart, 2023a).

Having introduced the research context, the methodology and myself as the researcher, it is time to turn to the results and findings. The two sections that follow present a list of fish species commonly caught in Mitiaro, and the various fishing methods used. The next section outlines the importance of fish in the Mitiaro diet and lifestyle, showcasing the stories I was told

by the interview participants. Finally, I present synopses of findings about five Mitiaro concepts relating to marine ecology.

5.5 Fish Species

This section presents a list of common fish caught in Mitiaro. In some cases, there are multiple scientific names given to one Māori fish name. Some Māori names apply to multiple fish species, labelled here according to their generic taxa under their English names (*).

Fish name	English name	Scientific name
‘Angamea	Two-spot snapper	Lutjanus bohar
Api	White spot surgeonfish	Acanthurus guttatus
‘Ātea	Black tip grouper	Epinephelus fasciatus
Karore	Surge wrasse	Thalassoma purpureum
Ka'uru	Goatfish*	Parupeneus insularis etc.
Kōkiri	Triggerfish*	Rhinecanthus rectangulus etc.
Kōma	Yellowstripe goatfish	Mulloidichthys flavolineatus
Koperu	Mackerel scad	Decapterus macarellus
Kū	Blotcheye soldierfish	Myripristis berndti
Ma'e	Golden grouper	Saloptia powelli
Maito	Surgeonfish*	Ctenochaetus striatus etc.
Marau	Grouper*	Epinephelus melanostigma etc.
Paka	Convict surgeonfish	Acanthurus triostegus
Pa'o	Giant trevally	Caranx ignobilis
Paru	Small toothed jobfish	Aphareus furca
Patiki	Peacock flounder	Bothus lunatus
Patuki	Grouper*	Epinephelus hexagonatus etc.
Patuki roi	Peacock hind	Cephalopholis argus
Rari	Flagtail grouper	Cephalopholis urodeta
Ru'i	Black trevally	Caranx lugubris

Tapa'uru	Bluefin trevally	Caranx melampygus
Tio/Nānue	Blue sea chub	Kyphosus cinerascens/bigibbus
Ume	Unicornfish*	Naso unicornis etc.
Utuveu	Island trevally	Carangoides orthogrammus
Ū'u	Parrotfish*	Chlorurus microrhinos etc.
Pelagic Fish		
‘A'ai	Yellowfin Tuna	Thunnus albacares
Au'opu	Skipjack Tuna	Katsuwonus pelamis
Mangā	Oneline snake mackerel	Promethichthys prometheus
Ono	Great Barracuda	Sphyraena barracuda
Pa'ara	Wahoo	Acanthocybium solandri
Tavere	Albacore	Thunnus alalunga
Varu	Dogtooth Tuna	Gymnosarda unicolor

Figure 29. Common fishes caught in Mitiaro, ordered alphabetically by Māori names.

5.6 Fishing methods

This section outlines the diverse range of strategies used by the fishers of Mitiaro to target the local fishes. Some techniques are tailored to the specific behaviours and tendencies of fish, rendering some methods more successful than others, based on what is targeted.

Matira: Using a matira (rod – bottom fishing) to catch fish from the reef crest or harbour is the most common fishing technique in Mitiaro. This involves the simplicity of rigging the matira with a line, and baited hooks or plastic lures.

Ī’ī: Many fishers excelled in using ī’ī, a general term for hook and line fishing methods such as the traditional drop-stone method (Figure 30) to catch large game including tuna, wahoo, and even marlin from their paiere (canoe). This is one of the most popular and cost-efficient fishing strategies. Ī’ī also describes the method used for targeting other small reef fish and night fishing by dropping a patara (a specialised rig) for mangā (snake mackerel).

Rama koura: Hunting for crayfish at night along the reef flats. Parties of people scan for the red beady reflections of crayfish eyes along reef flats using torches, while wading through waist deep water wielding gloves, and sometimes a mask and snorkel.

Tā'ei māroro: This term describes catching flying fish in Mitiaro with an uata (scoop net) at night. This is normally done with two or more people – a skipper to chase flying fish, and someone at the bow navigating the skipper and weilding the uata to scoop flying fish.

Tāvere: Other ways to target large fish is via tāvere (trolling) from the motorboats using lures. This used to be done by paddling from the paiere. But with the introduction of motor engines, boats became the main mode for this fishing method.

Titi'a: This is spearfishing, an effective strategy to target certain fishes, particularly with the advantage to target herbivorous fishes. Two types of spears are used: pata (iron sling) and pupu'i (spear gun). A bonus is that titi'a allows being selective about fish size. Freediving while spear fishing also allowed harvesting of shellfish including pa'ua (clams) and ungakoa (sea worms).

Tītomo: This fishing method was adopted from the Northern group of the Cook Islands effective at targeting koperu. Tītomo is done by being in the water with a short line and baited hook, and luring koperu from the depths by chewing and spitting pieces of coconut as they followed the burley trail up towards the hook.

Figure 30. Traditional drop-stone: leaves containing a baited hook and burley fastened to a rock using a slip-knot.

The following section focuses on the importance of fishing to life in Mitiaro, showcasing the stories of the interview participants in their own words.

5.7 “Fishing – that’s my life”

During my time in Mitiaro, I spent most of my days at Te Ao Omutu Harbour, since it was the main place where fishers would launch their canoes or boats. It was also a popular meeting place for the papas to visit throughout the day, escape the day’s heat in the shade, and chat and watch the fishermen several hundred meters out at sea. When the fishers return to land, any passers-by at Te Ao Omutu will lend a hand to lift the canoes out of the water and safely up the wharf. It seems to be an unspoken code: if you’re there, help.

The title of this section expresses what many of the interview participants shared with me. Fishing was their passion and way of life, not only bringing them personal satisfaction, but also maintaining their mana (social status) as one of those who provide for the sustenance of their entire community.

5.7.1 Learning to fish

Children in Mitiaro start interacting with the sea from an early age. Learning to fish continues to be a pivotal practice within one’s household because it ensures the physical wellbeing of the family and wider community. One participant recalled that they “started at 5 or 6 years old. Going for mackerel for the older papas to go out and get tuna and mangā. That’s the best bait anyway, eh?”

During my fieldwork, I often saw younger children standing within the safety of the Te Ao Omutu Harbour, fishing with simple matira ironwood or bamboo rods, with hook and line, using as bait the appendages of small unga (hermit crabs) they had collected the previous evening. Older children diversify their activities, learning to rama koura (night hunting crayfish with torches) along the reef flat.

The following story comes from the only female I interviewed, an elder who had grown up on Mitiaro over 50 years earlier. As she recalled her childhood in response to my prompts, she expressed nuances of both joy and sorrow, thinking about her parents and the times she had seen.

