Assessing citizen science in the marine environment

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ABSTRACT

Citizen science, where the general public is engaged with and participates in a scientific project, is increasingly being recognised as an effective tool for science education, developing knowledge and science skills, promoting guardianship, democratising science and reducing the costs of long-term data collection compared to normal scientific research. However, there is reluctance by environmental managers to use it as a scientific method for monitoring due to concern regarding the quality of data collected by volunteers.

The robustness of data collected by citizen scientists, in this case students (aged between five and fifteen), was assessed during a facilitated citizen science project that monitored the impacts of a dredging programme on the rocky intertidal shore of Otago Harbour in Dunedin, New Zealand. Students assessed biodiversity and percentage cover of substrate at two shore heights across six locations over three years (2016-2018) using transect/quadrat methods. In one year, trained scientists (minimum three years of tertiary education in marine science and experienced with the local marine environment) collected data in the same manner as students and the two datasets were compared to assess the quality of the student-collected data. Comparisons indicated that students and scientists showed similar ability to quantify species presence and abundance in a specific area. Multivariate analysis showed there were dissimilarities between the two datasets which was attributed to estimated densities of *Austrominius modestus* (beaked barnacle).

Scientists and students estimated substrate cover using three different techniques (printed out photographs, volumetric measurements of sediment and visual percentage cover estimates) were assessed for their practicality for a citizen science project and agreeability of estimations between the two surveyors. It was found that using a combination of photographs and visual surveys was the most appropriate method for monitoring sediment on the rocky intertidal.

Mind maps and identification tests were used to assess the development of science skills and knowledge during the project. Pre- and post-tests showed that students' identification skills improved after participating in the project. There was also an increase in the number of students achieving 100% correct identification. Mind maps showed a shift in thinking from

planning out their own scientific investigation (asking additional questions, gathering background information and predicting outcomes) to thinking about the methods and equipment required to carry out an investigation in the marine environment and future implications of the dredging. This research validated the data collected by citizen scientists as part of a facilitated marine monitoring project. It also provided valuable insight into Otago Harbour ecosystems and demonstrated an opportunity to engage students in collecting useful environmental data on a relevant issue.

Long-term monitoring of coastal areas is greatly needed and the collaboration between scientists and the general public could be utilised to fill in the gaps in current monitoring schemes. Citizen science has the ability to improve environmental management by providing useful data sets that can be used to inform managers when making management decisions whilst increasing public environmental awareness. However, citizen science is not applicable for all forms of monitoring and should be only considered where appropriate levels of support are available, when science outcomes align with the goals of the community involved (which should be clarified prior to commencement of projects) and information gathered can be relayed on to the community. In order for citizen science to make a valuable contribution to scientific research, funding is essential for engaging scientists, volunteers and managers who each provide important roles ensuring citizen science projects collect quality data in an efficient manner.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Monitoring the Environment and Ecosystems

Understanding the current state of the environment and associated natural cycles is considered to be a cornerstone for ecological research and management (Oakley et al., 2003; Lindenmayer & Likens, 2009; Müller et al., 2010; Magurran et al., 2010; Sergeant et al., 2012). Multi-objective approaches to management such as ecosystem-based management (EBM), are becoming more frequently adopted by managers (Crain et al., 2009) as they encompass ‘a holistic view of managing resources in the context of their environment’ (Berkes, 2012). By broadening the scope of management, social, economic and environmental factors can be monitored (Crain et al., 2009; Berkes, 2012), however, to implement management effectively (as is the case with all management) baseline environmental data is required (Sergeant et al., 2012). Baseline data is necessary as a starting point to measure and explain particular phenomena in an area (or object) of interest as well as identify and predict future risks through modelling (Wolfe et al., 1987; Magurran et al., 2010; Lohner & Dixon, 2013).

It is becoming increasingly difficult to separate past or on-going anthropogenic effects from the variability associated with natural processes (Wolfe et al., 1987; Müller et al., 2010; Borja et al., 2016). The consistent pressure of human activities on the environment, coupled with limited historic data sets, makes it difficult to quantify a meaningful baseline state of the environment prior to human impact (Lotze et al., 2006; Bates et al., 2007; Murray et al., 2016). Most monitoring regimes start in response to environmental change, increased anthropogenic disturbance or assessing management actions and is invaluable for detecting change over time (Lindenmayer & Likens, 2009; Holland et al., 2012). Monitoring data often has to be collected over a period of time sufficiently long enough to account for temporal variability (Oakley et al., 2003; Steinbeck et al., 2005; Lohner & Dixon, 2013). This is often dependent on what is being monitored (Oakley et al., 2003; Lohner & Dixon, 2013). Knowledge from monitoring can be useful for informing management decisions (Wolfe et al., 1987; Oakley et al., 2003) as well as determining the effectiveness of management decisions (Borja et al., 2016).

Gathering information for ecosystem management can be challenging as long-term monitoring schemes can be expensive (Agardy et al., 2005; Galloway et al., 2006; Magurran et al., 2010) and long-term funding is not always available (Sergeant et al., 2012; Lohner & Dixon, 2013). Long-term monitoring is also time-consuming (Magurran et al., 2010; van der Velde et al., 2017), requires suitably qualified personnel (Galloway et al., 2006; Cox et al., 2012) and can require expensive/technical equipment (Bates et al., 2007). Therefore, long-term monitoring projects are not always completed (Agardy et al., 2005; Magurran et al., 2010; Holland et al., 2012), may lack direction (Holland et al., 2012) or are terminated pre-emptively (before long-term relationships can be identified) (Lohner & Dixon, 2013), which can result in ill-informed decision making (Sergeant et al., 2012; Lohner & Dixon, 2013).

1.2 Citizen Science as a Solution?

Resource managers are increasingly utilising alternative sources of gathering long-term data (usually 10 years or more – Wolfe et al., 1987) by accessing information collected, analysed or transcribed by the public (Conrad & Hilchey, 2011; Cigliano et al., 2015). This is collectively known as citizen science collected data (Hidalgo-Ruz & Thiel, 2013; Todd et al., 2016; McKinley et al., 2017). "Citizen science" is a process where members of the general public, usually with non-scientific backgrounds, voluntarily collaborate with scientists or participate in scientific research (Silvertown, 2009; Ballard et al., 2017; van der Velde et al., 2017). The concept of collaborating with volunteers to collect data is not new and has been applied in research for at least 100 years, contributing large data sets to various long-term studies (Bonney et al., 2009; Magurran et al., 2010; Conrad & Hilchey, 2011; McKinley et al., 2017). Among of the most well-known of these projects is the Christmas Bird Count (CBC) organised by the National Audubon Society in North America since the beginning of the 20th century (Delaney et al., 2008; Bonney et al., 2009; Silvertown, 2009; Dickinson et al., 2010; Magurran et al., 2010; McKinley et al., 2017; van der Velde et al., 2017). Data from the CBC has been used by many research groups and organisations to observe distribution, range and population trends for bird species in North America (Delaney et al., 2008; Silvertown, 2009; Bonney et al., 2009; Devictor et al., 2010). As of 2013, it is estimated that 300 papers have been published using the CBC dataset (Chatzigeorgiou et al., 2016).

Citizen science encompasses a range of projects that vary in terms of scale and purpose but are often focussed on monitoring over time (Conrad & Hilchey, 2011; Todd et al., 2016). Citizen science projects of lengths similar to the CBC are rare, but it is not uncommon to have citizen science data collected over 10 years (Devictor et al., 2010). Citizen science has the capacity to provide data to inform management decisions (Danielsen et al., 2014; Dean et al., 2018). This could benefit resource managers by reducing project costs (Conrad & Hilchey, 2011; Vann-Sander et al., 2016; Ellwood et al., 2017), allowing for a larger sampling size (increasing statistical power) (Silvertown, 2009; Devictor et al., 2010; Gray et al., 2017), covering larger sampling areas (Bonney et al., 2009; Devictor et al., 2010) and collecting data over greater timeframes (Bonney et al., 2009; Conrad & Hilchey, 2011).

1.3 Concerns Around Citizen Science

Collaborations between scientists and the general public in citizen science are becoming more and more common (Conrad & Hilchey, 2011; Cigliano & Ballard, 2017) as seen in the increase in the number of journal publications on citizen science over the past ten years (Sbrocchi, 2014; Follett & Strezov, 2015; McKinley et al., 2017) (Fig 1.1). Despite this, there are concerns surrounding the accuracy and validity of data collected by citizen scientists (Bonney et al., 2009; Conrad & Hilchey, 2011; Gillett et al., 2012; Cooper et al., 2014; Ellwood et al., 2017; van der Velde et al., 2017). Variation in skill level and commitment of citizen scientists may affect the precision of measurements (e.g. species identification or abundance) (Bonney et al., 2009) or introduce bias (either over- or under-representing a sample) (Bonney et al., 2009; Bird et al., 2014) leading to lower confidence in the quality of the data. Conflict of interest, personal bias and the different prioritisation of tasks have also been raised as potential issues surrounding the final quality of data provided by citizen science (Guerrini et al., 2018). Therefore, community collected data is unlikely to be formally documented/reported (Lindenmayer & Likens, 2009) as systems are not yet in place to integrate citizen science collected data into environmental reporting (Peters et al., 2015a).

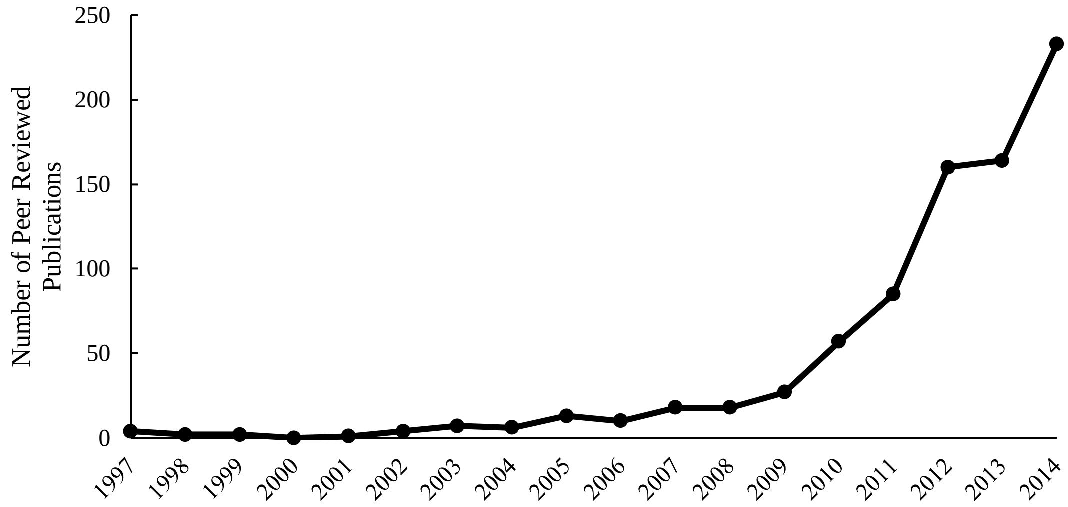

Figure 1.1: The growth of published peer reviewed articles on citizen science between 1997 and 2014 (modified from Follet & Strevov, 2015) (n=811)

Despite these doubts and sources of potential bias, research comparing citizen science data to scientist-collected data has found the quality of data to be relatively similar (Delaney et al., 2008; Edgar & Stuart-Smith, 2009; Gillett et al., 2012; Cox et al., 2012; Cooper et al., 2014; Lewandowski & Specht, 2015; Anton et al., 2018). Comparability between scientists and citizen scientists is thought to be influenced by design of the project and the tasks involved (Wiggins et al., 2011). Training of participants (Galloway et al., 2006; Delaney et al., 2008; Kosmala et al., 2016), iterative tasks (Dickinson et al., 2012; Kosmala et al., 2016), and availability of calibrated and easy to use equipment are all factors that have been identified as important to improve the quality of data collected (Kosmala et al., 2016). Accounting for bias and error, as is done with scientific data, is recommended for quality control (Kosmala et al., 2016; Specht & Lewandowski, 2018; Guerrini et al., 2018). Incorporating most, if not all, of these aspects into project design requires considerable planning prior to the commencement of citizen science projects but doing so will reduce concerns surrounding data quality (Wiggins et al., 2011).

1.4 Citizen Science in the Marine Realm

Effective monitoring is critical in today’s changing oceans, where resource depletion is being driven by the growing human population, coupled with indirect effects from climate change (Worm et al., 2006). Coastal areas, where the majority of the human population lives (Connell, 2001), are particularly threatened by issues such as overexploitation of fisheries, degradation of habitat and excess sediment via coastal erosion (Agardy et al., 2005). The subsequent effects surrounding human activities can lead to a substantial loss of ecosystem services (Agardy et al., 2005; Worm et al., 2006; Halpern et al., 2008) and so these areas are in dire need of quality long-term monitoring. Monitoring in these areas is often expensive and can be challenging (Borja et al., 2016; Fulton et al., 2018), therefore new and additional tools are needed for management and restoration of sensitive, declining, changing and diverse coastal ecosystems (Day, 2008; Friewald et al., 2018; Synder et al., 2019).

Citizen science has been recognised as being useful for gathering data in coastal and marine settings (Cigliano et al., 2015; Martin et al., 2016a; Cigliano & Ballard, 2017), yet marine-focussed citizen science projects are far less common (Cigliano et al., 2015; Fulton et al., 2018) when compared to other environments (such as terrestrial and freshwater) (Theobald et al., 2015). Although there are many groups that utilise the marine space (Martin et al., 2016a), managers and scientists monitoring the coastal environment have yet to realise the potential that could be unlocked by engaging marine users in citizen science. Costs associated with boats and equipment, the need for specialised participants (e.g. trained to use SCUBA) as well as safety and liability concerns are unique challenges to marine citizen science projects (Cigliano et al., 2015; Hyder et al., 2015; Martin et al., 2016b). As such, this has limited marine-focussed citizen science projects to predominantly high-income communities or popular diving locations (Fulton et al., 2018).

Retention and recruitment of volunteers is an on-going problem for ensuring the longevity of citizen science projects (Dickinson et al., 2012; Follet & Strezov, 2015) and this is anticipated to be the same, if not more, of a limitation in marine citizen science projects. A way to encourage citizen science in marine and coastal monitoring projects could be to collect data from more accessible locations such as the rocky intertidal, also known as the rocky shore. The rocky intertidal accounts for approximately 30% of the world's coastlines (Thorner et al., 2014), and in many areas is easily accessible from land (Connell, 1972; Thorner et al., 2014). Additionally, the rocky intertidal is a well-studied environment (Connell, 1972; Agardy et al., 2005; Coutinho et al., 2016; Chemello et al., 2018) so there is a strong background understanding of the ecological drivers in this system (Connell, 1972; Bertness & Leonard, 1997; Menge et al., 1999; Underwood, 2000; Sanford, 2002; Coutinho et al., 2016). The abundance of sessile organisms (Connell, 1972; Bertness & Leonard, 1997; Underwood, 2000; Sanford, 2002; Guerra-García et al., 2006), being able to monitor marine and terrestrial sourced impacts (Coutinho et al., 2016) and measure both physical and biological parameters (Bertness & Leonard, 1997; Underwood, 2000; Sanford, 2002) makes the rocky intertidal an ideal location to monitor the impacts of anthropogenic change over time (Agardy et al., 2005; Guerra-García et al., 2006; Lathlean et al., 2015; Coutinho et al., 2016).

1.5 Coastal Pressures in New Zealand

The Ministry for the Environment New Zealand has identified excess sediment and coastal degradation as one of the most important pressures on New Zealand coastal waters (Morrison et al., 2009; Ministry for the Environment & Statistics New Zealand, 2016). Sedimentation can occur from both natural (e.g. extreme weather events) or anthropogenic sources (Anderson et al., 2019). Excess sediment is often a result of terrestrial run-off from the intensification of catchment-based activities including agriculture, forestry and urban development (Schwarz et al., 2006; Moller et al., 2008). Not only can run-off load aquatic environments with added sediment, but it can also transport additional nutrients (e.g. phosphorus and nitrogen) into these systems (Parfitt et al., 2006; Moller et al., 2008). The combination of these impacts can reduce biodiversity, drive the formation of algae blooms and lower water clarity (Death et al., 2003; Moller et al., 2008; Desmond et al., 2015).

Evidence of the impacts of sediment in freshwater systems has been documented over time, yet any impacted freshwater will end up in coastal waters (Parfitt et al., 2006; Morrison et al., 2009). Despite this, the impacts of excess terrestrial sediment in marine coastal environments has been comparatively under-studied. In addition, coastal environments have added pressure from marine-based sedimentation resulting from disturbances of the sea floor via dredging, trawling or resource extraction (Morrison et al., 2009). Although bottom trawling in New Zealand has declined (Ministry for the Environment & Statistics New Zealand, 2016), the dredging of harbours and ports to maintain access for maritime vessels has becoming increasingly common and now occurs in most major harbours in New Zealand (Anderson et al., 2019).

1.6 Background to Dredging

Shipping now accounts for 90% of global trade (Corbett & Winebrake, 2008; Andrews, 2017; Carse & Lewis, 2017) and there are approximately 700 million container movements in and out of the worlds' ports per year (Andrews, 2017). With the increase in size of ships and thus their carrying capacity (Gourlay et al., 2015; Tran & Haasis, 2015), there is now pressure on port authorities to accommodate larger vessels by further modifying harbours and shipping channels (Carse & Lewis, 2017; Vogt et al., 2018). However, many harbours, ports, rivers and canals are not naturally deep or wide enough to ensure ships can safely manoeuvre in and out (Vogt et al., 2018; Brown et al., 2018). In response to shipping needs, dredging has been utilised to maintain important accessways into harbours around the world (Carse & Lewis, 2017; Vogt et al., 2018). This can be seen in the increase in the global dredging activities (measured in financial turnover as opposed to volume dredged), which has risen from 800 million Euros in 2000 to 4.6 billion Euros in 2017 according to International Association of Dredging Companies (IADC) (IADC, 2010; IADC, 2017). In New Zealand, there are currently six capital dredging projects operating, with many stating that the frequency of larger vessels coming into harbours and ports was a driver to initiate intensive dredging (Port Otago Limited, 2010; Port Napier, 2017; Ironside, 2018).