> My father was a fisherman. He would always go out fishing for the family. I think I was 7 or 8 years old when my father took me on the ocean to get koperu [mackerel]. I would stay on the rock until he finished fishing the koperu. From that time, I learnt from my father how our family survived with fish. When I was 7, I asked my father to make me a hook and line so that I could go on the reef when the sea was calm. Every time when my father would go out on the ocean, I used to go down too. But my mum used to say to me, “go and rake the tita [rubbish].” But I didn’t. I would run down with my hook and my line to go over there and fish.

Another of the older people also recalled starting by fishing koperu, and how his parents would cook some of the catch so that it could be eaten later.

> I was going to school at that time... I started fishing koperu. Mackerel, eh? I started fishing for mackerel at about 9 to 10 years old. We would collect around 60 to 100 koperu. There were no freezers in that time. We would save it when we got home. My mama and papa would put it in the Māori oven, eh? When we got back, the umu [earth oven] would already be burnt, eh? They would cook it. I would put my bait aside, about 20 for bait. And the rest in the umu. That's for our life, eh? That's for the next day's dinner, the one in the umu.

5.7.2 Preserving fish

Some of the older participants spoke about how they and their parents worked to preserve their caught fish in their younger days, before the times when electricity and refrigeration were available. These accounts suggested that refrigeration can be either a blessing or a curse, depending on how it is used. Refrigeration minimises the toil of repeatedly harvesting fresh food, and provides for times when rough weather prevents fishing. But it also provides the opportunity and temptation to over-exploit the fishery by catching more than necessary. The elders talked about how they cooked and preserved their fish, and the traditional methods used to keep food.

> Our forefathers that time when they protected their food, they would use a flat rakau, a timber. They'd put the timber above the umu and they'd stack the 'a'ai, they'd stack it on the timber. They stack it on the timber so when they burn the umu down below, the smoke will go up, eh? To spray the insects! The insects going to the fish! That's how they protected their food when they got plenty of fish. Plenty of koperu, plenty of kū, plenty of marau, plenty of 'a'ai.

Two further methods of fish preservation were shared by another participant:

> They can preserve the fish by returning it back to the oven. Cook it today, and whatever's left is put back in the oven for the next day, and the next day. During my days it was very hard without a fridge. Sometimes they'd put it in the sun to dry the fish. But most of the time it was oven after oven, oven after oven.

One papa recalled the first fridges arriving to Mitiaro:

> Some of the people got a kerosene fridge when they first came here. I think there were only four fridges at that time. You know, they can save their food for another day. Not us! We've got no food. We cook our food today, eat it.

> Not finished? Throw it for the pig. That's some man waiting for the food, the pig.

5.7.3 Is the Mitiaro diet shifting away from fish?

But is the tide changing for the importance of fish in the diet of the Mitiaro people? Besides refrigeration displacing traditional methods for preserving food, it is clear that Mitiaro is undergoing a slow transition towards a money economy. Purchasing imported goods is much less laborious than tending plantations and depending on catching fish. Today's older generations show a strong preference for the traditional diet. Younger adults are at the pivot point – still brought up on planting and fishing, but also enjoying the occasional carton of chicken or chops, and welcoming the convenience of a tin of corned beef now and then. Today's generation of children, born into a more cash-dependent milieu, are still being taught how to fish, plant, and keep pigs alongside their elders (see next section). But with imported foods constantly at hand, could diet preferences be shifting too?

When I asked about reliance on imported foods, one older participant responded:

> That time if you wanted to drink tea, then you would go to the shop to get sugar. But we depended on fish and taro. Not now. You know the children now? Chips and Vaiora. My time, I never drank anything like that. Now kids don't want to take the banana to school. You know, when I was at school, I liked eating fish. And if I didn't eat fish one day, then the next day I would want to eat fish. Because I love fish.

Another participant related a potential shift away from fish due to the increasing difficulty of catching fish compared to in their youth, over 40 years ago.

> Back then we didn't go to the shop much. But now, yes. Because for the babies, eh? They like their noodles! They like their creamed rice, the canned drink, yes. But I think fishing during those days compared with today is a big difference. Trolling those days too, woah! When you go trolling, you'd come back with eight wahoo, more than eight. Good size, not these baby ones. Maybe now it's because of commercial fishing.

While questions about changes in the Mitiaro fishery are beyond the scope of this paper, a key point can be drawn. The sea has always had a profound role in the Mitiaro way of life. Working traditional lifestyles by tending to plantations, raising pigs, and learning to catch fish still have significance in Mitiaro daily routines, particularly for the older generations. Those elders continue to share their knowledge, to keep their values and practices alive.

5.8 Mitiaro concepts relating to fishing and marine ecology

This section delves into five indigenous Mitiaro concepts relevant to fishing and relationships between people and nature. A summary of information I found out about these five concepts is presented in turn in the paragraphs below: Arāpō; Ravakai; Māroro Tū; Aka'oki'anga Kakā; and Ra'ui.

5.8.1 Arāpō

The arāpō is the Māori system of reading the lunar cycle, which is one of the most important natural signals on which Mitiaro people base their activities and decisions, often used to guide planting and fishing. This traditional astronomical knowledge follows not only the changing phases of the moon, but also the moon's position in the sky, and thus the ocean's tide level. The arāpō is often referred to in conversation as a way of tracking the year, especially in the lead up to the Māroro Tu (see below). I often observed discussions between people checking the stage and position of the arāpō with each other and discussing which fish they expected to be abundant. Knowledge of the arāpō was taken for granted by my interview participants, but it was not a topic they wanted to talk about in more detail, and some even seemed puzzled by my interest.

During my days spent at the Te Ao Omutu harbour, I began to notice that the papas would drive their quad bikes up to the harbour, look out to the water for a short moment, then drive off again. This was happening quite frequently. One time, I managed to capture the attention of a papa to ask why he and others would drive up, then leave again shortly thereafter. He told me it was so they could check the level of the tide, to gauge the best time to plant their taro, especially if the moon is not visible during the day. I was taught that if you observe the moon at its centre-most peak, the sea will be at low tide. When the moon is positioned near the horizon, the sea will be at high tide. When the moon is out of view, people can judge its position by observing the tide.

Indigenous knowledge of the astronomical cycles - the annual cycle of the earth around the sun, and the monthly cycle of the moon around the earth – since time immemorial has acted as the natural clock and calendar for people around the world, and early scholars in the Pacific collected that knowledge, such as the booklet of arāpō from around the Pacific and Aotearoa by Best (1922), including an arāpō from Mangaia (p. 40). Astronomical cycles as measures of time have been supplanted only very recently in the overall history of humanity by CCT (clock and calendar time), which has been described as central to the overall project of modernity (Postill,

2002), including the colonisation by European nations of Indigenous peoples and their homelands, in this case the Cook Islands.

It is noteworthy that in Mitiaro the arāpō is still considered basic commonsense and used to align human activities with nature. The arāpō shown in Figure 31 is my reinterpretation copied from a classroom wall poster at Api'i Tematangarengare (Mitiaro School), which shows this ancient knowledge is still being passed on to the younger generations. As expected, it is very similar to the one from Mangaia published by Best, mentioned above. In Figure 4, each of the four boxes represents a quarterly phase of the lunar cycle in clockwise order, with the name and shape shown in each quarter. The top row shows the 'filling' or waxing phase, from new to full – Tiroe to Otu, labelled Arāpō Anga-raro. The lower row shows the 'emptying' or waning phase, from full to new – Marangi to Motu labelled Arāpō Anga-nua.

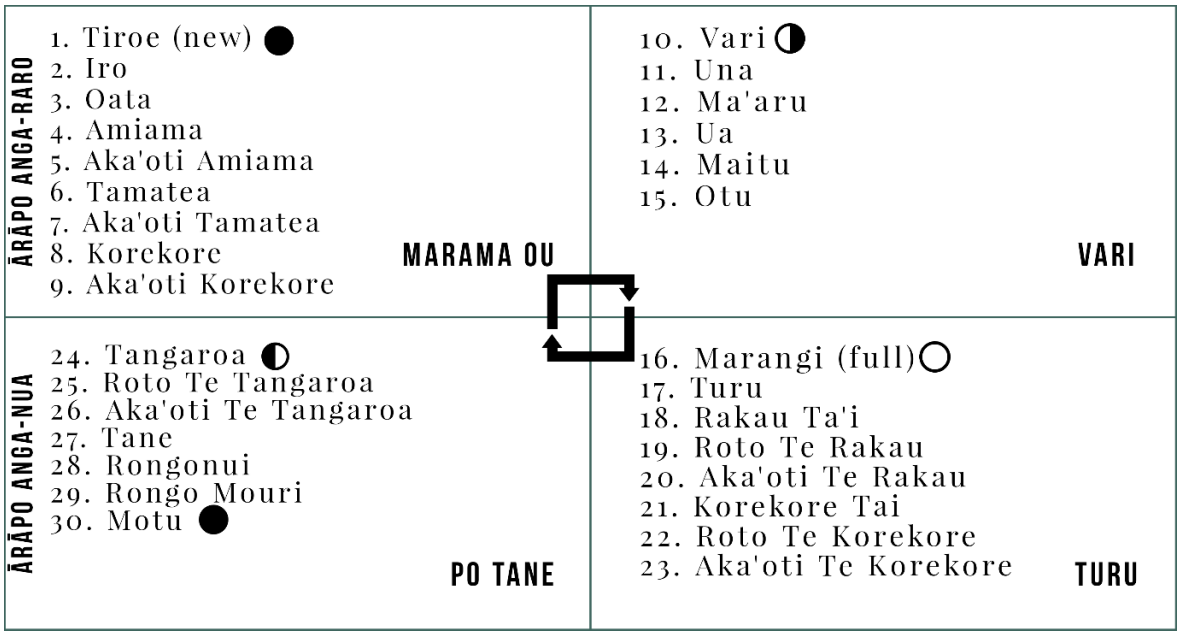

Figure 31. Mitiaro Arāpō

5.8.2 Ravakai

The Mitiaro word for a person who fishes is ravakai, and this is a word I used frequently while living there, since those were the people with whom I mostly wanted to spend time. Despite its literal meaning, it soon became apparent to me that being ravakai in Mitiaro referred to much more than simply the activity of catching fish. The term may be considered as a combination of two words, rava+kai, rava meaning enough or sufficient, and kai meaning food. This simple derivation suggests the importance of ravakai to the survival of the community, as well as what they achieve as people. As expert fishers (see Figure 32), ravakai will adapt their strategies and methods as needed to ensure success, depending on a number of factors: their own particular

skillsets; the conditions of wind, tides and current; proper use of the paiere (canoe); targeting specific fish based on preference, season, and arāpō; or their state of health.

The full meaning of ravakai encapsulates the knowledge required to be a successful fisher, as well as the peu (customs, culture) of ensuring that one provides for others. The peu of ravakai is shown by their actions on returning to land and the distribution of their catch. Fish distribution is a communal approach to shared food security and wellbeing in which everyone reciprocates. A long recognised but threatened practice in the Pacific (Johannes, 1978). The custom of the ravakai sharing out their catch is called tapupu ika (lit. chop up fish); an unspoken act of selfless and openhanded giving, expecting nothing in return, believing in reciprocity as part of the shared effort to support the wellbeing of all. That wellbeing focuses on the kōpū tangata (family) and the wider matakeinanga (people of a tribe or village) to ensure that everyone eats and survives.

If only one of several ravakai were to return to land with an abundant haul, the swift swinging of a knife to hack and portion out their fish to the unsuccessful ravakai, and anyone else nearby, would ensure that everyone could return home with food. Some people are prioritised in the tapupu ika, including the oro metua, elders, families with no ravakai, and manu'iri (visitors). The rest of the catch goes to the ravakai and their families.

I witnessed very few transactions whereby people traded fish for cash. It certainly happened, mostly at the convenience of the buyer, who would request fish in preparation for a particular community or household event. On other occasions it might be done for the purposes of fundraising, or even the odd side hustle here and there within the community. The fish sold most commonly was the māroro: ravakai would spend several hours at night netting hundreds of flying fish to sell early the following morning. But large fish were often gifted away. When large fish such as tuna are sold in Mitiaro, it would be for a significantly lower price than the market, using an estimate by eye to determine the asking price. On a few occasions I was involved in helping sell wahoo and tuna for $5 per kilogram, yet everyone knew that meanwhile tuna was selling for $32 per kilogram in Rarotonga. So the sale and purchase of fish in Mitiaro did not seem to be done with any intentions for financial exploitation, especially since fish were frequently shared freely anyway.

Figure 32. Ravakai on their paiere (canoes) and boat outside the Te Ao Omutu harbour.

5.8.3 Māroro Tū

The māroro tū is a periodic mass spawning event of the locally abundant pelagic flying fish species called māroro. During the event, enormous aggregations of māroro occur along the shorelines, turning the water white with their sheer number. This event also used to happen on other nearby islands, but no longer does. The māroro tū is thus a unique Mitiaro fishery, famous across the Cook Islands and beyond. Science has no answer as to why this event now only occurs at Mitiaro; it is a question awaiting research.

The māroro tū occurs during a 3–4-day window, sometimes between July and December. The fishers of Mitiaro track and determine when it will occur using their knowledge of the arāpō. It begins on the first quarter of the lunar cycle, the moon phase called Vari, followed by Una, Ma'aru, and Ua.