Although dredging is considered important for social and economic development (IADC, 2010), there are concerns about associated environmental and sustainability issues (Gourlay et al., 2015; Vogt et al., 2018). An example of this is the resuspension of sediment, which can cause problems such as reducing light availability to aquatic plants (Rogers, 1990; Desmond et al., 2015), modifying risk behaviours in sessile organisms (Chew et al., 2013) and clogging fine gill structures of fish and filter feeders (Vogt et al., 2018) which can in turn reduce local biodiversity and alter ecosystem structure (Agardy et al., 2005; Gallardo et al., 2016; Bollen et al., 2016).

Areas subject to dredging can create conflict between stakeholders (Hart & Bryan, 2008; Pearson et al., 2016) as they often hold cultural and recreational significance. Ports are often near large urban areas and have long been an entranceway – for both people and goods – to a city (Andersson et al., 2016). Moreover, harbours, canals and rivers usually provide customary and recreational fisheries, amenities for water-sports as well as being aesthetically pleasing (Boyd, 2008; Port Otago Limited, 2010). Therefore, these areas need to be monitored to ensure they can be enjoyed by others in the future – a way to do this is to engage the public in monitoring schemes through citizen science.

1.7 Monitoring Impacts of a Dredging Operation on the Rocky Shore Using Citizen Science

In 2014, the Otago Harbour port company (Port Otago Limited) was granted consent by the Otago Regional Council to commence a capital dredging project to remove 7.3 million cubic metres (m^3) from the main shipping channel deepening the channel to 14 m to allow larger vessels to enter the Port (Port Otago Limited 2010; Port Otago Limited, 2016). Vessels that arrive in Port Chalmers are either container, logging or cruise vessels, and the number of vessels in each category is gradually increasing each year from 501 in June 2013 to 529 as of June 2018 (Port Otago Limited, 2019). The amount of exported logs (in tonnes) also increased from 789,000 to 1.06 million in this same time period (Port Otago Limited, 2019). The dredging was to be completed by two vessels – a suction dredge (the New Era) and a grab dredge (Vulcan).

Local residents were concerned about the potential environmental impacts this may have on the harbour and approached the New Zealand Marine Studies Centre (NZMSC) – the education and outreach facility associated with the Department of Marine Science, University of Otago (Desmond et al., 2016). In response to these concerns, a facilitated citizen science project, was developed and commenced in 2016 involving local schools. The goals of the citizen science project were two-fold: first, to collect valuable scientific data about the impact of dredging on the intertidal community and second, to engage with local communities, educate them about the marine environment and encourage them to take guardianship of their local shorelines.

1.8 Study Site Description

The Otago Harbour (45° 50’ S, 170° 35’ E) is located on the East Coast of the South Island, New Zealand (Fig 1.2). It covers an area of 46 square kilometres (km^2) (23 km long by 2 km wide on average). The average depth is 4.5 m, however there is a shipping channel approximately 12 m deep which has been subjected to dredging since circa 1877 (Smith et al., 2010). Two islands, Quarantine Island and Goat Island, and two peninsulas at Port

Chalmers and Portobello are located in the middle section the harbour, separating the inner harbour from the outer harbour resulting in variable environmental conditions (Smith et al., 2010). The inner harbour is generally shallower with finer sediments whereas the outer harbour is deeper with coarser sediments (Port Otago Limited, 2010; Smith et al., 2010). There are two dominant sources of anthropogenic development: the city of Dunedin (located at the harbour basin) and its associated port (Port Chalmers). The dominant freshwater input is from the Leith River, which enters at the harbour basin.

The harbour and surrounding coastline are popular for a range of recreational activities (including sailing, rowing, diving) and both commercial and recreational fishing (Boyd, 2008). The harbour also has important kai moana (seafood – primarily shellfish in the harbour) gathering sites for the local iwi (tribe) (Boyd, 2008; Port Otago Limited, 2010; Smith et al., 2010). The importance of this customary gathering site prompted the legislation to establish the Ōtakōu Mātaitai Reserve (a form of customary protection) in 2016 as part of the Fisheries (South Island Customary Fishing) Regulations (Fisheries (Declaration of Ōtakou Mātaitai Reserve) Notice, 2016). The city of Dunedin has a well-established eco-tourism industry (Darling, 2010) due in part to the variety of unique marine fauna that reside in the area (Port Otago Limited, 2010). Many tourists often enter Dunedin via cruise ships, the number of which has risen over the past five years (Port Otago Limited, 2019). Furthermore, there is also a long history of marine scientific research in Dunedin (Hickman, 2010), predominantly carried out by the University of Otago since the Portobello Marine Laboratory (previously a fish hatchery, established in 1904) was purchased by the University of Otago in 1951 (Putnam, 1977). Through a funding grant from the Otago Participatory Science Platform (Ministry of Business, Innovation and Enterprise Curious Minds, MBIE) the NZMSC was able to employ staff to educate and support schools students to collect baseline data. The NZMSC provides opportunities for school students to engage in citizen science and work alongside tertiary students and scientists to investigate Otago Harbour.

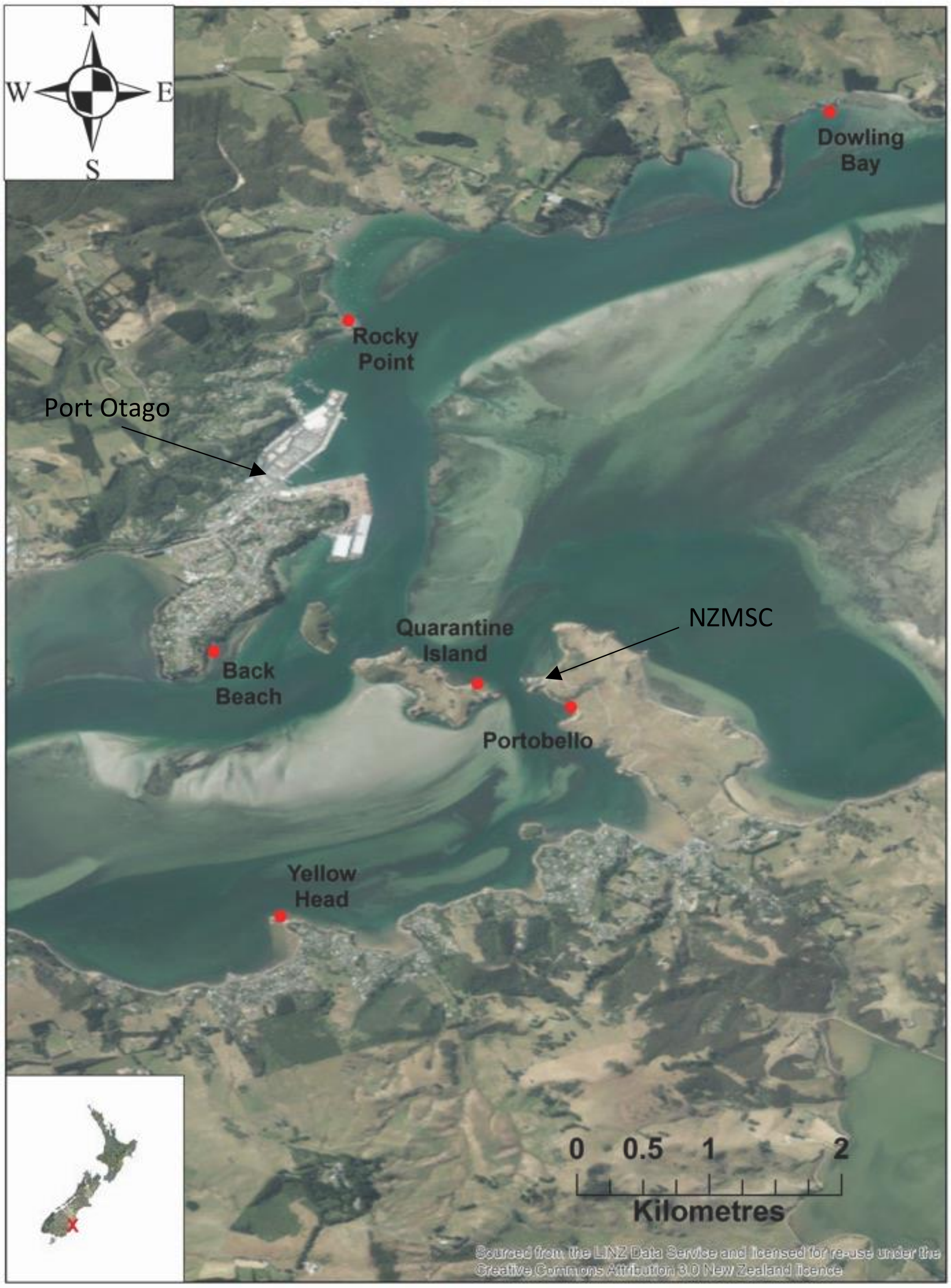

Figure 1.2: Map of the Otago Harbour, Dunedin. Sites are indicated by red circles. Red X on the insert of New Zealand indicates the location of Dunedin

1.9 Aims of this Project

The primary objective of this project was to assess the strengths and the weaknesses of both scientific and educational outcomes of a facilitated citizen science project (i.e. a citizen science project facilitated through a research institute or organisation). This was achieved by thoroughly evaluating a marine monitoring project in order to provide information on approaches that work well and identify issues surrounding marine-focussed citizen science projects and the data provided. This thesis primarily focuses on the monitoring data collected during 2017 and 2018 (with 2016 acting as baseline data for the citizen science project).

This facilitated citizen science project ran consecutively between 2016-2018 and involved students aged five to fifteen (though the average age of students was was 9.8 years (± 0.2 years)). Schools monitored six sites along the rocky intertidal within the harbour (Fig 1.2). The structure and methods used in the first year of the project remained consistent in the following two years (aside from some modifications to collect more data). Over the course of six months, each school was allocated approximately eight hours of contact time with the scientists which was split into six sessions. These sessions consisted of: an introduction session, two data collection sessions, two data entry sessions and a summary session. During the course of this three-year monitoring project, ten schools (primary and secondary) participated with approximately 450 students and 100 parents/teachers being involved, as well as 28 scientists (Fig 1.3).

Figure 1.3: Image of parents, the lead scientist, teacher and students completing a mid-tide survey at Rocky Point, June 2017

My role in the project, as the lead scientist, was to co-ordinate all aspects of the project from contacting schools and scheduling sessions to organising open access meetings to present the students' work to the public. Additionally, I prepared presentations to give to the schools, completed health and safety paperwork prior to data collections, gathered appropriate equipment and resources (which could involve creating activities for students in the classroom) for each of the sessions and organised transportation for the schools (if required) as well as rostered on support staff. I also summarised the project results in yearly reports for the schools and the funding agency and Port Otago Limited. Reports were also made publicly available via the project website (https://www.mm2.net.nz).

Chapter Two: Monitoring the rocky intertidal in Otago Harbour using a citizen science project

This chapter assessed the quality of the data collected by citizen scientists (in this instance students) by comparing it to data collected by scientists. This comparison determined whether student-collected data could be verified to scientific standards and provided an opportunity to investigate whether there are differences between the two datasets and if so, what was driving these differences.

Chapter Three: Assessing different methods to estimate sediment accumulation for a citizen science project

This chapter focussed on assessing different ways to estimate sediment accumulation on the rocky intertidal that could be applicable for citizen science. Assessments aimed to identify which method would be the most consistent for both students and scientists as a measure of effectiveness and simplicity

Chapter Four: Investigation into science-based skills and knowledge developed during a facilitated citizen science project

This chapter investigated the educational outcomes of a facilitated citizen science project and how these can be applied to the national curriculum. This investigation was completed to determine whether students could improve their science skills and/or knowledge after participating in the citizen science project.

Chapter Five: General discussion

The applicability of citizen science to environmental monitoring was discussed with emphasis on structuring a citizen science project and the challenges in doing so. Finally, recommendations for the future of citizen science, particularly in a New Zealand context, are put forward.

CHAPTER TWO

MONITORING THE ROCKY INTERTIDAL IN OTAGO HARBOUR USING CITIZEN SCIENCE

2.1 INTRODUCTION

2.1.1 Human Impacts on the Coastal Environment

Coastal and estuarine ecosystems are under significant pressure globally from human activities (Morrison et al., 2009; Chew et al., 2013; Ellis et al., 2015; Aguilera et al., 2016; Snyder et al., 2019). These activities can add stressors (e.g. excess nutrients, toxins, sediment and freshwater) into the environment (Townsend et al., 2008), which affect individual taxa or community composition and alter ecosystem structure and functioning (Townsend et al., 2008; Morrison et al., 2009; Snyder et al., 2019). One of the most significant environmental stressors in New Zealand coastal and estuarine systems is sedimentation (Schwarz et al., 2006; Morrison et al., 2009; Chew et al., 2013; Ministry for the Environment & Statistics New Zealand, 2016). Excess sedimentation can have both direct and indirect effects on coastal organisms (Schwarz et al., 2006; Morrison et al., 2009; Chew et al., 2013). Clogging of fine breathing or feeding structures (Schönberg, 2016), changes in behavioural responses (Chew et al., 2013), lower light availability for photosynthetic organisms (Desmond et al., 2015) and burial and scouring (Airoldi, 2003; Schönberg, 2016) can reduce biodiversity and critical habitat essential for valuable species (Schwarz et al., 2006; Morrison et al., 2009; Cussioli et al., 2015). As is the case with most environments, stressors do not act in isolation (Townsend et al., 2008; Crain et al., 2009; Morrison et al., 2009). In coastal ecosystems, this often results in the interaction of impacts resulting from both land-based and marine-based human activities (Crain et al., 2009; Morrison et al., 2009; Brown et al., 2018). An example of this is the deposition of sediment from large-scale land clearances, or re-suspension and disturbance of sediment from dredging and mining activities in the marine environment (Hart & Bryan, 2008; Morrison et al., 2009; Chew et al., 2013). Most research on coastal sedimentation focusses on terrestrially-sourced sedimentation (Schwarz et al., 2006; Walling, 2006; Morrison et al., 2009), however, there is a growing need to assess marine-sourced sedimentation as dredging and mining activity increases worldwide (Brown et al., 2018).

2.2.2 Port Dredging

Many ports and harbours are under-going intensive modifications driven by increased trade and tourism (Port Otago Limited, 2010; Chew et al., 2013; Pirotta et al., 2013), population growth (Chew et al., 2013; Pirotta et al., 2013), and expansion of defence forces (Pirotta et al., 2013; Firth et al., 2014; Brown et al., 2018). A large component of these modifications involves the extraction and removal of substrate via dredging. Dredging can be classified into two main categories: capital dredging and maintenance dredging (van Raalte, 2006). Capital dredging, as defined by van Raalte 2006, "involves the creation of new or improved facilities such as a harbour basin, deeper navigational channel or lake, or an area of reclaimed land for industrial or residential purposes". In comparison, maintenance dredging removes natural siltation from channel beds to maintain the desired depth of navigation channels and ports (van Raalte, 2006; Cussioli et al., 2015).

Although the dredging of harbours has been a regular way of maintaining shipping channels since the latter part of the industrial revolution in the late 1800s (van Raalte 2006; Cussioli et al., 2015), dredging is now a billion-dollar global industry (IADC, 2018). The number of dredging vessels has increased 75% since 2000 with approximately 1,481 operating worldwide (Pirotta et al., 2013). As of 2018, most major ports and harbours in New Zealand, have had or are currently undergoing capital dredging projects in addition to regular maintenance. This includes Marsden Point (Whangarei Harbour) (Bickler & Clough, 2017), Port of Napier (Port Napier, 2017), Tauranga Harbour (Cussioli et al., 2015), Lyttleton Port (Sneddon & Barter, 2009), Port of Auckland (Ironside, 2018) and the Otago Harbour (Port Otago Limited, 2010; Chew et al., 2013). This is due to increased trade (both exports and imports are transported by sea) and the growth of tourism in New Zealand (Port Otago Limited, 2010; Ironside, 2018).

2.1.3 Monitoring Impacts from Dredging

Environmental impacts associated with dredging are numerous, such as underwater noise (Pirotta et al., 2013; Gourlay et al., 2015), release of toxic pollutants (Agardy et al., 2005; Pirotta et al., 2013) and increased turbidity of suspended sediment (Agardy et al., 2005; Wilber et al., 2005; Pirotta et al., 2013; Cussioli et al., 2015). To understand the impacts of stressors, appropriate longitudinal baseline data is needed. Monitoring of these stressors is required to ensure operations are set within acceptable environmental limits as well as to provide information for future management decisions (IADC, 2018). As long-term monitoring can be an investment of resources (both financially and time wise), often intensive short-term studies are completed first to provide insight into areas to focus on and provide feedback on effectiveness of protocol (Lovett et al., 2007).