When the māroro tū season begins, fishermen paddle out on their paiere (canoe) to capture the spawning aggregations of māroro using uata, long scoop nets. The first load of catch brought in by each fisherman is designated for gifting out to everyone else on the island, including women, children, the elderly, pastors, and visitors. Any subsequent catch after that is reserved for the fishermen and their families.

The whole island commits to uphold rules for the time of the māroro tū in order to ensure a successful harvest. One of these rules is that fishing during the māroro tū is done only by men; women are prohibited from the harbour or beach front while the men are harvesting the māroro tū. Also, the oro metua and his wife must stay inside their home to pray, otherwise the

fishermen may experience poor weather, or the māroro will not come. Finally, the use of power boats is prohibited from four days before the start of māroro tū (Tamatea – Aka'oti Korekore), until four days after (Maitu – Turu), to minimise the chance of frightening away the māroro. Some dispute this rule, arguing that the restriction should not apply after the fourth day, Ua, since the māroro tū is finished by then.

5.8.4 Aka'oki'anga Kakā

On Mitiaro, cyclone season begins in December, when for up to four months the island is likely to endure harsh winds, rough seas, and torrential rain. During the thick of the cyclones, the harbour and seawall disappear from sight under the extreme height of the waves. Leading up to the cyclone season, people can be seen at work, harnessing down their iron roofing with ropes tied to anchors fixed in the ground adjacent to their homes, in preparation for strong winds that could tear and damage roofs.

At the start of April each year, to mark and celebrate the ending of the cyclone season, all the Mitiaro people work in their households and families to prepare for the event known as the Aka'oki'anga kakā, meaning the return of the glory. This name acknowledges God's protection throughout the cyclone season, and the return to glorious island weather. To prepare for the celebration, each household puts together a large basket of food that they can contribute. Baskets contain one or more of the following types of food: traditional local harvested foods including large pelagic fish (tuna, wahoo), grown produce (taro, maniota, bananas, coconuts), livestock (pig, chicken, goat) or imported goods (flour, rice, noodles, corned beef).

On the morning of the event, every household brings their basket to the host community hall for that year, where they are set out and displayed on woven kikau (see Figure 33). The next step is a communal process of sorting the foods into their different types, with everyone helping. The aronga mana (community leaders) then carry out a process of re-distribution to each home or household according to social status and circumstances, such as number of dependents. Everyone gets a bit of everything. This process of communal gathering and re-distributing of kai among the community constitutes the main activity of this event to mark and celebrate the end of the cyclone season; another tribute to the values placed upon caring for the kōpū tangata and matakeinanga. The end of cyclone season also emphasises local concepts of time through seasonality alongside CCT.

Figure 33. Food baskets for the celebration of Aka'oki'anga kakā.

5.8.5 Ra'ui

Ra'ui is a famous Pacific concept that has been studied by many scholars (Chambers, 2016; Hviding, 1998; Johannes, 2002). As mentioned in the Introduction section above, before going to Mitiaro I had heard a lot about ra'ui in New Zealand, where in science-related discussions ra'ui is typically assimilated to the concept of a marine protected area (MPA): a no-take zone designed to protect an ecosystem in perpetuity. But this is a romantic distortion of Indigenous knowledge, which is actually always human-centred, and in Mitiaro is based on kōpū tangata and matakeinanga, the wellbeing of families and the whole community. The elision of ra'ui to MPA overlooks the fact that MPA is a Western invention to ameliorate ecological damage caused by (Western) human activities. Within traditional Mitiaro culture, ra'ui are one aspect of a way of living sustainably and in harmony with natural cycles and food sources of the local marine ecosystem.

Ra'ui govern the right to access resources at sea or on land, and are usually delimited in terms of the area, and temporary in terms of the length of time for which they apply. A ra'ui prohibition may be applied to a designated locality, whereby all resources within the area are not to be harvested for a specific period of time. These habitats can include forests, lakes, lagoons, and shallow intertidal reef areas. The restrictions can also be applied to certain resources such as trees, coconut crabs, shellfish, and finfish species. In more recent times, the concept of ra'ui has been extended to cover bans on the use of specialised equipment such as spearguns. The size and duration of a ra'ui can vary depending on a communities resource goals.

The primary purpose of traditional ra'ui is to sustain and conserve a community through the sustainable management of food resources. In an economy based on fishing for survival, ra'ui is a way to manage available fishing stocks, in order that people can eat. In essence, ra'ui serve as temporary or periodic closures to a resource to enable the rehabilitation of wild food stocks, so they may be harvested later. When lifting ra'ui from an area, the prohibition may be shifted to another location, thus creating a rotating system of regenerative food source partitioning. Traditionally, ra'ui is a concept of caring for the people; it is not about 'caring for the fish' as per the romantic myths about all Indigenous cultures.

Ra'ui are traditionally issued by the authority of an ariki (chief) but post-colonial influences are evident in the use of ra'ui; for example, on the main island of Rarotonga, ra'ui ceased to exist in the 1950s as the mana of ariki had eroded with submission of customary rights to the Crown (Evans, 2001). Since 1998, ra'ui have been reinstated in Rarotonga and a level of mana returned to the people. Three of the 15 islands, Mitiaro, Mangaia, and Pukapuka, still retain the sovereignty of ariki and aronga mana, however, and authority over resources has been continuously with the people, managed by Indigenous traditions, including ra'ui.

On Mitiaro, ra'ui are currently instated by agreement among the aronga mana and local council. Since a ra'ui is a shared commitment to communal food security, breaching a ra'ui is, in effect, an insult to one's wider society. This socio-cultural pressure continues to influence people's behaviour. There is also the respect or fear of the tapu (taboo) of a ra'ui (Dixon, 2016). Historically, the consequences for infringing ra'ui would be decided by the ariki, and could include the loss of land rights, physical punishment, exile from the village, and even execution (Tiraa, 2006). Nowadays, although there is no legal enforcement, the island council imposes monetary fines or community service on those who infringe ra'ui.

Today, ra'ui are created to prepare for significant community events, ensuring there are enough fish to feed masses of people. The aronga mana might establish a ra'ui of several months to a couple of years in duration, in preparation for such events, including hosting visiting tere pati (travelling parties), funding the travels of tere pati from Mitiaro, or catering for sports tournaments, conferences or cultural events. A ra'ui might be established to support a fundraising event. When a ra'ui is lifted, the whole Mitiaro community works together to harvest from those areas, each person contributing their catch to a large pool, to be used to fulfil the purpose of the ra'ui. This is also the time when the community and aronga mana assess the fish to evaluate the impact of the ra'ui.

While I was living in Mitiaro, a ra'ui was in place to help fundraise for a specific community purpose, which was later cancelled, so the ra'ui was opened to the Mitiaro people on a certain date. That day, the mayor ordered all government workers, making up the majority of the island's adult population, not to go to work, but instead to go out into the freshly-lifted ra'ui,

to fish and harvest as much as they could, and return to the village with the pooled catch, to be distributed among the Mitiaro households and people. On that day I shot an excellent giant trevally, which turned out to be the largest fish anyone shot that day. As the trophy fish, it went directly to the oro metua, which made me a little sad, but I was proud of demonstrating my prowess and playing my part, and it was an ego boost to know that everyone knew it was my fish. But of all the fish I shot that day, I was given only two small reef fish to take home.