Many environments require long-term study because they change slowly over time and regular monitoring of key variables in ecosystems can provide a record of change (Wolfe et al., 1987; Lovett et al., 2007). In order to be effective, EBM models require high-resolution data sets that range both temporally and spatially (Crain et al., 2009). This can be challenging as these data sets are often more expensive to collect and so require sustained sources of funding (which is not always guaranteed) (Lovett et al., 2007). Despite the need for comprehensive data sets to make informed management decisions (Garcia-Soto et al., 2017), there are still gaps within many monitoring projects that can lead to actions that may not be suitable (Sergeant et al., 2012; Theobald et al., 2015; Chandler et al., 2017). Resource managers faced with the challenges of collecting high-resolution and/or longitudinal data sets are more frequently engaging and collaborating with citizen scientists to achieve management objectives (Freiwald et al., 2018). This is because citizen science can collect data over broad temporal and spatial scales at a reduced cost and effort (compared to surveys completed by professional scientists) (Hochachka et al., 2012; Theobald et al., 2015).

2.1.4 Coastal Citizen Science

Despite concerns surrounding the quality of data provided by citizen science, much of the research investigating the quality of data collected by citizen scientists has found that the quality meets standards as set by professional scientists (Delaney et al., 2008; Cooper et al., 2014; Gillett et al., 2012, Anton et al., 2018). These comparisons have been made across a variety of different participatory projects with a range of topics including: water quality (Ballard et al., 2017), invasive species (Delaney et al., 2008; Anton et al., 2018), marine debris (Hidalgo-Ruz & Thiel, 2013; Eastman et al., 2014; Aguilera et al., 2016; van der Velde et al., 2017), intertidal diversity (Koss et al., 2009; Cox et al., 2012) and subtidal reefs (Edgar & Stuart-Smith, 2009; Gillett et al., 2012).

In comparison to terrestrial-based projects, marine and coastal citizen science projects are under-represented (Theobald et al., 2015), possibly as a result of the ease of accessibility and deeper understanding of terrestrial ecosystems, as well as greater concerns regarding safety when working in the marine environment (Cox et al., 2012; Theobald et al., 2015; Jarvis et al., 2015; Hyder et al., 2015; Cigliano et al., 2015). Few studies have assessed the reliability of the data collected by citizen scientists in temperate marine environments (Cox et al., 2012; Jarvis et al., 2015; Hyder et al., 2015). Thus, validation of the robustness of data collected in such environments is necessary.

2.1.5 The Rocky Intertidal as a System to Explore Marine Citizen Science

Accessibility to the marine environment and financial cost are often barriers to further engagement of local communities in marine-focussed monitoring projects (Jarvis et al., 2015; Cigliano et al., 2015; Cigliano & Ballard, 2017). Many marine citizen science initiatives require participants with SCUBA qualifications and experience and/or access to boats, which can exclude volunteers (Fulton et al., 2018; Freiwald et al., 2018) and can also be expensive (Thompson et al., 2002; Guerra-García et al., 2006; Cigliano et al., 2015; Cigliano & Ballard, 2017). Therefore, the monitoring of marine habitats closer to shore, such as the rocky intertidal, are more feasible and thus prevalent.

The rocky intertidal is an important part of the coastal ecosystem (Agardy et al., 2005; Bates et al., 2007) and in temperate areas, are often highly productive (Agardy et al., 2005). As intertidal ecology is relatively well-understood (Menge et al., 1999; Thompson et al., 2002; Sanford, 2002; Gorgula & Connell, 2004; Agardy et al., 2005; Guerra-García et al., 2006), this provides background knowledge to help explain natural patterns and interactions that can then be built upon through further research. Rocky intertidal systems are under considerable pressure from both terrestrial and marine-based stressors (Gorgula & Connell, 2004; Halpern et al., 2008; Brown et al., 2018) yet there has been little research on impacts of sediment loading on the rocky intertidal (Airoldi, 2003).

2.1.6 Objectives

This chapter aimed to assess the quality of data collected by citizen scientists during a facilitated citizen science project. This assessment involved comparing species density and diversity data collected by primary and secondary school students (aged seven to fifteen) to scientist-collected species density and diversity data in order to investigate whether the data collected by students could be compared to data collected by scientists. As this was a facilitated citizen science project, with multiple quality control measures in place, it was expected that students would be able to collect a diversity of data that met scientific standards. However, student-collected diversity data was predicted to have greater variability than scientist-collected data due to the wider range in ability found amongst the students involved in the project.

Dredging in Otago Harbour is currently a combination of capital dredging and maintenance dredging (Port Otago Limited, 2010). The Otago Harbour has been dredged since 1865, with the first capital dredging project commencing in 1877 to maintain the depth and width of the already narrow shipping channel (Port Otago Limited, 2010; Smith et al., 2010). Over this time, an estimated 34 million m^3 of substrate has been removed from the harbour (Port Otago Limited, 2010). In 2014, Port Otago Limited began the capital dredging project 'Next Generation', with consent to dredge 7.3 million m^3 out of the harbour over a period of 25 years (Port of Otago Limited, 2016). The purpose of this dredging project was to widen and deepen the channel from 13 m to a maximum of 15 m (though current plans are to dredge only to 14 m) to account for the increasing size of both cargo and cruise ships entering the harbour (Port of Otago Limited, 2016).

Although environmental consultants were contracted to complete assessments of the ecosystem health of Otago Harbour (Port Otago Limited, 2010), these assessments were irregular (approximately every three years) and did not include monitoring of the rocky intertidal. This opened up an opportunity to establish a regular monitoring project along the rocky intertidal and engage with the local community who were concerned about the dredging. In response, a facilitated citizen science project was established in 2016 and monitored species presence and abundance on transects along the intertidal habitat within the harbour. This project ran for three years and was used as a case study throughout this thesis.

For this particular chapter, the focus was on the second year (2017) where participating students were aged from seven to fifteen.

2.2 METHODS

2.2.1 Study Sites and School Involvement

Study sites, with intertidal reef located within Otago Harbour, were selected based on: their proximity to the shipping channel and the port (where dredging was occurring), and providing a representative overview of the harbour ecosystem, accessibility for schools (including travelling time and ability for children to access the rocky intertidal) and slope/structure of the shoreline. All sites had a hard rocky substrate comprised of reef, boulders or a combination of both (Desmond et al., 2016). Six sites were surveyed over the three years of the project: Back Beach, Dowling Bay, Portobello, Quarantine Island, Rocky Point and Yellow Head (Fig 1.2).

Throughout the three years of the facilitated citizen science project, ten schools with 450 students (aged five to fifteen years old) and 15 teachers were involved. Each school was assigned a site for each year of the project. The following schools were assigned to these sites; Back Beach (Ravensbourne School 2016 & 2018, Sawyers Bay School 2016 & 2017), Dowling Bay (St Brigid's School 2016-2018), Portobello (Portobello School 2016 & 2017, Macandrew Bay School 2018), Quarantine Island (Otago Girl's High School 2016-2018), Rocky Point (Arthur Street School 2016, Abbotsford School 2017, Musselburgh School 2018), Yellow Head (Broad Bay School 2016-2018). Each school had eight hours contact time split over six sessions (an introductory session, two data collection sessions, two data entry sessions and a summary session).

2.2.2 Introductory Sessions

The purpose of this session was to introduce the scientists involved and provide students with an overview of the issue. This included background information to the issue and an explanation of dredging (as this term was unfamiliar to most students). The potential impacts the dredging process could have on the environment (for example smothering of organisms, clogging of filter feeding structures and scouring of larvae) were also explained.

A brief discussion was conducted on the study location, who might be interested in the data, type of data to collect, methods and equipment. This briefing ensured students were prepared for the field work.

2.2.3 Data Collection Sessions

2.2.3.1 Structure of Data Collection Sessions

Two data collection sessions were run in each year of the project. Each session was two hours long and had at least two scientists present. Scientists (n = 28) had at minimum of three years of tertiary education in marine science and had experience with the local marine environment. Scientists included 15 postgraduate students (two doctoral candidates, eleven master's candidates, two honours candidates), four people with doctoral degrees, one person with a master's degree and four with extensive marine field science experience (i.e. worked at the NZMSC for multiple years). Data collection sessions were timed with good low-tide times that were less than 0.5 m (most tide heights were lower than 0.4 m) that also occurred within appropriate hours for schools, and were spaced to provide an adequate temporal gap between sampling sessions for data entry and analysis and to ensure we were sampling different seasons. Tide times for Port Chalmers were retrieved from Land Information New Zealand (LINZ, 2018). Data collection sessions began with a ten-minute briefing by the scientists that covered: the purpose of the field trip, how we would collect the data (reviewing methods and equipment needed) and health and safety elements for the students as well as animal welfare. Surveys were completed by placing a 30 m transect at two shore heights at low tide (on water's edge) and mid tide (determined by scientists). Quadrats (1 m_2) divided into four quarters with string were placed randomly along the transect using a random number generator on RStudio in 2017 (version 1.1.14, RStudio Team, 2016) and 'Random #' mobile app in 2018 (version 5.0, Dean, 2013). Parent helpers and teachers were present with most groups of students to help them stay on-task and they often recorded students' findings in each quadrat. Usually two scientists (depending on group size) floated between groups to check on their progress and assist groups with the identification of species. Each school surveyed three to seven quadrats at both mid and low tide. Students worked in groups of three to six per quadrat (dependent on the number of students present on the data collection trips).

2.2.3.2 Sampling Approach

In each quadrat the following information was recorded onto an accompanying datasheet: the percentage cover of substrate, the number of animals and the percentage cover of plants. Dead or empty organisms (often shells) were not counted or recorded. Substrates needed to add to 100% and were classified into six categories loosely based on Wentworth's fragment descriptions (Wentworth, 1922) - reef, boulder, cobble, gravel, sand, sediment (refer to Wentworth's description of silt, Wentworth 1922). Although students and scientists recorded animals as counts, if there were large aggregations of a particular species that were small (< 4 cm) within the 1 m^2 quadrat, an estimate of the number of that species was taken. This was completed by using a smaller 0.01 m^2 quadrat (equating to 1% of the 1 m^2 quadrat) to estimate the cover of dense areas of algae (often turf-forming algae or holdfasts) and sessile organisms (Airoldi & Virgilio, 1998; Drummond & Connell, 2005). After counting the number of individuals within the 1% area, this was then scaled to calculate how many individuals were in the 1m^2 quadrat. For example, if there were 50 individuals in a 1% area and there was an estimated 7% cover of a species within the quadrat then 350 individuals were recorded on the datasheet. At each data collection session, some environmental parameters were also measured, including salinity (measured with a refractometer in parts per thousand) and temperature of the air and the water (in degrees Celsius) and water clarity (using a 1 m long water clarity tube). Photographs of each quadrat were taken using a Panasonic camera (Lumix DMC-TZ55) from above the quadrat to get the whole frame inside the shot.

For the scientist surveys in 2017, ten quadrats were assigned random numbers using RStudio and were placed along each transect for both low and mid tide heights. Two scientists collected the species abundance data and substrate data, and two scientists recorded this information. There were some exceptions to this methodology – Dowling Bay (only had low tide quadrats surveyed due to a fast incoming tide), Portobello (eleven quadrats surveyed at low tide and nine surveyed at mid tide) and Rocky Point (five quadrats surveyed at both shore heights). For the student surveys in 2018, students only collected species abundance data and substrate data for low tide at Back Beach. This was due to the age of the students as well as the size of the school involved (approximately 20 students) which meant they needed to focus on one tide height.

The following identification resources were available each sampling trip: Guide to common intertidal species of the South Island, New Zealand (Schiel & University of Canterbury Marine Ecology Research Group, 2006), Collins Field Guide to the New Zealand Seashore (Carson & Morris, 2017), New Zealand Seaweeds: An Illustrated Guide (Nelson, 2013). Additionally, locally produced guides from the NZMSC with the most common species found on rocky shore and sandy/muddy shore (i.e. inlets and estuaries) for the North and South islands of New Zealand were also provided.

2.2.3.3 Dates of Data Collection

Scientists collected data between the 24th and 31st of May 2017 from Back Beach, Yellow Head, Portobello, Dowling Bay and Quarantine Island and on 24th of July 2017 at Rocky Point. Scientists completed their surveys earlier (four weeks prior) than students when low tides were less than 0.4m and scientists were available. Students completed two data collections in between 23rd-29th June and 22nd-25th August 2017 with an additional data collection on 8th September 2017 on Quarantine Island. Students had two data collection periods in 2018 between the 15th- 20th March, 29th March and 4thApril 2018 and 13th-18th and 27th June 2018. In 2018, scientists estimated percentage cover of substrate, prior to the student surveys. Although the project ran over three years, scientists collected data in 2017 (species and substrate) and 2018 (substrate only).

2.2.4 Data Entry Sessions

Data entry sessions were run in the classroom within one working week of the data collection sessions. The data entry session ran for an hour and primarily consisted of entering the data online into the nationwide database ‘Marine Metre Squared’ (www.mm2.net.nz). Prior to each of these sessions, the lead scientist had gone through the datasheets to correct spelling and species identification and check for any errors (quality control). Errors were classified as: seaweed recorded as a count, no indication of the species (e.g. ‘oyster’), substrate percent cover did not add up to 100, animals as percentage cover (applicability determined by scientist), no data recorded (applies to substrate and animals only), no value written next to species (for example one group of students wrote “too many to count”), unrealistic identification (for example, subtidal species found at mid tide). Scientists aided students in using the website as well as with other activities provided. Additional activities were based on critical thinking by comparing data between shore levels and sampling trips (including producing graphs and summarising findings) as well as thinking about the impacts that a changing environment may have on different species and asking further questions.

2.2.5 Summary Sessions

The purpose of the summary sessions was to present the summarised data collected over their two field sessions (average number of species present) to each school and discuss what they had found, what the data meant and how each individual site compared to the average for the whole harbour. Comparisons between the schools' data collected at different shore heights and between their two sampling trips were also presented. The information that was presented was; the mean number of unique taxa (for mid and low tide), mean percentage cover of sediment (for mid and low tide), number of unique species for different rankings of sensitivity to sediment as well as the changes in the number of some selected species. Before showing the data, a recap discussion was held to remind students of the overall purpose of this project. To conclude the session and the project, there was a class discussion as to how they could share their data and continue collecting data beyond the scope of this citizen science project.

2.2.6 Quality Control

As there were differences in who collected the data, when the data was collected and sampling effort (number of quadrats surveyed at each tide height), standardisation of the biological and environmental data collected was needed. This was to allow the data to be comparable between students and scientists, study sites and years of the project. Differences in the data were standardised by averaging the number or percentage cover of species and substrates by the number of quadrats surveyed at that location for each year the project operated. The majority of statistical analysis, including standardising the dataset and quality control, was run using RStudio.

In 2017, scientist data was entered into Microsoft Excel (version 15.35). Throughout the project, all student-collected data was entered into the online database. The multi-year data was downloaded from the website as csv files and filtered by project name. Each survey was distinguished from one another by the unique survey ID number that was assigned when the survey was entered into the database. For the scientist surveys, each survey was assigned a number in consecutive order from 1-90 (excluding scientist-collected data from Rocky Point, that was entered into the online database).

The first stage involved reading the data into RStudio and 'cleaning' the dataset to make the different variables readable into the software (as it is programmed to do). There were variations in the spelling or formatting of some variables, such as site names. Therefore, the structure/format of variables had to be standardised so that variable spelling didn't cause a study site, for example, to be recognised as multiple sites. It was decided that all information would be formatted in lowercase and have no spaces (underscores would be used instead). The 2017 scientist data was entered in this way however, this formatting was not the default for data downloaded from the online database and so was converted into the standardised format. Both scientist and student data were repeatedly searched to identify anything straying from this format.

In preliminary summaries of the data, the student datasets showed that the number of surveys did not equal the number of quadrats (which was often due to mis-entered information such as the date of collection). This was found by dividing the student datasets into the number of entries by shore height, survey date and site. For each site, it was first checked that all the raw data had been entered by matching the raw data to the online data through a combination of factors including study site, sampling date, names of the surveyors involved and shore height. If all these details matched, then it was deemed that no further investigation was needed at this point. If there were inconsistencies, further investigation was taken to identify where the inconsistencies were. This was determined by comparing the list of species between the online data to the raw data to identify whether the survey was unique or a replicated survey. If no raw data could be matched to online data, then a new survey was entered into the website.

In some instances, the same species had been entered multiple times on one survey. Surveys with such issues were identified and were assessed on a case by case scenario against the raw data. Any necessary changes were done to the online database. The primary reason for multiple entries of species was whether or not it was counted (as a tally) or measured as a proportion (percentage cover). All of the data was classified as either entered as a 'cover' (percentage cover) or a 'count' (tally). Whilst looking for multiple entries of a species, any species entered as both a count and a cover in the student dataset were also identified. Species listed as unknown (generally due to the fact that the correct species was not available on the online database) were put aside until their ID could be assigned. Issues with cover and count were assessed on a case by case basis and there were two decisions that could be made: to convert all the data to be either counts or covers, or to keep data recorded as it is with a species recorded as both counts and covers. Ideally species were entered as either count or cover, however it was not always possible to achieve a clear consensus as it was possible that data collected as a cover and as a count made sense (for example fish eggs). Nevertheless, it was decided that algal species were always entered as cover and animals were always entered as a count – some exceptions were eggs from *Forsterygion* sp. (triple-fin eggs), bryozoan species (Phylum Bryozoa), *Halichrondria* sp. (Encrusting sponge) and *Boytrolloides* sp. (colonial ascidians) as it was deemed feasible that these species could be either covers or counts (see Appendix 2.1 for a species list).

2.2.7 Analysis

To standardise the sampling effort, which varied due to the different number of quadrats surveyed each trip, raw data was converted to the average number of each species found per m^2 (diversity). Species were listed by scientific name as sometimes there were multiple common names for one species. A two-way ANOVA (analysis of variance) followed by a Tukey's HSD (honestly significant difference) post-hoc test were run comparing the average number of species found per m^2 between student-collected data and scientist-collected data. All figures were created using RStudio unless stated otherwise. All statistical testing had the significance set to a level of $\alpha = 0.05$.