5.9 Conclusion

On the surface, having my trophy fish gifted away in return for two small fish seems unfair, perhaps even slightly unkind. But like the other examples given above, this experience contains deeper levels of meaning when seen through a Mitiaro perspective. It demonstrated to everyone that I was just another Mitiaroan, no longer perceived as manu'iri. When I arrived on the island, I was as naive as the young children I would see learning to fish in the safety of the harbour. But in that fish exchange, I was being treated as a young ravakai. That was the greatest gift and highest honour the people could have bestowed on me.

This paper has presented my learnings about some of the knowledge and customs of the Mitiaro people relating to fish and the sea, but it is only a starting point, and in any case, it is impossible to capture in writing everything I learned from my time spent living in Mitiaro. There is a parallel here with the fact that the methods of marine science can never fully capture the TEK of an Indigenous people like Mitiaro.

The Māori title of this paper, marara te tai, uses the Mitiaro idiom in which marara is a shortened form of the word ma'ara'ara, meaning to remember, to keep thinking about (Buse et al., 1996, p. 207). To conclude, I will use a proverbial saying in Mitiaro I was taught by an uncle – a final piece of Indigenous wisdom designed to teach a young person about their ecological responsibilities and the narrative of nourishment:

Marara tai koe, marara uta koe.

Keep thinking about the sea, keep thinking about the land.

5.10 Glossary of Māori words

As used in this paper. Excludes fish names and fishing methods (see above page 96).

Māori (Mitiaro)	**English**
akamea	pretender, ‘wannabe’
aka'oki'anga kakā	return the glory, event to mark end of cyclone season
akapapa'anga	genealogy, family tree, ancestral descent
akau	reef
arāpō	lunar cycle
ariki	high chief
aronga mana	social leader(s)
ika	fish
kai	food
kikau	coconut frond
kōpū tangata	family
makatea	volcanic rock
mana	social status
maniota	arrowroot
manu'iri	visitor(s)
Māori	person from Cook Islands (trad. normal, ordinary)
marae	community centre
marara	(local idiom of ma’ara’ara) remember, keep thinking about
māroro tū	flying fish spawning event
matakeinanga	community, kinship group or ‘tribe’
matira	fishing rod
moana	sea
oro metua	priest
paiere	fishing canoe
pā metua	chief
papa(s)	local usage for men, especially father figures
peu	customs
rakau	timber, tree
rama koura	night hunting by torch for crayfish
ra'ui	restriction on gathering food or accessing resources
rava	enough, sufficient
ravakai	fisher
tai	beach, coast, oceanward
tapere	district
tapu	restricted, under protection
tapupu ika	to distribute a catch
taro	type of root vegetable
tere pati	travelling party
uata	long-handled scoop net
‘uipā’anga are	community meeting halls
umu	ground oven
unga	coconut crab

Chapter 6

General discussion

6.1 Discussion and conclusion

The primary objective of this thesis was to conduct a fishery-focused investigation on the island of Mitiaro, as a case study that addressed the paucity of information on small-scale remote coral reef fisheries. To achieve this, I focused on exploring the nexus at which the biological, ecological, and social components of Mitiaro's fisheries intersect. In Chapter One, I furnished the vision for this research, identified its unique nature, justified why this research is important, and stated my aims and objectives. In Chapter Two, I conducted a comprehensive literature review of coral reef fisheries to date, its dynamics, challenges, and gaps of knowledge. In Chapter Three, I conducted a comprehensive population dynamics analysis of two commonly caught and consumed surgeonfish species, using established fisheries science methodologies to provide age, growth, and reproductive modelling information pertinent to fishery management decisions. Chapter Four presented a comprehensive fisheries investigation, where various aspect of fishing activities, catch landings, seasonality, fisher behaviour and knowledge were documented. Chapter Five presents an ethnographic investigation delving into the lives of the people of Mitiaro reflecting on the physical, cultural, and spiritual relationships to the sea. This chapter has both academic and personal significance as it showcases key exchanges between the Mitiaro worldview and marine ecology. Furthermore, it allowed me to honour the people of Mitiaro, who gave me the opportunity to observe, document and experience their intrinsic connection to a resource that is vital to the historical formation and ongoing survival of the community.

Pacific Island fisheries encompass the exploitation of coral reef and nearshore pelagic fish species that form the bodies of localised small-scale fisheries. However, these small-scale fisheries are broad across a large spatial scale that constitute regionally specific variation in targeted fisheries, economic factors, community management strategies, and complex social drivers. This thesis argues that Pacific Islands fisheries management is not a one-solution fits all strategy and requires localised information specific to individual cultures and communities. That is why these fisheries remain data-poor and compounded by global ocean-related challenges including climate change, overfishing, IUU (illegal, unreported, and unregulated) fisheries fleets, and plastic pollution.

The three key components explored in this thesis are specific to the context of Mitiaro. These include, 1) investigating and establishing the population dynamics of case-study coral reef fish species that are targeted primarily for subsistence; 2) documentation of the Mitiaro fishery by analysing catch landings, and calculating CPUE (catch-per-unit-effort) across fishing techniques, vessels, and taxa; and 3) an in-depth analysis of the Mitiaro culture that highlights the human-environment relationship and how these unique characteristics shape marine resource

management and exploitation through a rich and detailed autoethnography and *korero* with expert participants.

6.1.1 Population dynamics

Chapter Three outlined the very first demographic study for two important acanthurid species from Mitiaro, *Ctenochaetus striatus* and *Acanthurus achilles*. This is also one of the first population dynamics investigations for the Cook Islands, and the first ever for *A. achilles* anywhere in the world. Length and weight distributions showed strong positive relationships across both species as well as sexes, exhibiting overall isometric growth patterns (b = 2.8 – 3.1). Size distributions of each species also exhibited general bell-shaped curves, while age estimated from counting sagittal otolith opaque rings displayed a distribution skewed towards younger specimens. Maximum size within the sample collected was the same for male and females of *C.striatus* (225 mm FL), however vBGF (von Bertalanffy Growth Function) analysis showed that males achieved a higher L∞ (186.44 mm FL) than females (177.17 mm FL). For *A. achilles*, females achieved a larger maximum size (215 mm FL) and L∞ (191.24 mm FL) compared to their male counterparts (199 mm FL and L∞?177.32 mm FL, respectively).

vBGF analysis also revealed that *C. striatus* and *A. achilles* displayed growth trajectories typical of acanthurids whereby they undergo rapid growth rates in their first couple of years and achieving asymptotic lengths within five years. Based on the L1 calculations from the reparameterised vBGF, females achieved faster initial growth (136.35 mm FL) compared to males (128.28 mm FL) in *C.striatus*. Meanwhile males achieved faster initial growth (150.21 mm FL) than females (140.26 mm FL) in *A. achilles*. This is typical of populations that exhibit sharper rapid initial growth resulting in smaller asymptotic sizes.

Length and age distributions resembled normally distributed trends for *C. striatus*. The age distribution for A. achilles also resembled a normal distribution, however, that of the length was bimodal. Maximum ages recorded for *C. striatus* and *A. achilles* were twenty-seven and nine years, respectively. The estimated mortality rates were 35% and 34% for *C. striatus* and *A. achilles*, respectively. Age- and size-at-maturity was unable to be estimated as there were no observed immature samples to show a maturity continuum. However, consistent with other surgeonfish populations studies (Choat & Axe, 1996; Ochavillo et al., 2011; D. R. Robertson, 1983; E. L. Trip et al., 2008b), Mitiaro populations of *C. striatus* and *A. achilles* were already sexually mature very young. These limitations can be addressed by sampling smaller individuals, however, given that my samples came from donations by local fishers I was limited to the cohort collected. The results of the life-history parameters established here provide an example of what type of demographic informations are required to manage Mitiaro's fishery,

and act as a baseline to recommended further demographic investigations in the wider Cook Islands.

6.1.2 Mitiaro fishery

The data presented in Chapter Four is the first comprehensive investigation of the Mitiaro coral reef fishery, capturing the island's coral reef and nearshore pelagic fish species over the course of 16-months. The results of this study are important because they deconstruct the characteristics of an oceanic island's fishery, demonstrating the wide array of fishes targeted and the fishing techniques adopted by fishers providing insight into the fisheries' yield. Twenty-two families of fish were identified in the catch data using nine different fishing techniques, assessed from 1949 fishing hours, calculated from over 598 fishing sessions. The results also demonstrate the CPUE for each high-targeted fish family and according to fishing technique and mode of transport across both reef and pelagic fisheries. Furthermore, rough geographical distinctions indicate where specific fish are being targeted. The UVC (underwater visual census) surveys also revealed acanthurids are, by a large margin, the dominant family along the western forereef. This is the case across most coral reef systems within the Indo-Pacific region where acanthurids are by far the most conspicuous family (Marshell & Mumby, 2015; Tebbett et al., 2022).

The calculated yield was 4.5-tonnes in which 88% was accounted for by the pelagic fisheries (4-tonnes) and the remaining 12% consisted of reef fish (562.5 kg). Land-based fishing was the most popular fishing method to target coral reef fish species where baited lines (bottom fishing) and spearing accumulated the highest effort and catch. Meanwhile, the traditional drop-stone method employed from a canoe was the most popular fishing technique within the pelagic fishery with the highest effort, followed by trolling by boat which resulted in the highest catch.

Considering that Mitiaro consists mainly of subsistence-based lifestyles, this thesis presents an important window into fishery dynamics of an oceanic coral reef island that is dependent on the sea for food security and supplement of livelihoods. In terms of livelihood, it is worth examining how national economic development influences changes in fishery exploitation levels and determining if the direction of change leads to increased or decreased efforts in fishing. Other Pacific Island communities have undergone shifts in fishing activity as livelihoods transition with socio-economic development and population change (Bell, Cisneros-Montemayor, et al., 2018; Schwarz et al., 2011). For example, increased reliance on socio-economy has resulted in reduced Pacific inshore fisheries (Turner et al., 2007). Furthermore, socio-economic shifts can cause emigration towards urban-centred communities due to the limited economic opportunities in outer islands, where depopulation can lead to decreases in fishing pressure (P. Craig et al., 2008). In other cases, changes influenced by economic

development of artisanal fisheries for local or overseas markets can lead to increased fishing pressure and commercialisation (Kittinger et al., 2015; Zeller et al., 2021). Thus, improved long-term monitoring of remote island fisheries is important in analysing ongoing changes and identifying effective management opportunities (L. C. L. Teh & Sumaila, 2013; Turner et al., 2007).

6.1.3 Mitiaro lens to marine ecology

To construct a wider and holistic view of the Mitiaro fishery, I conducted an investigation of its rich socio-cultural dynamics through the worldview lens of its people and their relationship with marine resources. This was achieved by weaving together in-depth auto- and participant ethnographic investigations, interviews, narratives and writing as a method of inquiry. Adopting this approach revealed the remarkable role of the fishery to the Mitiaro culture and lifestyle. Narratives that extend over 70 years highlighted the imperatives of learning how to catch and preserve marine resources at an early age to ensure food security. Changes to the Mitiaro ethos and marine ecology are also uncovered as stories share how fishing now requires increased effort compared to four to six decades ago. As the island has transitioned with technological advancements and money, the contribution of convenient imported foods to food security raises questions about how daily routines could impact Mitiaro fisheries in years to come.

I also explored five concepts within Mitiaro culture that describe interactions between the community and fishing. Firstly, the Arāpō or Māori lunar cycle provides an example of traditional ecological knowledge that is exercised to govern fishing and planting activity. The different phases of the lunar cycle and position of the moon have been associated with sea tides levels, planting success, and seasonality linked with fish migrations. A particular fish migration season significant to Mitiaro and this study is the mass spawning event of flying fish known as māroro tū, determined by first quarter moon phases between June and December. The māroro tū yields local customs that influence how and who within Mitiaro community can exploit this fishery – one of many customs that intersect with marine resource use. One of the customs underlines the practice of flying fish distribution across the entire island community by the fishers. The gifting of fish to elders, women, children, and visitors, ensuring food security and healthy wellbeing among everyone is a custom held firmly by Mitiaro ravakai (fisherman). A ravakai, identified in this study as a concept itself implies not only the act of fishing, but the knowledge and customs in doing so successfully. This includes the knowledge of the Arāpō, seasonality, fishing techniques, safety at sea.

The customs that also dictate the value of ravakai include the tapupu ika, the portioning and distribution of fish often reciprocated, as a shared responsibility of sustainable food supply. We see this shared responsibility of food security in the two remaining concepts addressed in

this thesis through the implementation of ra'ui and traditions around the aka'oki'anga kakā. Through the aka'oki'anga kakā we observe concerted efforts from every household bringing together baskets containing a variety of foods destined to be equally distributed amongst families. An important note here is that not all original baskets consist of the same food items. Therefore, the re-distribution process enables a balanced variety of foods.

Ra'ui on the other hand demands shared efforts for food security through abstinence from harvesting marine resources. In doing so, periodically closing access to certain areas for fishing safeguards the Mitiaro community as a method of sustainable marine resource management.