To further investigate comparison, both student- and scientist-collected datasets were separated at a quadrat level (using the number of individuals (of a species) per m^2) and made into PCO plots, followed by a PERMANOVA (permutational multivariate analysis of variance) using PRIMER (v6, Anderson, Gourley & Clarke, 2008). All data on PRIMER were subjected to a square-root transformation and used the Bray-Curtis similarity index to calculate the resemblance matrix prior to analysis. SIMPER (similarity percentage) analysis was run on these plots to identify species responsible for approximately 50% of dissimilarity between the two groups of surveyors. Density values of the identified species from the SIMPER analysis were compared between students and scientists. This was completed using a two-way ANOVA followed by a Tukey's HSD post hoc test.

2.3 RESULTS

2.3.1 Comparing Data Between Scientists and Students

There were no statistical differences in species diversity (average number of species found per m^2) between the surveys conducted by scientists and students in 2017 (Two-Way ANOVA $F_{(3,18)} = 0.293$, p-value = 0.616) (Fig 2.1, Table 2.1). There were also no significant differences between the two shore heights (p-value = 0.456), nor were there any statistical differences in the interaction between surveyor (students and scientists) and shore level (Two-Way ANOVA $F_{(3,18)} = 0.293$, p-value = 0.833) (Fig 2.1; Table 2.1).

Multi-variate analysis using a PCO plot showed that despite some overlap between the densities of species identified in the student and scientist quadrats, there were still some dissimilarities between the two surveyors (Fig 2.2). A PERMANOVA run on the PCO plot showed there were significant differences between student- and scientist-collected datasets ($p_{PERMANOVA} = 0.01$) (Table 2.2). Approximately half of this dissimilarity was attributed to 11 species (out of 118 found in 2017) which was predominately made up of faunal species (Fig 2.2; Table 2.3). When analysing the 11 dissimilar species, there was a significant difference between the density values between scientists and students (Two-Way ANOVA $F_{(21, 2508)} = 10.41$, p-value <0.05) (Fig 2.3; Table 2.4). Upon further investigation, using a Tukey's HSD test, only one of the eleven dissimilar species had a significant difference between the students and scientists, which was the beaked barnacle *Austrominius modestus* (p-value <0.05 for Tukey's HSD) (Fig 2.3; Table 2.4).

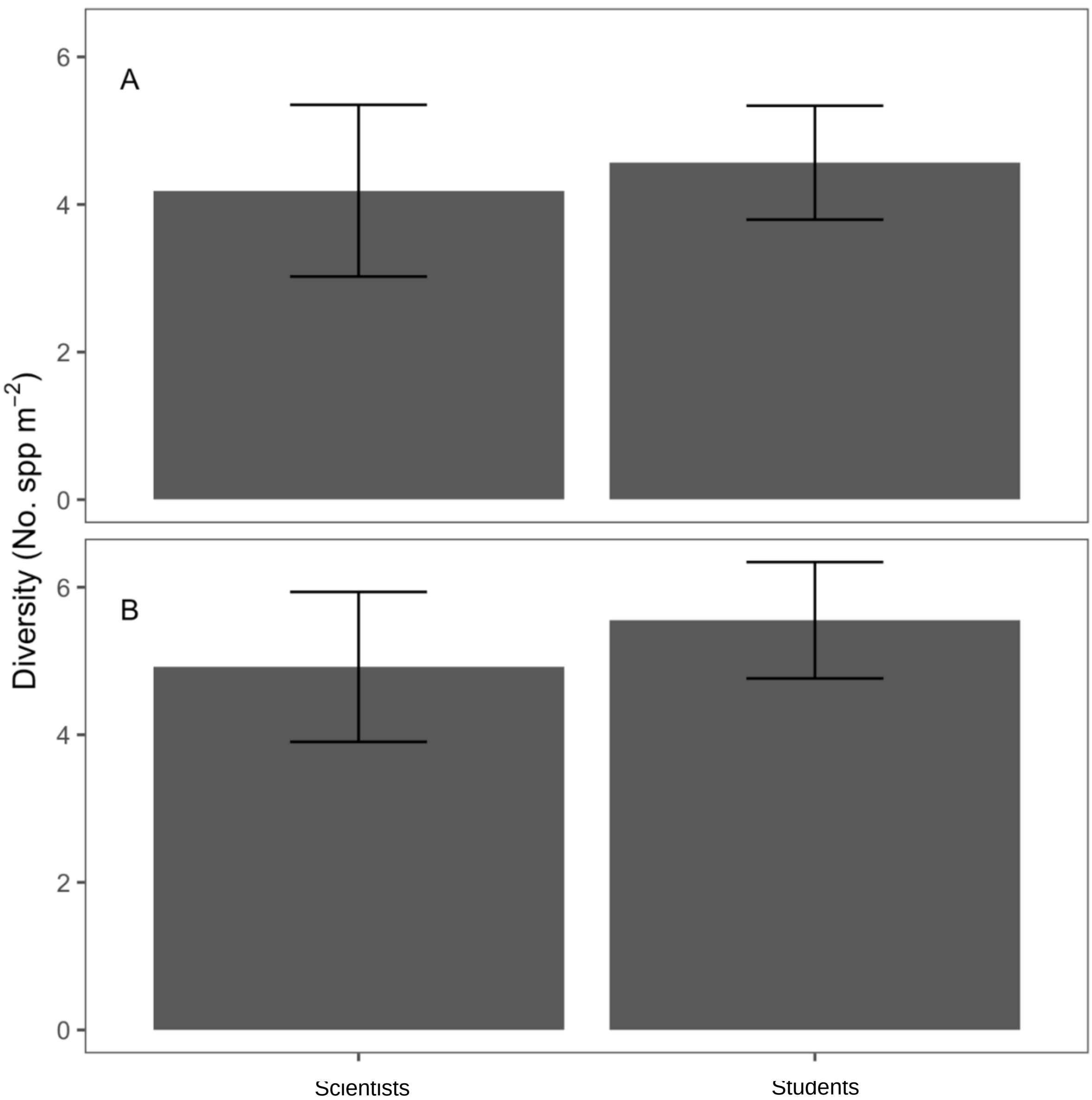

Figure 2.1: Average number of species found per m2 for the Otago Harbour by scientists and students for low (A) and mid (B) shore height ± SE in 2017 ($n_{(low)}$ = 43, $n_{(mid)}$ = 54)

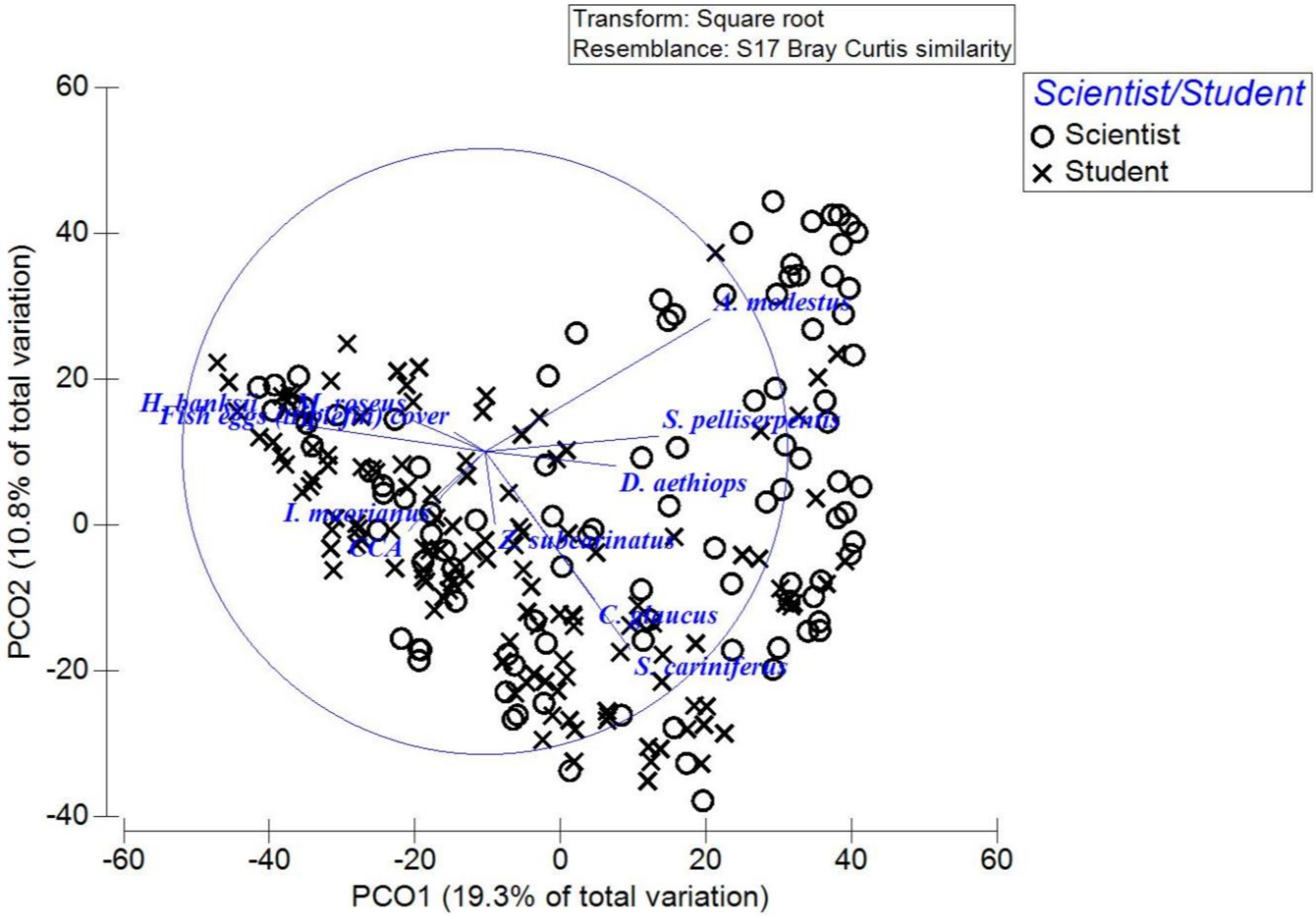

Figure 2.2: PCO (Principal co-ordination analysis) plot comparing the average number of individuals of each species identified in quadrats surveyed by scientists (white circle) and students (black cross). Blue circle and text around data points represents the 11 species that make up approximately 50% of the dissimilarity between surveyors ($n_{(scientist)}$ = 100, $n_{(student)}$ = 130)

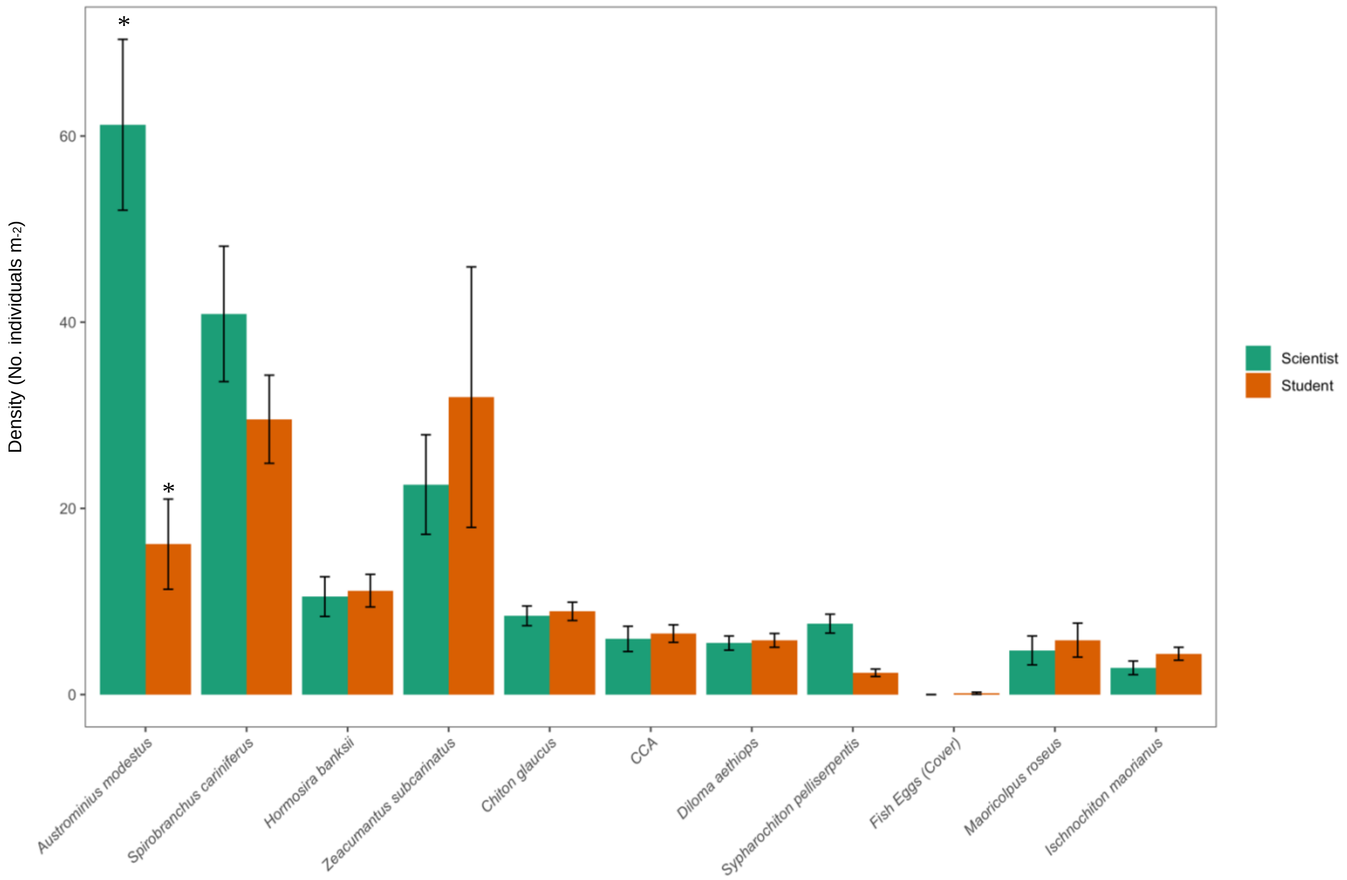

Figure 2.3: Densities (average number of individuals per m^2) of 11 species that were identified as dissimilar between students (orange bars) and scientists (green bars) using SIMPER analysis ± SE for $n_{(scientist)} = 100$, $n_{(student)} = 130$). Asterisks represent significant differences for Tukey's HSD tests, $\alpha = 0.05$

Table 2.1: Two-way ANOVA for the average number of species found per m^2 at low tide and mid tide shore levels in the Otago Harbour by students and scientists in 2017 ($n_{(low)} = 43$, $n_{(mid)} = 54$)

Factor	F	df	p-value
Shore level	0.550	1	0.456
Surveyor	0.261	1	0.616
Shore level x Surveyor	0.0461	1	0.833

Table 2.2: PERMANOVA on PCO plots for the quadrats surveyed by scientist and students during the 2017 year of the project ($n_{(scientist)} = 100$, $n_{(student)} = 130$)

Factor	Pseudo F	df	p-value
Surveyor	11.437	1	0.001
Residuals		228	
Total		229	

Table 2.3: List of species that explain approximately 50% dissimilarity between data collected by students and scientists calculated using SIMPER analysis (average dissimilarity = 79.80) (n = 11)

Species Scientific Name	**Species Common Name**	**Contribution to Dissimilarity**	**Sum of Dissimilarities**	**Cover or Count**
Austrominius modestus	Beaked barnacle	9.27	9.27	Count
Spirobranchus cariniferus	Blue tube worm	8.36	17.63	Count
Hormosira banksii	Neptune's necklace	6.00	23.63	Cover
Zeacumantus subcarinatus	Horn snail	5.06	28.61	Count
Chiton glaucus	Green chiton	4.01	32.7	Count
Corallina sp. (or CCA)	Encrusting coralline algae	3.59	36.29	Cover
Diloma aethiops	Spotted top snail	3.39	39.68	Count
Sypharochiton pelliserpentis	Snakeskin chiton	3.35	43.3	Count
N/A	Fish eggs	3.04	46.07	Cover
Maoricolpus roseus	Turret snail	2.71	48.26	Count
Ischnochiton maorianus	Brown chiton	2.69	50.96	Count

Table 2.4: Two-way ANOVA for the density (average number of species found per m^2) of 11 species identified to have dissimilar counts between students and scientists in the Otago Harbour in 2017 ($n_{(scientist)} = 100$, $n_{(student)} = 130$)

Factor	F	df	p-value
Surveyor	4.88	1	<0.05
Species	16.4	10	<0.01
Surveyor x Species	4.92	10	<0.01

2.4 DISCUSSION

2.4.1 Comparing Scientist- and Student-Collected Data

Overall, there were no statistically significant differences between scientists and students in the average number of species found per m^2 (or per quadrat) irrespective of shore height. This is supported by previous research with citizen scientists in the intertidal which found that citizen scientists were able to perform tasks that met scientific standards such as species identification (Delaney et al., 2008; Cox et al., 2012) and collecting species richness and diversity data (Koss et al., 2009). When the two datasets were further explored at a species level, it was found that there were some differences between the two surveying groups. The dissimilarity matrix identified 11 species that contributed to approximately 50% of the differences between scientists and students. Comparisons of density data collected by both scientists and students for these dissimilar species showed that only one species, *A. modestus*, had significantly different densities between the two surveying groups. As this is highly unlikely to be an identification issue (there were rare incidents where another species of barnacle was present), this difference is most likely to be related to counting.