6.2 Challenges and future research

The remoteness of Mitiaro presents challenges for research ubiquitous across small, oceanic islands, hundreds of nautical miles from large civilisations. This often includes minimal access to specialised equipment, facilities, field assistants and expertise. The collection of samples for the population dynamics study highlighted three key challenges: firstly, being a remote island where subsistence fisheries provide for local sources of sustenance, collecting samples from fishers to minimise destructive sampling methods meant that I was at the behest of benevolence from the local fishers as to when or if they would donate a small part of their catch to me for sampling. Secondly, as the samples were destined for consumption, fishers targeted larger individuals making it difficult to detect immature individuals within the population, which most likely would have been younger and sexually immature. Lastly, due to the lack of laboratory facilities on the island, samples had to be appropriately stored prior to being transported to the Auckland University of Technology, New Zealand. However, this became impossible for an extended time as COVID-19 restrictions had been placed during the fieldwork component of this research, preventing travel to New Zealand for over a year.

Chapter Four provides a substantial and accurate description of the Mitiaro fishery. However, the results are not without caveats and challenges. Although most of the fishing recorded occurred during the daytime, there were some fishing sessions that occurred in the late evening and early morning. However, I was not able to record these sessions for various practical reasons. Additionally, fishers targeting coral reef fish offered two challenges to the study. Firstly, reef fishing could occur at multiple areas around the island, making it impossible to monitor every fishing trip. Secondly, reef fishing normally consisted of high counts of fish, making data recording an unattractive and disruptive process for participant fishers. This essentially meant that I had limited time to visually record a fisher's catch without imposing on their valuable time and eagerness to process and prepare their fish for cooking.

In this PhD I explore both the quantitative and qualitative components of the Mitiaro fishery. Assessing that which cannot be quantified, such as marine ecology through the Mitiaro worldview, including the traditional knowledge and cultural customs which provided insight into the practices that intersect, and ultimately, shape marine resource utilisation. The Mitiaro worldviews are crucial to understanding the fishery, as it presents specific accounts of the local marine resource use and management, and aids in identifying drivers behind social and economic outcomes. As explored, in Mitiaro, this is seen through the value of fish as a source of food and wellbeing, and the cultural relevance in traditions and resource distribution. The alternative perspectives of marine resource use may also give insight into changes in the fishery that quantitative methods would fail to detect. With sustainable marine management and food security being at the ultimate objective, it is important to recognise the value of the Mitiaro worldview and the subsequent social structures, as adjustments to management strategies are about managing people rather than managing fish.

However, holistic approaches are often challenged in scientific academia which identify this disciplinary intersection as a breach of the western scientific pedagogy and epistemology. In this thesis however, the qualitative methodologies adopted are meant to supplement the quantitative analyses and provide a fuller and richer picture of Mitiaro's fishery. Here, I advocate for the integration of traditional ecological knowledge, by arguing that the adoption of holistic strategies is needed to better understand the complex ecological issues relating to marine resource exploitation in the Pacific. I believe this PhD provides an explicit formula to understanding Pacific Islands fisheries by integrating the measurable statistics with the immeasurable philosophies that truly embody traditional and Indigenous-governed fisheries.

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Appendices

Appendix A. Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

14 November 2019

Armagan Sabetian
Faculty of Health and Environmental Sciences

Dear Armagan

Re Ethics Application: **19/351 Pacific Island coastal reef fisheries: a case study of Mitiaro, Cook Islands**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 14 November 2022.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted. When the research is undertaken outside New Zealand, you need to meet all ethical, legal, and locality obligations or requirements for those jurisdictions.

Please quote the application number and title on all future correspondence related to this project.

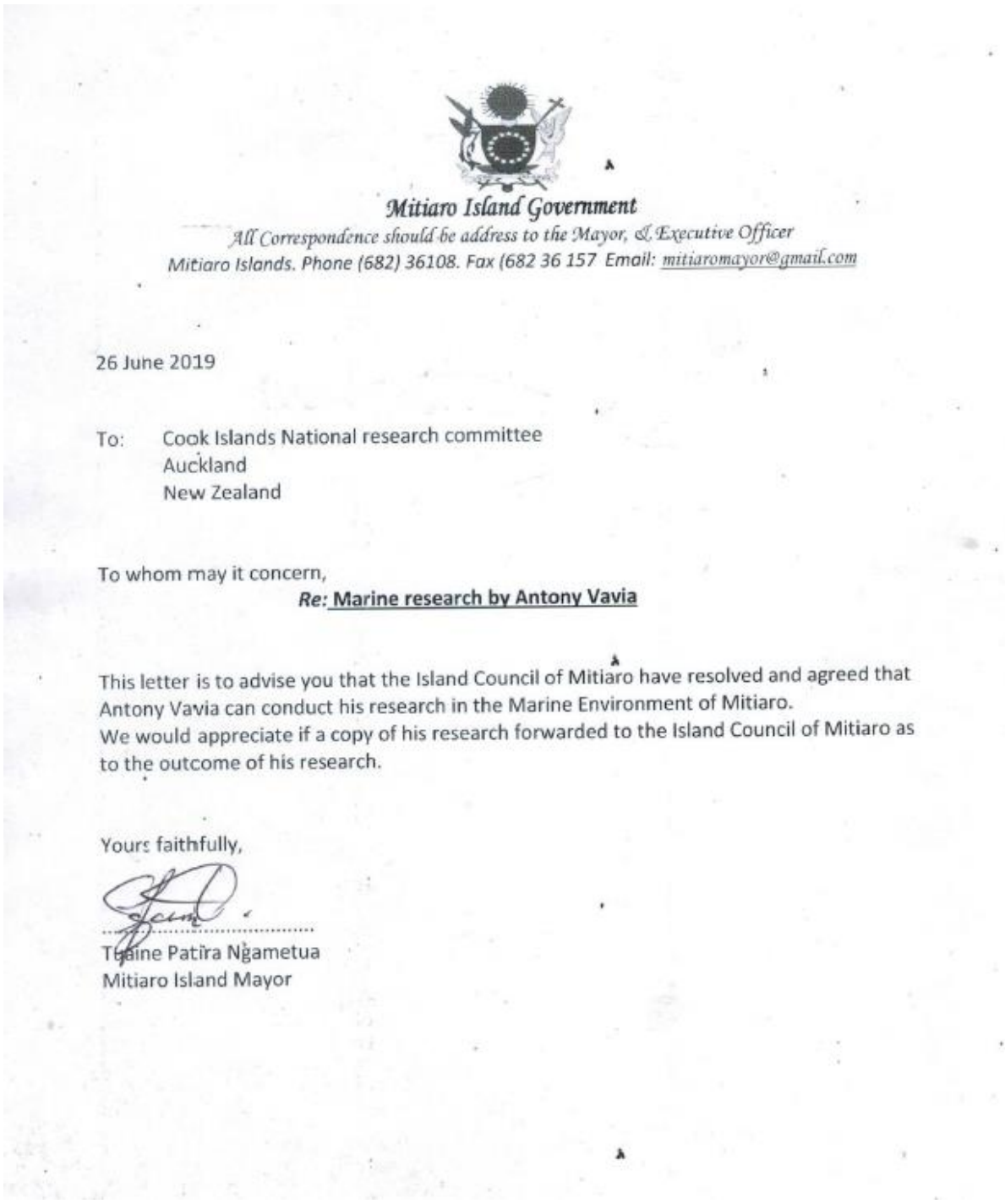
For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: antony_vavia@hotmail.com