A. modestus are common on the rocky intertidal (Carson & Morris, 2017) and often occur in clusters at densities of 100 or more per 0.01 m^2 (O'Riordan & Ramsay, 2013). Counting all these individuals can be seen as a tedious task, which may result in unreliable estimates of species density or no record of the species at all. Other research has shown that citizen scientists can have selective bias to focus on large, colourful or charismatic species (Parrish et al., 2018). In the context of the rocky shore, this was often species of crabs, sea stars or intertidal fish (pers. observation). Therefore, to encourage counting of species that are small (less than 4 cm), sessile or slow-moving and have dense patchy distributions, sub-sampling by moving the smaller quadrat (0.01 m^2) around the 1m^2 quadrat was an option to estimate species density. This technique used to estimate species density was often utilised by students, whereas scientists would be more likely to take the time to count all the individuals. The differences in the approach could explain how students and scientists calculated different densities of *A. modestus*. This explanation could also be applied to *Spirobranchus cariniferus* (blue tube worms), which although not statistically significant between surveyors, still showed some differences in density. *S. cariniferus* are similar to *A. modestus* in the sense that they are small (up to 40 mm), sessile and can be in aggregations of 1000 individuals per m^2 (Carson & Morris, 2017) and therefore, were also likely to be counted using subsampling. Densities recorded by students for *Zeacumantus subcarinatus* (horn snails) were variable as shown by the large standard error surrounding the average density for this species. *Z. subcarinatus* are small (up to 15 mm), can often be found in clusters over 1000 snails (Carson & Morris, 2017) and were typically found underneath rocks (pers. observation), so were likely to be counted using the smaller quadrat. The inconsistencies in the densities for *A. modestus*, *S. cariniferus* and *Z. subcarinatus* suggests that the estimation method is not an accurate way to record animal species. Consequently, there needs to be alternative ways investigated to ensure small, sessile or slow-moving animals that congregate in high numbers are recorded in a more accurate manner.

2.4.2 Importance of the Project and Information Gathered

This facilitated citizen science project has proven to be useful in different ways for the different groups that were involved. For the scientists, the validation of the data collected during 2017 supports the literature that finds that citizen scientists can gather information at a comparable level to scientists (for examples see: Delaney et al., 2008; Koss et al., 2009; Cox et al., 2012; Gillett et al., 2012; van der Velde et al., 2017). As methodology (including scientific engagement and support) remained consistent in all three years of the project, it was presumed that the data collected by citizen scientists over the duration of the project would be considered of similar quality to that of a generalist.

It must be acknowledged that these results were achieved in a facilitated manner with continuous interactions between scientists and citizen scientists through each year of the project. This study recognises, as is also common in the literature, that scientists are required to supply some form of support, whether it be providing training and resources to help with identification (Koss et al., 2009; Dickinson et al., 2010; Cox et al., 2012; Ratnieks et al., 2016; Kosmala et al., 2016), assistance with identification (either in the field or online verification) (Delaney et al., 2008; Dickinson et al., 2010; Ratnieks et al., 2016; Specht & Lewandowski, 2018), assigning tasks that are suitable to the level of those involved (Kosmala et al., 2016; Parrish et al., 2018) or a combination of these factors.

The amount of support required is likely to depend on the citizen scientists involved in the study. For this research, a range of age groups were involved d including school children from age seven to fifteen (with an average age of was 9.8 years (± 0.2 years)). The age of the students may be a potential issue, but considerate planning of activities and tasks can reduce this (Parrish et al., 2018). Despite this, other authors have commented on the lack of students – particularly primary school children – involved in citizen science projects (Eastman et al., 2014). There is evidence to support citizen science projects as a way to develop skills relevant to the educational curriculum (Bonney et al., 2016; Shah & Martinez, 2016; van der Velde et al., 2017).

Many participants involved in long-term monitoring projects tend to be older, educated members of the public that already have a natural interest in environmental issues (Koss et al., 2009; Dean et al., 2018). Schools provide access to a diverse sector of the community (e.g. range of cultures, socio-economic sectors) and engage with both children and adults (e.g. parent helpers are necessary for the field trips), which allowed an excellent accessway to engage with the wider community. This can lead to environmental awareness and education, in turn encouraging stewardship for local environments (Eastman et al., 2014; Branchini et al., 2015; Ballard et al., 2017; van der Velde et al., 2017). This too can be applicable for communities who can begin to address local issues that may cause concern and can commence initiatives to monitor these issues.

While citizen science is a valuable tool for monitoring, it does not mean that citizen science can replace monitoring completed by scientists (Kamp et al., 2016; Bela et al., 2016; Dennis et al., 2017). Citizen science could be utilised for long-term data sets that complement scientific research as citizen science collected data can cover time frames and areas that are not covered regularly during scientific surveys (Dickinson et al., 2010; Cigliano et al., 2015; Dennis et al., 2017). However, as shown by this case study, scientists still have an important role in the citizen science process (particularly with validation, training and analysis). These collaborations could provide a solid foundation that would allow for well-informed decisions to be made by resource managers and local government (Bela et al., 2016). For investigating impacts on the marine environment, the rocky intertidal provides a unique platform to monitoring species abundance over time (Thompson et al., 2002) that allows for collaboration between scientists and citizen scientists.

2.4.3 Limitations and Future Recommendations

For some organisms, identification to species level may have been too complicated for both students and scientists alike. An example of this was *Diloma aethiops* (spotted top snail). In the top shell family Trochidae there are close to 50 species in New Zealand but *D. aethiops* is the most common top shell on the rocky intertidal (Carson & Morris, 2017). Therefore, when students found a top shell on the intertidal, they were recorded as *D. aethiops* by default. This was decided because of current restrictions in the online database (which does not have a more general option for top snails such as *Diloma* sp.) and the fact that scientists were not able to check the identification of every species recorded by each group of students. Although the majority of observations would have been likely to be this species, it is possible that this assumption may have masked the true identity of some other top shell species. In contrast, scientists attempted to identify all top shells to a species level but as they were not experts (i.e. trained taxonomists) all their identifications may not have been accurate (Ahrends et al., 2011). The comparison of *D. aethiops* densities between students and scientists was not a true comparison due to inconsistent identification standards. Therefore, a difference (although small) between the two groups of surveyors was unsurprising for this species.

In future both students and scientists should be given the option to identify top shells as *D. aethiops* or *Diloma* sp. This can allow for true comparisons to be made with top shells we are confident about and ones we are not. Identifying species at higher taxonomic levels on the rocky intertidal has been recommended by Pearse et al. (2003) and Bates et al. (2007). Bates et al. (2007) argues that high-resolution data (identifying to a species level) is often not necessary for routine biological monitoring on the rocky shore and identification to the genus or family level can be deemed as satisfactory (however this is dependent on the intended use of the data). Identification to higher taxonomic levels may be useful for the rocky intertidal which, due to the wide diversity of species present, makes it difficult to provide effective identification training for all the species that may be encountered (Freiwald et al., 2018). This could be particularly useful for younger students.

Without financial support, facilitated citizen projects struggle to operate as although these projects are often less expensive than scientific research projects, there are still costs involved such as transport, equipment and scientific support (Cox et al., 2012; Chandler et al., 2017). Yet funding is competitive (Chandler et al., 2017), and many organisations cannot provide secure, multi-year funding (Peters et al., 2016), which can make planning for long-term environmental monitoring very difficult (Lovett et al., 2007). Therefore, strategic planning of where in the project scientists should focus their time and effort is recommended. This can assist in keeping costs low and also ensure that funding, and the scientists' time, is used efficiently.

One of the most important aspects of research is quality control. This case study was no exception and the lead scientist put in three to four times as many hours as the students did. Research has found that programs involving quality assurance and quality control (QA/QC) are correlated with budget and are typically more expensive to implement (regardless of the scale of the project) (Wiggins et al., 2011). This is often due to the cost of employing people with technical expertise that can manage large datasets and complete statistical analysis (Dickinson et al., 2010; Peters et al., 2016). Having someone to do this is very important but can cause conflict between financial restrictions and maintaining quality of the data. Technical expertise may also not be readily available to projects not associated with project partners such as universities or government agencies (Peters et al., 2015b). As a result, significant portions of funding should be dedicated to implementing systems that can reduce the time scientists spend completing more simplistic quality control tasks (such as going through the datasheets to check for errors) so they can put more time into complex tasks such as statistical analysis. Formal error checking systems are common on online databases and can be used to flag or filter out entries of unlikely species or unusually large number of species and send them to the regional expert to verify (Bonter & Cooper, 2012; Kosmala et al., 2016). In this case study, much of the cleaning process was automated using software (RStudio), which sped up the process as opposed to doing it manually. However, there was still some manual labour involved when cross-referencing the raw data when issues arose. Often these issues were related to incorrect entries into the online database, therefore, incorporating a flagging system to notify project co-ordinators of potentially incorrect entries into the online database is highly recommended and would replace the time spent manually looking for inconsistencies.

2.5 CONCLUSIONS

As has been found in other studies with other age groups and other ecosystems, students (aged seven to fifteen) were able to collect basic density and taxonomic data in intertidal habitats at a comparable level to that of trained scientists. This was done in the rocky intertidal, an environment that is well-studied in terms of community ecology but is under-represented in citizen science. It is an important habitat to monitor changes in coastal ecosystems which are under stress from both marine and terrestrial based anthropogenic activities. Citizen science can be useful in collecting broad scale environmental data over time that would be of service to long-term monitoring. This case study also identified some areas of weakness, particularly estimating densities of small, sessile species such as *A. modestus*, which was statistically different between students and scientists. Given the quality of the data collected during this case study, it is highly recommended that monitoring of the Otago Harbour by citizen scientists is continued. Information gathered through citizen science can assess some of the localised impacts of the dredging, becoming more useful as time passes. Citizen science has the potential to track broader changes (such as species patterns or changes in climate) over longer time scales and can be used to inform future management interventions (e.g. effectiveness of restoration, future development). It should be noted that this case study had a significant amount of scientific support and involvement. Investigation into ways that technology could be used for maintaining data quality is needed. Using technology instead of scientists for some aspects of quality control could reduce costs and thus, ensure longevity of this citizen science project. This case study aids in strengthening the argument that members of the public can be – and should be – engaged in the collection of scientific data, particularly with issues that are of local concern.

CHAPTER THREE

ASSESSMENT OF METHODS USED TO ESTIMATE SEDIMENT ON THE ROCKY INTERTIDAL

3.1 INTRODUCTION

3.1.1 Coastal Sedimentation – a Global Issue

Coastal systems operate on a dynamic balance between the import and export of sediments (Steiger et al., 2003; Thrush et al., 2004; Crain et al., 2009). Sediment can enter coastal systems via both natural and anthropogenic processes (Airoldi, 2003; Wilber et al., 2005; Walling, 2006). Human activities can alter these dynamics by either 'starving' a system (i.e. reducing the amount of sediment) or 'loading' a system (i.e. increasing the amount of sediment) (Thrush et al., 2004; Walling, 2006; Crain et al., 2009). Sediment loading can result from terrestrial development (e.g. deforestation) (Thrush et al., 2004; Wilber et al., 2005; Lotze, 2006; Crain et al., 2009; Chew et al., 2013; Desmond et al., 2015), natural disasters or extreme weather (Airoldi, 2003; Schwarz et al., 2006; Walling, 2008; Morrison et al., 2009; Cochard, 2017), mining/gas exploration (Thrush et al., 2004; Walling, 2006; Hart & Bryan, 2008) and dredging (Rogers, 1990; Wilber et al., 2005; Chew et al., 2013; Brown et al., 2018). Increased sedimentation as a result of human activities is a significant issue in coastal areas worldwide (Morrison et al., 2009; Chew et al., 2013) and has negative impacts on local ecosystems (Airoldi, 2003; Walling, 2008; Cussioli et al., 2015).

3.1.2 Coastal Sedimentation in New Zealand

Sedimentation in the coastal environment is listed as one of the top four issues impacting the marine environment in New Zealand (Ministry for the Environment & Statistics New Zealand, 2016). In many regions throughout New Zealand the amount of sediment loading per year has almost doubled compared to estimated pre-human sediment loads (Owens et al., 2005; Morrison et al., 2009; Dymond, 2015). This is most likely a result of land clearance for agriculture and forestry practices (Owens et al., 2005; Schwarz et al., 2006; Morrison et al., 2009; Chew et al., 2013; Dymond 2015), urban development (Owens et al., 2005; Schwarz et al., 2006; Clapcott et al., 2011) and the modification of harbours (Schiel et al., 2006; Crain et al., 2009; van Rijn, 2011; Chew et al., 2013; Ellis et al., 2015). Most research on sediment loading in New Zealand is focussed on freshwater (Owens et al., 2005; Clapcott et al., 2011) or estuarine environments (Norkko et al., 2002; Thrush et al., 2004) and there has been little work done on the sediment impacts in a coastal marine setting (Schwarz et al., 2006). This is likely due to the additional challenges that monitoring sediment in coastal environments possesses. Accumulation rates of sediment over time can be difficult to monitor in dynamic coastal environments as fine sediment is easily transported from the original source of disturbance (Smith et al., 2010; Fettweis et al., 2011; Carse & Lewis, 2017) as a result of tidal and wind driven currents (Norkko et al., 2002; Schwarz et al., 2006; Fettweis et al., 2011; Pritchard et al., 2013).

3.1.3 Impacts of Coastal Sedimentation

Increased sediment loading can reduce light (and thus primary production in aquatic plants) (Rogers, 1990; Wilber et al., 2005; Pritchard et al., 2013; Desmond et al., 2015), reduce filtration and feeding efficiency among vertebrates and invertebrates (Airoldi, 2003; Wilber et al., 2005; Schwarz et al., 2006; Cussioli et al., 2015; Ministry for the Environment & Statistics New Zealand, 2016) and smother sessile and benthic organisms (Airoldi, 2003; Wilber et al., 2005; Schiel et al., 2006; Chew et al., 2013). Most sessile or benthic organisms can tolerate some degree of sedimentation (Thompson et al., 2002; Wilber et al., 2005) due to adaptations that provide resilience to negative effects, such as sponges forming hard outer layers to protect themselves against sediment (Schönberg, 2016). However, persistent and high levels of sedimentation can cause harm to ecosystems (Wilber et al., 2005; Schwarz et al., 2006). An example of this is the decline of temperate coastal kelp forests, attributed in part to increased sediment loading (Steneck et al., 2002; Krumhansl et al., 2016). As kelp forests are identified as ecosystem engineers (Morrison et al., 2009; Desmond et al., 2015), the reduction of these forests can result in loss of ecosystem services (Worm et al., 2006; Desmond et al., 2015), which can result in the loss of economically valuable species (Rogers, 1990; Schwarz et al., 2006; Schönberg, 2016). This example shows the potential implications that persistent sediment loading can have in coastal ecosystems (Desmond et al., 2015). Therefore monitoring of sediment in coastal environments is required to generate knowledge that can be used to inform managers to support management initiatives (Desmond et al., 2015).

3.1.4 Monitoring Coastal Sedimentation

The majority of coastal monitoring in New Zealand falls upon regional councils and government agencies (Hart & Bryan, 2008; Ministry for the Environment & Statistics New Zealand, 2016). Large-scale and long-term monitoring projects would be useful in gathering fundamental information on sedimentation, in particular trends and changes of sediment loading as well as whether it is from natural or anthropogenic sources (Airoldi, 2003). Collecting complex data sets, as is required for long-term monitoring, can often be beyond budget restrictions in place for local resource managers and so adequate information may not be collected within the timeframe required (Wolfe et al., 1987; Lovett et al., 2007). Citizen science can be of use to gather broad scale data over time (Dickinson et al., 2010; Hochachka et al., 2012). However, if chosen to be incorporated into monitoring, this requires significant planning time (as discussed in Chapter Two) especially surrounding study design and the complexity of tasks that citizen scientists are required to do (Kosmala et al., 2016; Parrish et al., 2018).

A 2014 review of marine monitoring in New Zealand commented on the lack of inexpensive and robust methods available to measure multiple variables in order to monitor changes in marine sedimentation (Hewitt et al., 2014). Similarly, sedimentation monitoring in freshwater systems also lacks consistency, with many regional councils using different methods (Clapcott et al., 2011). Therefore, having a set of regulated guidelines to monitor sediment in New Zealand is needed. Consistent methodology is of particular importance as most major harbours in New Zealand – including Lyttleton, Tauranga and Otago – are currently undergoing capital dredging projects to increase the size of shipping channels (Sneddon & Barter, 2009; Cussioli et al., 2015; Berthelsen, 2017). Capital dredging operations involve the removal of material from within the shipping channel and disposal of it to a designated location offshore (Smith et al., 2010). Dredging is a common practice worldwide (IADC, 2018), as most harbours are not naturally deep or wide enough to allow for safe access of large cargo and cruise vessels (Vogt et al., 2018; Brown et al., 2018). In recent years, there has been growing awareness of the potential impacts from suspended material disturbed during dredging (Gourlay et al., 2015; Vogt et al., 2018). This has led to greater focus on monitoring the effects of suspended sediment (Wu et al., 2007).

Most ports are required to monitor variables that can indicate sediment disturbances in order to comply with government-issued environment standards (Darbra et al., 2009; Pearson et al., 2016; IADC, 2018). One of the most common variables to monitor is water turbidity (Wu et al., 2007; Darbra et al., 2009). Often this involves the use of remote-sensing water turbidity devices or aerial images of sediment plumes (Wu et al., 2007; Kutser et al., 2007). Although useful, these techniques do not indicate whether water turbidity is a consequence of a particular activity (e.g. dredging) (Wu et al., 2007) and can involve substantial costs (Kutser et al., 2007; Evans et al., 2012). Additionally, turbidity is not a measurement of sedimentation (Airoldi, 2003), rather an index of water clarity and the amount of light that is available in the water column (Davies-Colley & Smith, 2001). In a 2009 survey of European port companies, 40% acknowledged that they had gaps in their monitoring data (Darbra et al., 2009). This shows there is a need for additional monitoring that is cost-effective yet still provides information on dredging activities.

3.1.5 Methods to Monitor Coastal Sedimentation

Sediment traps (defined as any device that can catch and trap suspended sediment) have been identified as a low-cost method to get a quantitative measurement of sediment accumulation over time (Butman, 1986; Asselman & Middelkoop, 1995; Airoldi et al., 1996; Airoldi, 2003; Hunt, 2005; Schiel et al., 2006; Storlazzi et al., 2011). Descriptions of the shape, size and structure of sediment traps varies as traps are often tailored to the environment they are placed in (Airoldi, 2003; Steiger et al., 2003; Schiel et al., 2006). There have been limited studies of their use completed in the intertidal zone (Schiel et al., 2006; Bolam et al., 2011) with most research being completed in low energy environments, such as lakes, rivers and estuaries, or in the deep coastal ocean (Steiger et al., 2003). Most monitoring of coastal sediment has focussed on benthic species in soft-bottomed environments (e.g. estuaries and inlets) (Ellis et al., 2015). Other low-cost methods include photographs or *in situ* visual surveys, however this research has been predominantly on coral reefs (Roelfsema et al., 2006; Alquezar & Boyd, 2007; Page et al., 2017) and does not quantify sediment accumulation rates. Despite the different options of low-cost ways to monitor coastal sediment available, most comparisons are designed to use visual field surveys as a validation for photographs (Roelfsema et al., 2006) and few comparisons have been made between different methods (Airoldi, 2003). Comparing methodology to estimate sediment could help to address issues around the consistency and reliability of monitoring sediment accumulation in coastal environments.

3.1.6 Aims and Objectives

The aim of this chapter was to assess three different methods used to estimate fine sediment accumulation on the rocky intertidal. Assessments looked at the strengths and weaknesses of each method as well as the quality of each methods (defined as agreeable between two groups of surveyors – students and scientists). This research used three methods mentioned in the literature and incorporated them into a facilitated citizen science project, which was set up in response to the dredging activity in Otago Harbour. By trialling different methods as part of a citizen science project, this provided an unique opportunity to test the simplicity of the tasks (by getting non-scientists to complete them) as well as the effectiveness of the methods for monitoring the rocky intertidal. These methods were – visual percentage cover estimates, percentage cover estimates using printed photographs and weight of sediment collected from sediment traps. When estimating percentage cover this research, sediment was defined as fine, mobile particles that were smaller than sand.

It was predicted that estimates of sediment cover collected visually (during shore surveys) would be the most consistent between students and scientists as both students and scientists were recording percentage covers at the same time. Also, as this was a facilitated project, students had support from adults and were able to work in groups.

3.2 METHODS

3.2.1 Visual Estimates

Visual estimates of the percentage cover of substrates were taken during the two data collection sessions in March/April and June 2018 at six study sites (Fig 1.2). Both students and scientists recorded the percentage covers of the six different substrate types (reef, boulder, cobble, gravel, sand and sediment) in the same 1 m^2 quadrats at low tide (except at Quarantine Island where estimates were compared using mid tide data to be consistent with photographic estimates). There was no data collected at Portobello by scientists for the June 2018 data collection trip. Substrate estimates were required to add up to 100% cover and estimates were taken of the upper most layer of the quadrat. To help with estimating cover of substrates, quadrats (1 m^2) were divided into quarters with coloured twine (0.25 m^2 or 25% of quadrat) and smaller 0.01 m^2 (or 1%) quadrats were also provided to place within the 1 m^2 quadrat to help aid estimation. Student data was entered into the online database (www.mm2.net.nz) and the scientist data was entered in Microsoft Excel (version 16.18). Both datasets were combined into one document in Microsoft Excel (using the unique survey IDs to pair up quadrats).

3.2.2 Photographic estimates

During the two data collection periods, photographs of all low tide quadrats were taken using a Panasonic DMC-TZ55 digital camera. At Quarantine Island, photographs of mid tide quadrats were used instead of low tide quadrats due to quality issues with the photographs taken at low tide. All photographs were printed onto A3 paper (297 mm x 420 mm) and divided into a grid of 100 equal sized squares so each square would represent 1% of the photograph. In each of the 100 squares, scientists and students determined which substrate type best represented the square by writing a letter in it (e.g. R = reef, B = boulder etc.). Each of the different substrate types were then tallied so the total would add to 100. Two copies of each photograph were printed so scientists and students could do the estimates using the same photograph. Students completed their photographs during the data entry sessions in pairs. Teachers and scientists were encouraged to only help students when necessary. These circumstances were in relation to keeping students on task or assisting them with calculating percentage cover. This method was trialled with some of the participating schools in 2017.

In some of the photographs, it was difficult to determine the substrate type in the squares due to obstruction by either seaweed or water glare. In these situations, students and scientists had the option to classify the square as ‘unclassifiable’. This occurred in 19 out of the 117 completed photographs. All data was entered and checked to determine if all photographs had substrate estimates that totalled to 100. Any photographs that had not been attempted by surveyors were not included in the study (four in total). If not all squares in the grid had been assigned to a particular substrate, substrate types were scaled up so that total substrate cover added to 100 as this was considered as a counting error. To compare the different substrate types between surveyors, students and scientists needed to have both estimated a substrate type within a quadrat (so that data could use both values as co-ordinates for plotting the figures). Unclassifiable substrate was not included in statistical analysis as there was only one incidence where both students and scientists identified unclassifiable substrate within the same quadrat.

Point intercept analysis using Coral Point Count (CPCe) (version 4.1, Kohler & Gill, 2006) was completed in 2017 to calculate substrate estimates collected by students (in August/September 2017) and scientists (in May 2017). However, all the photographs were analysed by scientists (regardless of when the data was collected) as the program was not readily available to students and could not be completed within the limited time available for data entry sessions. Therefore, to get data that the students themselves had completed, it was thought that using A3 printouts was a better alternative.

3.2.3 Sediment Trap Weight Estimates

A flat bottomed sediment trap design was trialled in 2017 to quantify the amount of suspended sediment settling on the rocky shore. Sediment traps were made with a flat plastic PVC plate (250 mm (L) x 250 mm (W) x 5 mm (D)), a synthetic AstroTurf square (glued to the PVC plate) and a galvanized reinforcing steel frame (45 cm x 45 cm) that was attached to the plate using plastic zip ties in order to weigh the trap down to prevent it from moving (Fig 3.1). The design of the sediment traps used was modified from designs used in experiments by Asselman & Middelkoop (1995) and a review by Steiger et al. (2003) – both completed in riparian environments. As the flat, square design used was considered appropriate for flowing waters (Asselman & Middelkoop, 1995; Steiger et al., 2003) it was thought this would be suitable for the intertidal.

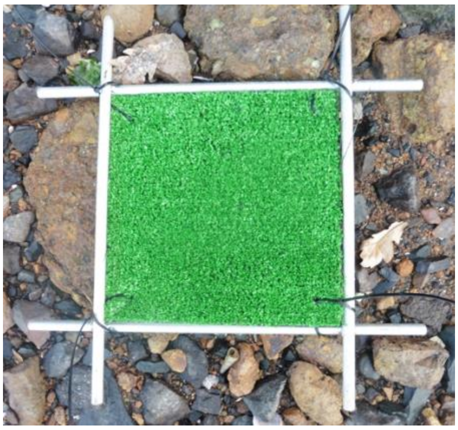

Figure 3.1: Image of sediment trap on the rocky intertidal (prior to deployment)

Sediment traps were utilised in both data collections during 17th-24th June 2017 and 13th-21st August 2017. Two sediment traps were deployed in approximately 20 cm of water at MLW (mean low water) at each site at both ends of the shore survey transect (approximately 30 m apart). After one week, sediment traps were collected and placed into large buckets (about 20 litres) and sediment was rinsed off the trap by scientists. The material in the buckets was left for approximately 30 minutes to allow suspended material to sink to the bottom of the bucket. Water was slowly decanted from the bucket so the remaining material in the bucket could be scraped out using a spatula and placed into small aluminium trays (dimensions: 102 x 25 mm, volume: 150 mL) to be dried in a drying oven at 35°C for a period of 36-42 hours.

During both data collection sessions in 2018 six sediment traps (three for each surveying group to collect) were placed approximately five metres apart along a 30 m transect in approximately 20 cm of water at MLW for five days. This time frame for the deployment of sediment traps was determined from preliminary trials. There were some exceptions due to unplanned schedule changes (due to bad weather and breaks in the school term) in which traps were placed out for longer than five days. These were; Portobello and Yellow Head (first data collection trip) and Back Beach (second data collection trip). To account for this, the weight of sediment collected from traps was standardised to the daily average for each site for the two surveying groups. Wind speed (kilometres per hour km/h) and rainfall (mm) were recorded each day throughout the periods in which the sediment traps were placed out in the harbour. Weather information was collected using MetService (https://www.metservice.com/towns-cities/dunedin) and the Portobello Marine Laboratory time series weather data.

Sediment was collected from the traps using similar methods as in 2017, with some modifications. All traps were washed using clear seawater and washing was ceased when the surveyors determined that sediment traps were clean (i.e. no more sediment could be seen on the trap). Next, material from the bucket was poured into a 1000 mL graduated cylinder using a large funnel. This was left to allow the sediment to settle out of the water before a volumetric reading (in cm) was taken. Different sized graduated cylinders were also available in case there was not enough sediment to take a reading in the 1000 mL cylinder. Wash bottles (250 mL) were used to remove any remnant sediment to ensure that all the sediment was collected from the traps and apparatus. To transport the sediment back to the laboratory to be dried, 1L screw top plastic containers were used. Sediment was then placed into either small (dimensions: 102 x 25 mm, volume: 150 mL) or large (dimensions: 190 x 108 mm, volume: 560 mL) aluminium trays depending on how much sediment was collected from the traps. Sediment was dried under the same conditions as described for 2017.

3.2.4 photoQuad Estimates

In order to compare different methods used to estimate sediment accumulation to a standard, the computer software photoQuad (version 1.4, Trygonis & Sini, 2012) was used to analyse photographs, as analysing digital photographs is considered to be one of the more accurate methods to estimate substrate (Pech et al., 2004). This software was designed with the intention of estimating the areas of different marine benthic habitats (such as substrate) and so was thought to be more applicable to this research than other software previously used (i.e. Coral Point). Photographs of all quadrats surveyed as part of 2018 were uploaded into the program photoQuad (see Trygonis & Sini 2012 for further description on how to use the software). This was completed by two scientists. All substrate cover added up to 100%. An average for each site was calculated using Microsoft Excel and then read into RStudio (version 1.1.14, RStudio Team 2016) for comparison between the other methods.

3.2.5 Analysis

A two-way ANOVA was run using RStudio comparing the mean percentage of sediment cover at low tide between the six study sites over the three years of the facilitated citizen science project. To be consistent, this was completed with student-collected data only as scientists did not collect data over all three years. Levene's tests were run to ensure heterogeneity between sites and the year of the project before completing a Tukey's HSD post-hoc test to investigate differences in percentage cover within locations over time.

All comparisons, either between students and scientists or between methods, were analysed and plotted using RStudio. Correlation tests were performed first to determine if there was a relationship between the values estimated by the two surveying groups (students or scientists) or between methods. Following this (if the correlation had a significance value of less than 0.05), an orthogonal regression was completed to further investigate the strength of the relationship and see if the estimations were close to a 1:1 ratio (this was determined by whether the value of one was included in the 95% confidence interval). An orthogonal regression was used after it was decided that there was no causal relationship between substrate estimates made by students and scientists, and both groups of surveyors would have some error associated with each method. For the comparisons between the four different methods, scientist-collected data and student-collected data were pooled and averaged for each study site using 2018 data only.

3.3 RESULTS

3.3.1 Visual Estimates of Sediment Over Time

Estimates of sediment cover were significantly different between sites (Two-Way ANOVA $F_{(11,147)} = 5.76$, p-value <0.01) (Fig 3.2; Table 3.1). This prompted further investigation, which identified that Quarantine Island had significantly different values of sediment cover in 2018 compared to the previous two years (p <0.05 for Tukey's HSD) (Fig 3.1). There were no differences in sediment cover between the three years of the project (Two-Way ANOVA $F_{(11,147)} = 5.76$, p-value = 0.248) nor between the interaction of study site and time (Two-Way ANOVA $F_{(11,147)} = 5.76$, p-value = 0.542) (Fig 3.2; Table 3.1).

3.3.2 Visual Estimations Between Surveyors

Visual estimations of all six substrate types were statistically similar between students and scientists (Fig 3.3, Table 3.2). Most substrate types had a strong positive relationship (r = +0.70 or above) for estimates made by students and scientists (Fig 3.3; Table 3.2). Students estimated a higher percentage covers of reef and sediment whereas scientists estimated higher percentage covers of cobble and boulder (Fig 3.3). Sand was the least abundant substrate type and was only found in 16 quadrats by scientists and students (Fig 3.3). Sand also had the largest confidence intervals as shown by the large range in percentage cover ranging from less than 25% cover to above 60% cover (Fig 3.3).

3.3.3 Photographic Estimations Between Surveyors

Estimations of the percentage cover of sand using photographs were statistically different between students and scientists (r = +0.116, p-value = 0.767) (Fig 3.4; Table 3.3). Correlation values were weak to moderately positive for photographic estimates and ranged from 0.116 (sand) to 0.596 (gravel) (Table 3.3). As was found in the visual estimates, there was less sand identified in quadrats (only 9) compared to the other substrate types (Fig 3.4). The remaining five substrate types were found to be statistically similar between scientists and students (Fig 3.4; Table 3.3). Scientists estimated more cover of reef and boulders than students (Fig 3.4). In contrast, students estimated higher covers of cobble, sediment and sand compared to scientists (Fig 3.4).

3.3.4 Sediment Trap Estimates Between Surveyors

There was a statistically significant relationship found between the weight (in grams) of sediment collected in traps per day between students and scientists (p-value <0.05) (Fig 3.5; Table 3.4). Although scientists often measured a larger amount of sediment compared to students, there was still a moderate correlation ($r = +0.528$) between students and scientists (Fig 3.5; Table 3.4).

3.3.5 Comparison Between Estimation Methods

3.3.5.1 Visual Estimates vs Photographic Estimates

Comparisons of the average estimated percentage cover of sediment using photographs and visual surveys had a weak positive correlation with no significant relationship between the two methods ($r = +0.152$, p-value $= 0.773$) (Fig 3.6; Table 3.5). For Back Beach, Portobello and Dowling Bay visual surveys estimated almost three times higher more sediment than estimated made using photographs (Fig 3.6). Interestingly, the average percentage cover of sediment estimated for Quarantine Island was reasonably close to the 1:1 ratio (13.2 % using visual survey methods and 12.2% using photographic methods) (Fig 3.6).

3.3.5.2 Photographic Estimates vs Sediment Trap Weights

There was a non-significant relationship between the estimated cover of sediment estimated by photographs and sediment collected from sediment traps ($r = +0.360$, p-value $=$ 0.483) (Fig 3.7; Table 3.5). The average amount of sediment ranged from 60 g at Back Beach to 9 g at Portobello whereas photographic estimates ranged from 33% cover (Yellow Head) to 9% cover (Portobello) (Fig 3.7). The amount of sediment collected from the sediment traps had greater variability (as shown by the larger error bars) compared to the photographic estimates (Fig 3.7).

3.3.5.3 Visual Estimates vs Sediment Trap Weights

There was no significant relationship between the visual surveys (average estimated cover of sediment) and sediment traps (average weight of sediment) (p-value = 0.521) (Fig 3.8; Table 3.5). There was a negative correlation between the two methods (r = -0.331) (Fig 3.8; Table 3.5).Visual estimates appear to be more consistent compared to the amount of sediment accumulated in the sediment traps (Fig 3.8). Average percentage cover of sediment estimated visually for the study sites ranged between 12% at Back Beach to 28% at Dowling Bay compared to the amount of sediment collected in sediment traps which had a much larger range between 9 g to 60 g (Fig 3.8).

3.3.5.4 Comparisons to photoQuad

At two study sites – Portobello and Quarantine Island – there was no sediment estimated using photoQuad (Figs 3.9-3.11). Estimates of the average percentage cover of sediment made using visual surveys and estimates of the average percentage cover of sediment using photoQuad were weakly correlated (r = +0.133) and had no significant relationship (p-value = 0.802) (Fig 3.9; Table 3.5). Estimates using photoQuad were much lower compared to the other three methods with the average percentage cover of sediment for most sites being less than 5% (aside from Yellow Head which had an estimated 11% cover) (Fig 3.9-3.11). In contrast, comparisons of the average estimated sediment cover between printed photographs and photoQuad were found to be significantly different to one another (p-value <0.01) and had a very strong positive correlation (r = +0.92) (Fig 3.9; Table 3.5). The confidence interval for this comparison was relatively narrow (0.440, 0.992) but did not demonstrate a 1:1 ratio of sediment cover between printed photographs and photoQuad (Fig 3.10; Table 3.5). There was no significant relationship or strong correlation between the estimates made using sediment traps and the photoQuad software (r = +0.65, p-value = 0.162) (Fig 3.11; Table 3.5). The confidence interval was slightly wider (-0.341, 0.957) compared to the other methods however still did not include the 1:1 ratio (Fig 3.11).