Appendix B. Mitiaro Island Council Approval



Mitiaro Island Government

All Correspondence should be address to the Mayor, & Executive Officer
Mitiaro Islands. Phone (682) 36108. Fax (682 36 157 Email: mitiaromayor@gmail.com

26 June 2019

To: Cook Islands National research committee
Auckland
New Zealand

To whom may it concern,

Re: Marine research by Antony Vavia

This letter is to advise you that the Island Council of Mitiaro have resolved and agreed that Antony Vavia can conduct his research in the Marine Environment of Mitiaro.
We would appreciate if a copy of his research forwarded to the Island Council of Mitiaro as to the outcome of his research.

Yours faithfully,

.....
Tuaine Patīra Ngametua
Mitiaro Island Mayor

Appendix C. Ministry for Marine Resources Approval

Ministry *of* Marine Resources
GOVERNMENT OF THE COOK ISLANDS

Po Box 85, Avarua,
Rarotonga, Cook Islands
P +(682) 28721
F +(682) 29721
E rar@mmr.gov.ck
www.mmr.gov.ck

RE: Research Proposal

BY: Anthony Vavia

TO WHOM IT MAY CONCERN:

I am writing this letter to support Mr Vavia's research permit (PhD) which is seeking approval by Research Committee.

Our Marine scientist team has read through Mr Vavia's research proposal and most have shown excitement since this deals with hard science that can have management implications, particularly for Mitiaro Island.

This research proposal requires Mr Vavia to spend a year on Mitiaro to collect the data set required for this study, already we have seen how enthusiastic he is to successfully get this research proposal initiated.

We wish him all the best.

Meitaki Maata

Koroa (Kori) Raumea
Director
Inshore Fisheries & Aquaculture Division
Ministry of Marine resources

Appendix D. Office of the Prime Minister (Cook Islands) Approval

COOK ISLAND RESEARCH COMMITTEE
OFFICE OF THE PRIME MINISTER
PRIVATE BAG, RAROTONGA, COOK ISLANDS
Phone +682 211-50 Facsimile +682 20-856
Email: research.secretariat@cookislands.gov.ck Web: www.cook-islands.gov.ck

File ref: **510.3**
Letter no: **19-036**

05th June 2020

Antony Vavia
PhD Candidate
Auckland University of Technology
Auckland
New Zealand

Kia Orana,

RE: APPROVED RESEARCH APPLICATION

I am pleased to advise that the National Research Committee has granted approval for your research titled **"Pacific Island Coastal Reef Fisheries: A case study from Mitiaro, Cook Islands"** in **Mitiaro** from **05th June 2020** to **05th June 2021.**

Enclosed is your research permit issue **# 36/19**

The following conditions listed below have been imposed by the National Research Committee

- **The researcher complies with the Cook Islands Immigration**
- **The researcher provides a preliminary report to the Office of the Prime Minister at the earliest**
- **The researcher provides three (3) hard copies + one (1) e-copy of the final output generated from this research to the Office of the Prime Minister by June 2022.**

Kia Manuia

Ben Ponia
CHAIRPERSON

PERMIT TO UNDERTAKE

Research in the Cook Islands

This is to certify that: **Antony Vavia**

Has permission from the Foundation for National Research to do a research in the Cook Islands from: **05th June 2020 to 05th June 2021**

On the island(s) of: **Mitiaro**

The topic of research is: **"Pacific Island Coastal Reef Fisheries: A case study from Mitiaro, Cook Islands"**

The Cook Islands Associate Researcher is: N/A

The following special conditions apply to this research:

- The researcher complies with the Cook Islands Immigration, Ministry of Marine Resources and National Environment Services requirements

- The researcher provides a preliminary report to the Office of the Prime Minister at the earliest

-The researcher provides three (3) hard copies + one (1) e-copy of the final output generated from this research to the Office of the Prime Minister by June 2022.

Permit Issued on: 5th June 2020

Issued by: **Ben Ponia**

CHAIRPERSON

Receipt Number: **Waivered**

Reference Number: 36/19

Signed: _____

For enquiries concerning this permit, please quote the Name of the Researcher and the Reference Number to the Chairperson, Foundation for National Research, and Office of the Prime Minister, Rarotonga, and COOK ISLANDS. Phone (682) 29 300, Fax (682) 20 856, or Email: research.secretariat@cookislands.gov.ck Website: www.pmoffice.gov.ck

Appendix E. Mitiaro Fishery Survey Form – Session Information

Date:_____

Page_____

Day Type:

1 = Weekend or public holiday, 2 = Weekday

Sea Conditions:

1 = Smooth, 2 = Slight, 3 = Moderate, 4 = Rough

Rain:

1 = nil, 2 = Light continuous, 3 = Light scattered, 4 = Medium scattered, 5 = Heavy rain

Overhead Conditions:

1 = Sunny continuous, 2 = Mainly sunny, 3 = Mainly cloudy, 4 = Continuous cloudy

Wind Speed:

1 = Nil, 2 = Light, 3 = Medium, 4 = Strong

Wind Direction:

1 = Nil, 2 = Variable, 3 = N, 4 = NE, 5 = E, 6 = SE, 7 = S, 8 = SW, 9 = W, 10 = NW

Fisher Data:

Fisher No.	Boat Type	Intercept Outcome	Time of Intercept (24 hour)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Boat No.	Boat Type	Intercept Outcome	Time of Intercept (24 hour)
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			

Outcome codes: I = Interviewed N = Not Interviewed R = Refused F = Fishing but refused

Boat Types: C = Canoe T = Trailer boat S = Surf cast

Appendix F. Mitiaro Fishery Survey Form – Fisher Information

Date:_____

Page_____

Fisher No.:_____

Page No.:_____

Boat Type: _____

Time of Intercept:_____

Fisher No.	Combo	Location	Method	Target Species	Time Start	Time Finish	Sex	Age Group

Fisher No.	Combo	Species	Length	Weight	Count	Obs

Fisher No.	Combo	Species	Count	Act

Obs (1 = Measured, 2 = Counted, 3 = Observed, 4 = Not observed)
Act (U = Undersize thrown back, L = Large thrown back, B = Used as bait, F = Filleted)