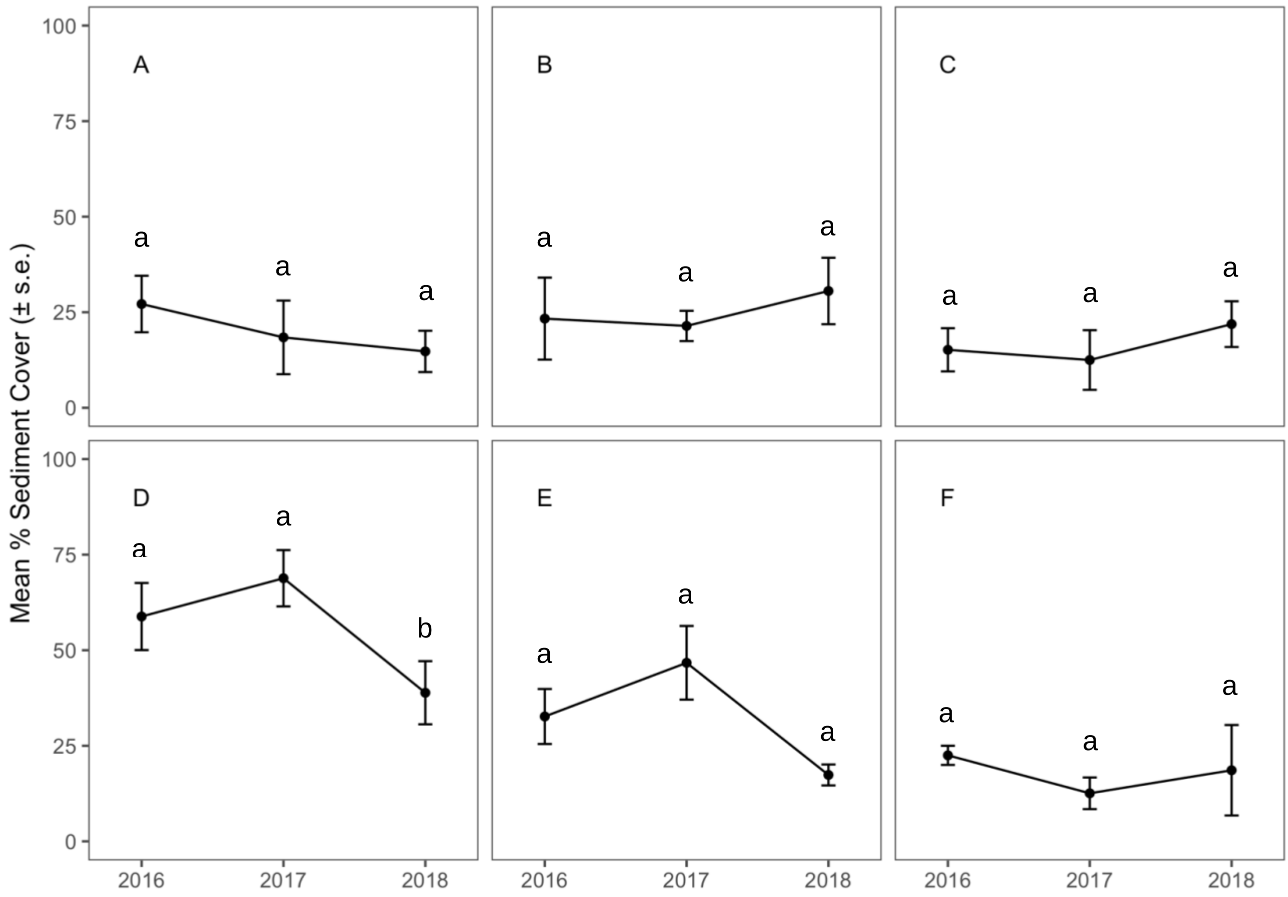

Figure 3.2: Mean percentage cover of sediment (± SE) visually estimated by students for each of the six study sites over a three-year facilitated citizen science project (2016-2018). Significance is indicated by the letters above the data points. Different letters indicate statistically different means at $\alpha \leqq 0.05$ (A – Back Beach, B – Dowling Bay, C – Portobello, D – Quarantine Island, E – Rocky Point, F –Yellow Head) ($n_{(2016)} = 50$, $n_{(2017)} = 63$, $n_{(2018)} = 46$)

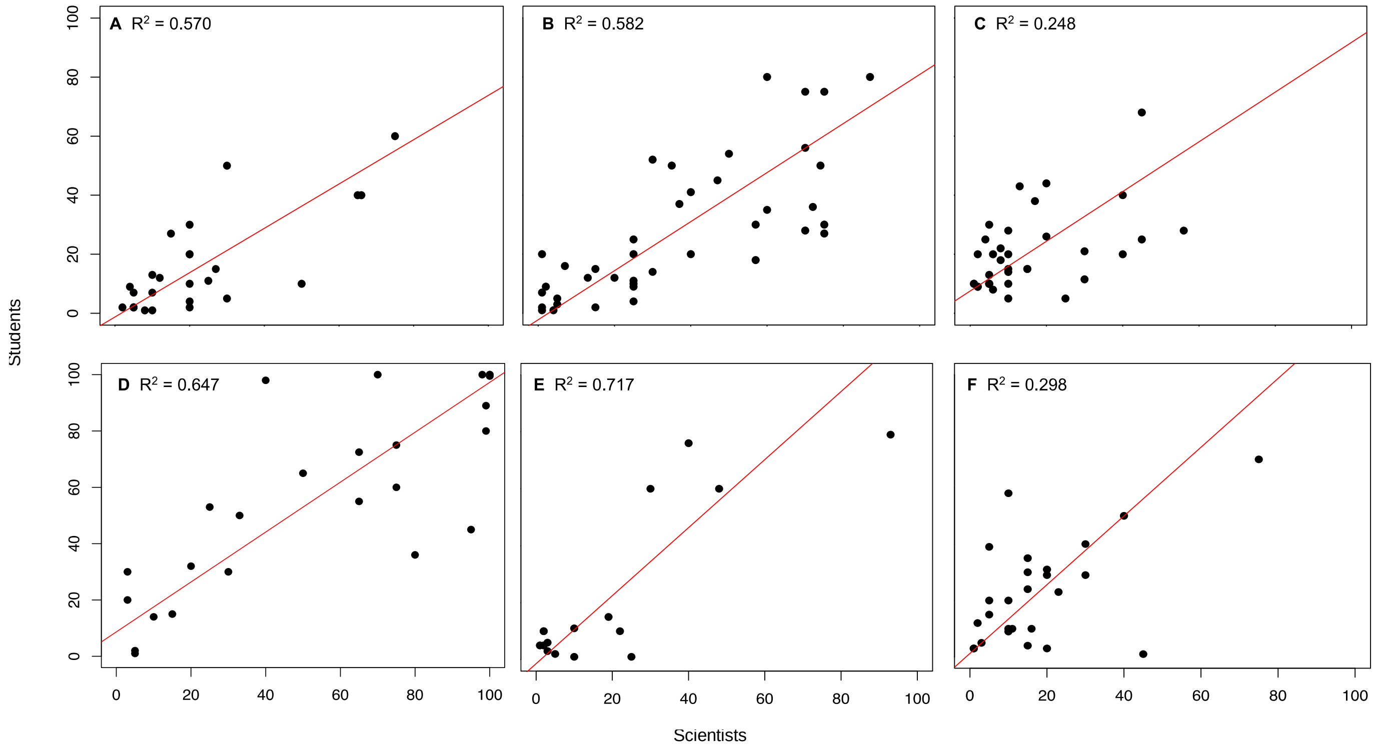

Figure 3.3: Visual estimates of the percentage cover of six substrate categories (A – Boulder, B – Cobble, C – Gravel, D – Reef, E – Sand and F – Sediment) by students and scientists. Red line indicates trend line for each substrate type (n = 115)

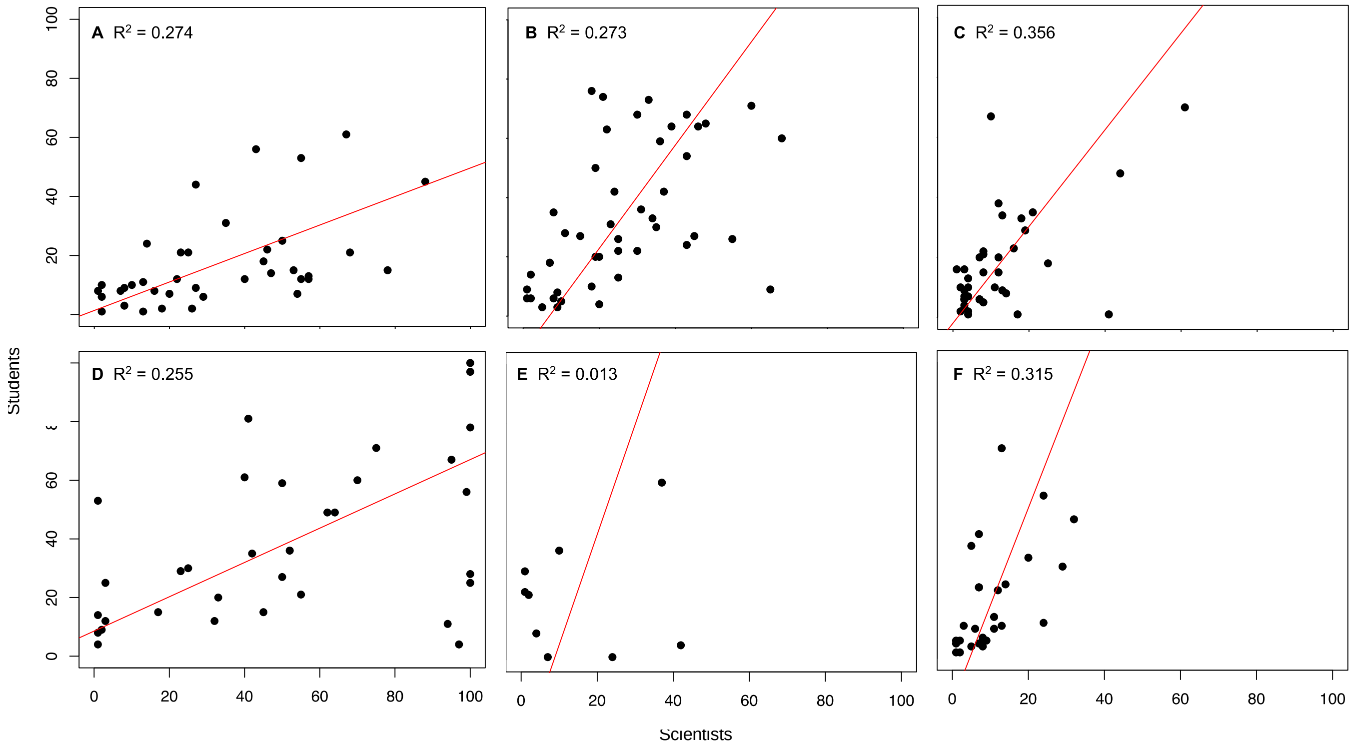

Figure 3.4: Estimations of the percentage cover of six substrate categories (A – Boulder, B – Cobble, C – Gravel, D – Reef, E – Sand and F – Sediment) using A3 printouts of photographs by students and scientists. Red line indicates trend line for each substrate type (n = 117)

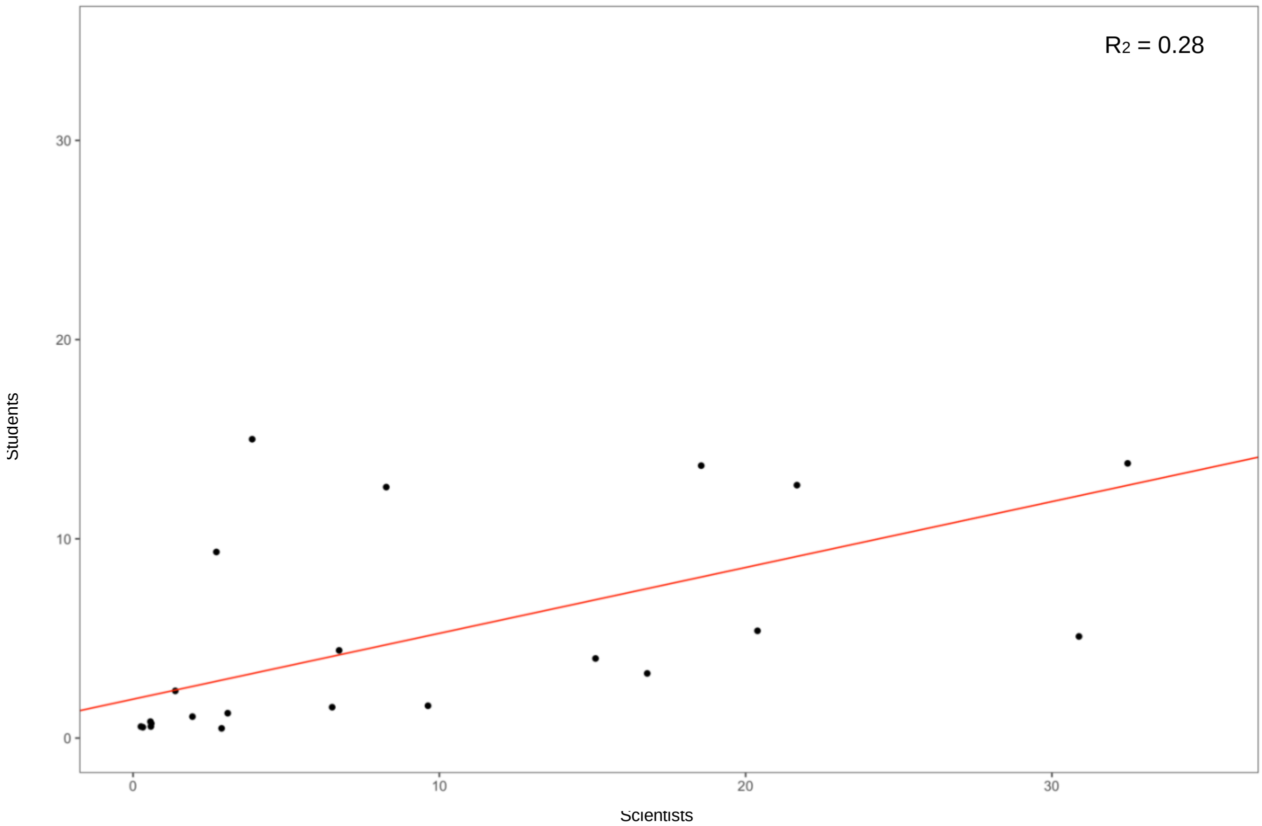

Figure 3.5: Comparisons of the weight of sediment (in grams) collected per day from sediment traps by students and scientists with trend line shown in red (n = 72)

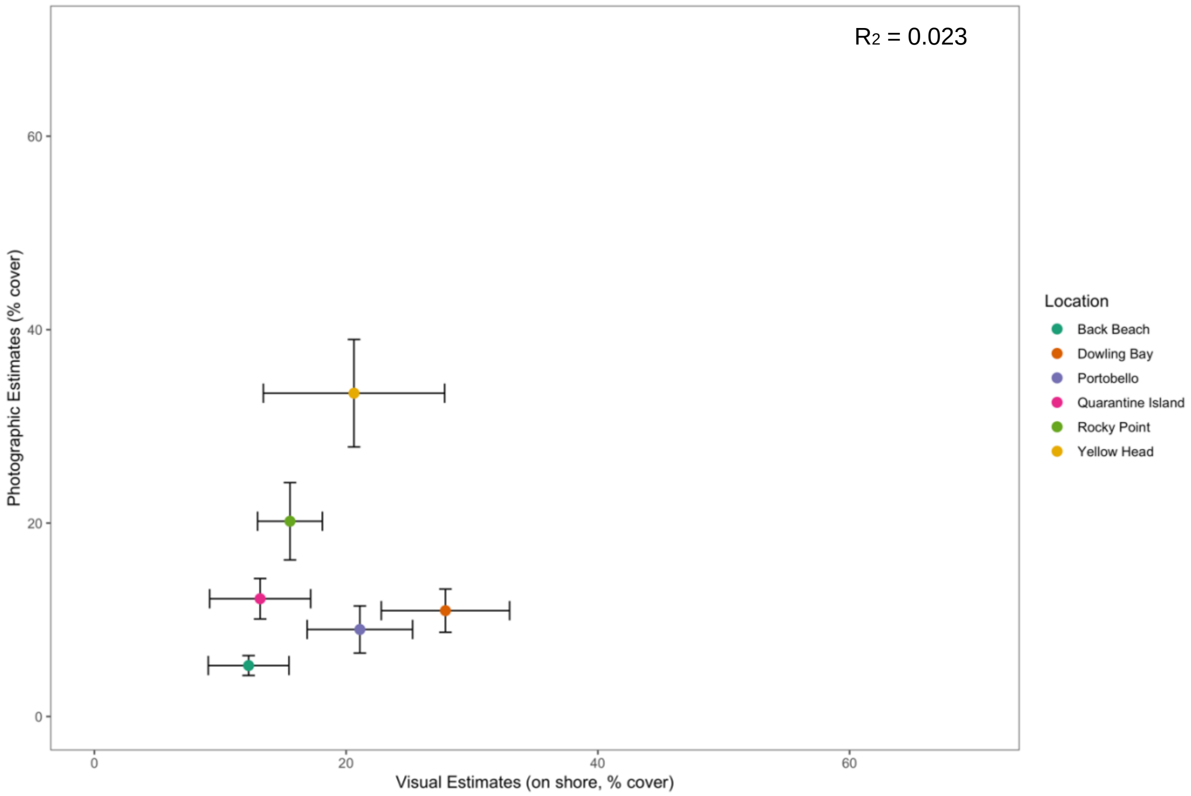

Figure 3.6: Comparison of the mean percentage cover of sediment estimated using photographs and visual estimates taken in the field for each of the six study sites. Horizontal error bars represent standard error for the mean percentage cover estimated visually and vertical error bars represent standard error for the mean percentage cover estimated using photographs ($n_{(photographs)} = 117$, $n_{(visual)} = 115$)

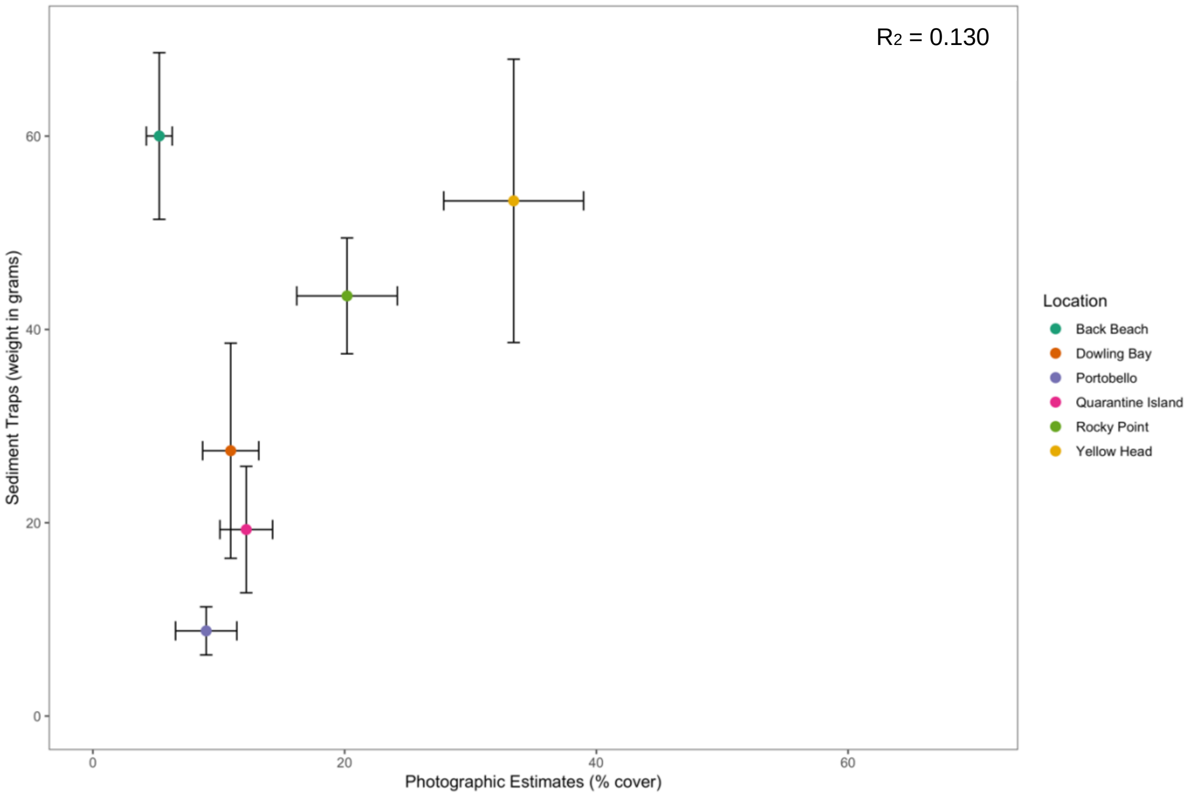

Figure 3.7: Comparison of the mean amount (percentage cover for photographs, weight in grams for sediment traps) of sediment at each of the six study sites. Horizontal error bars represent standard error for the mean percentage cover estimated using photographs and vertical error bars represent standard error for the mean weight collected using sediment traps ($n_{(photographs)}$ = 117, $n_{(traps)}$ = 72)

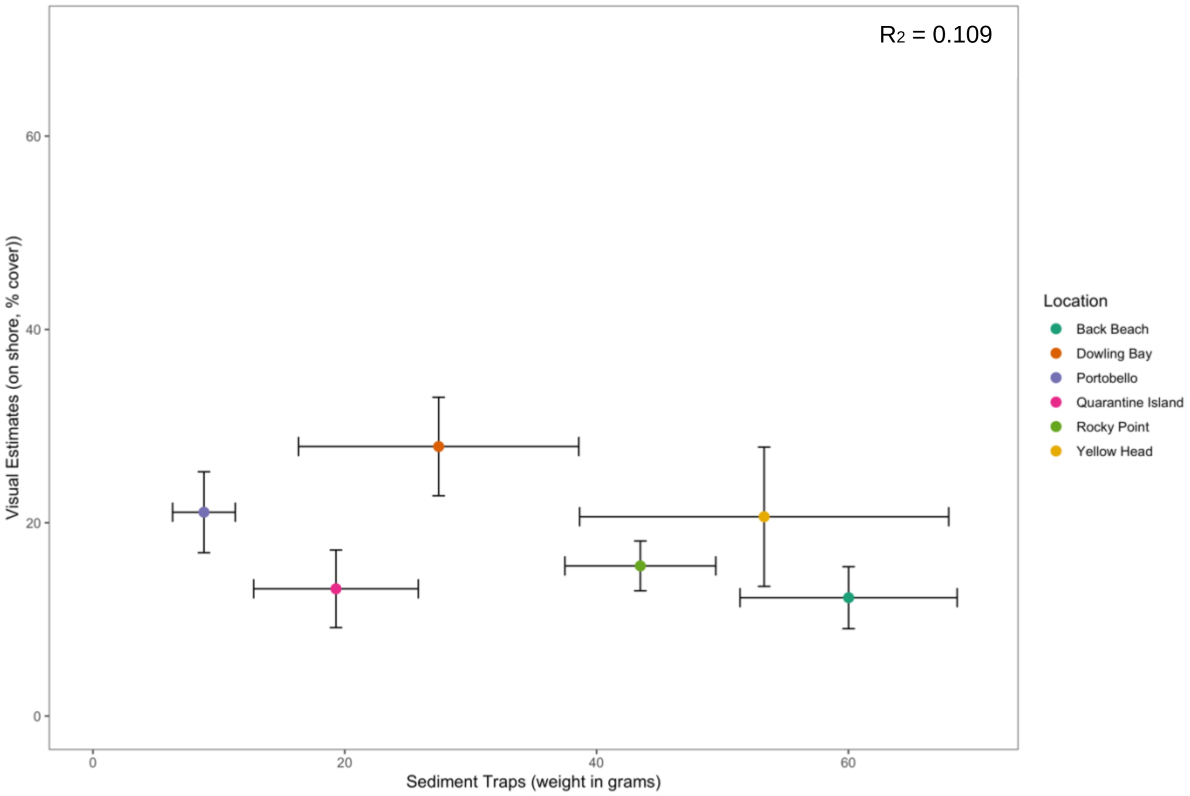

Figure 3.8: Comparison of the mean amount (percentage cover for visual estimates, weight in grams for sediment traps) of sediment at each of the six study sites. Horizontal error bars represent standard error for the mean weight collected using sediment traps and vertical error bars represent standard error for mean percentage cover estimated visually ($n_{(visual)}$ = 115, $n_{(traps)}$ = 72)

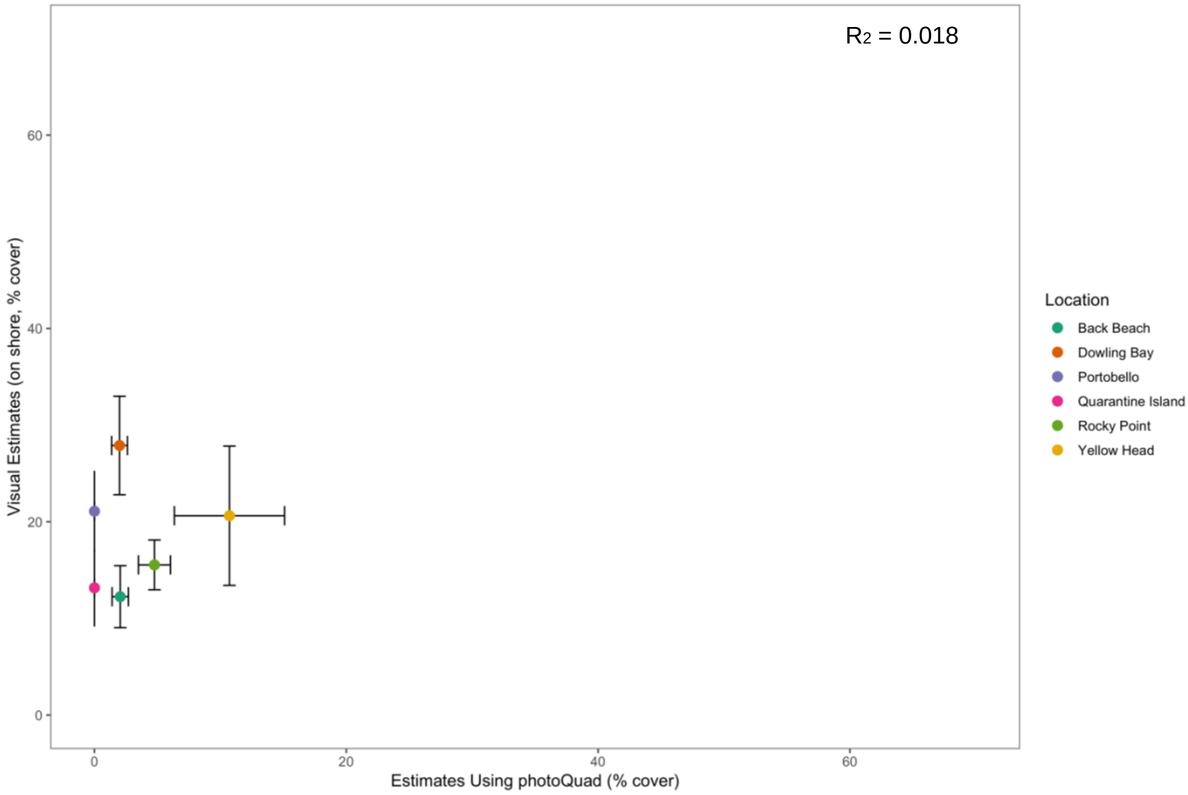

Figure 3.9: Comparison of the mean percentage cover of sediment estimated visually (on shore) and using an electronic program (photoQuad) for each of the six study sites. Horizontal error bars represent standard error for the mean percentage cover estimated using photoQuad and vertical error bars represent standard error for mean percentage cover estimated visually ($n_{(visual)} = 115$, $n_{(photoQuad)} = 117$)

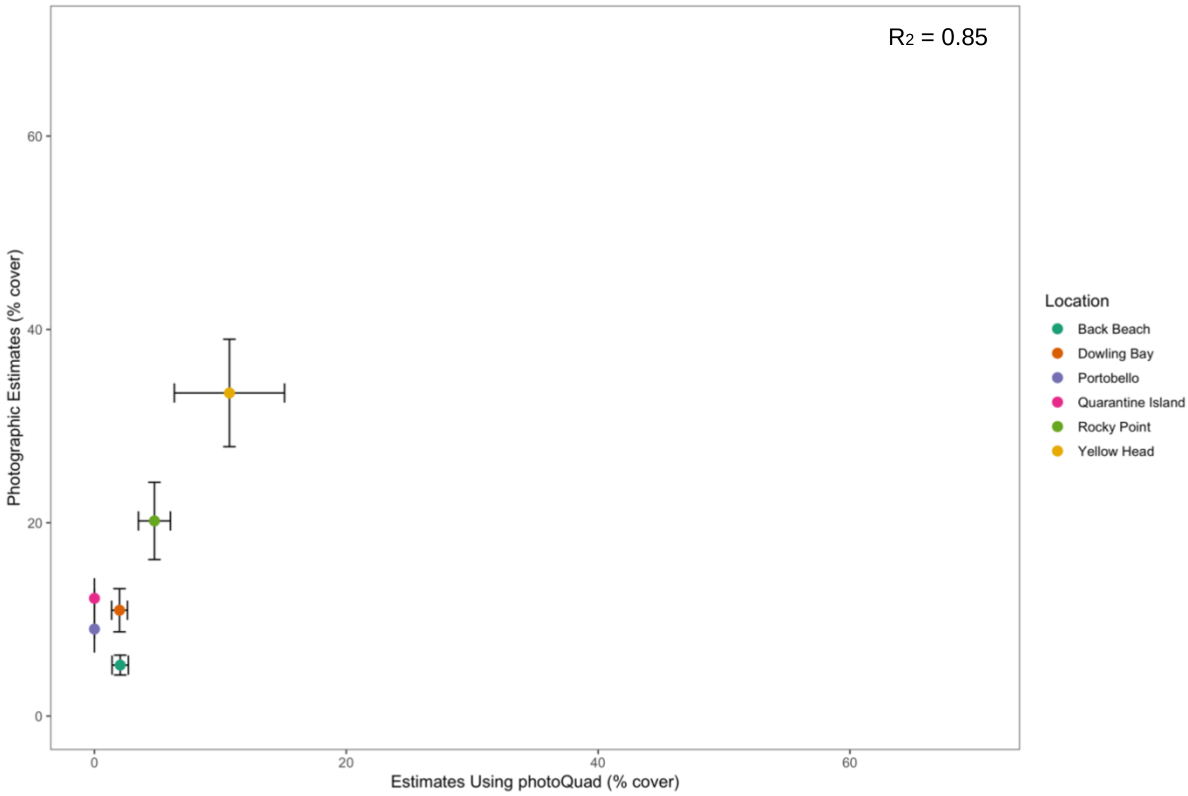

Figure 3.10: Comparison of the mean percentage cover of sediment estimated using printed A3 photographs and using an electronic program (photoQuad) for each of the six study sites. Horizontal error bars represent standard error for the mean percentage cover estimated using photoQuad and vertical error bars represent standard error for mean percentage cover estimated using photographs ($n_{(photographs)} = 117$, $n_{(photoQuad)} = 117$)

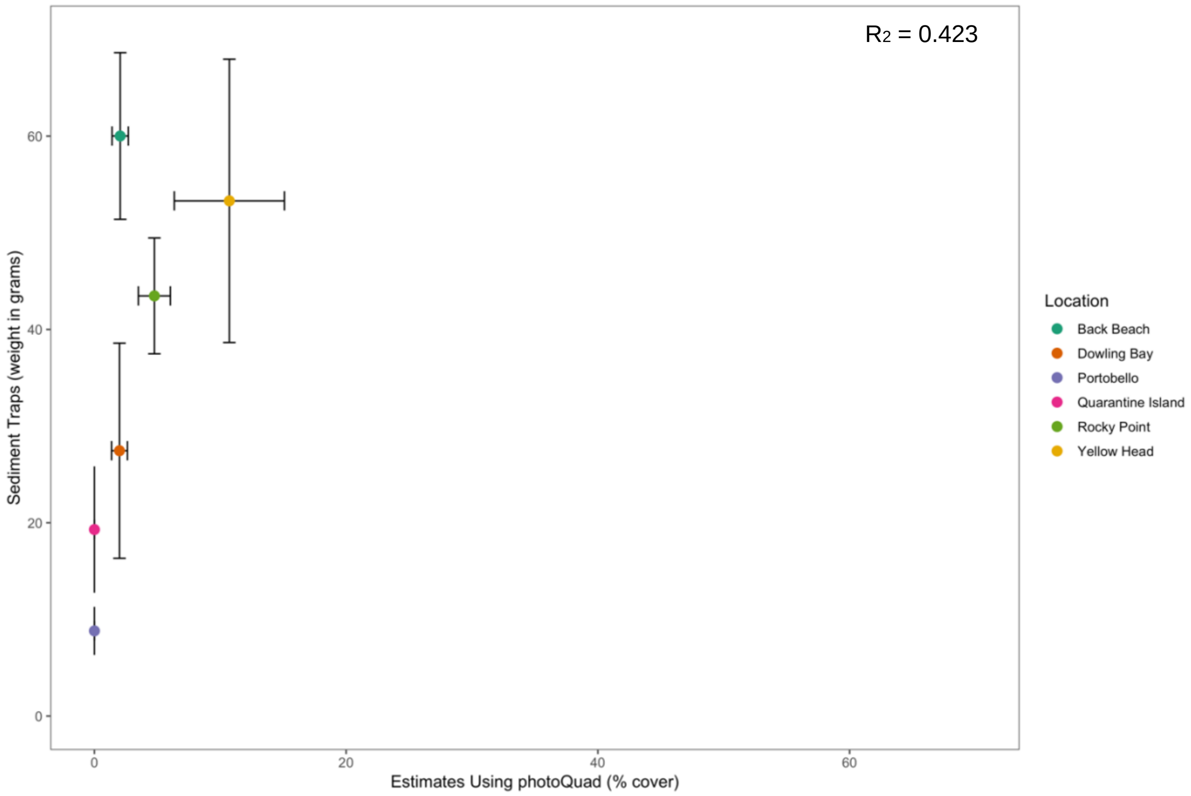

Figure 3.11: Comparison of mean weight (in grams) of sediment collected from sediment traps and the mean percentage cover of sediment estimated using an electronic program (photoQuad) for each of the six study sites. Horizontal error bars represent standard error for the mean percentage cover estimated using photoQuad and vertical error bars represent standard error for mean amount of sediment collected using sediment traps ($n_{(traps)} = 72$, $n_{(photoQuad)} = 117$)

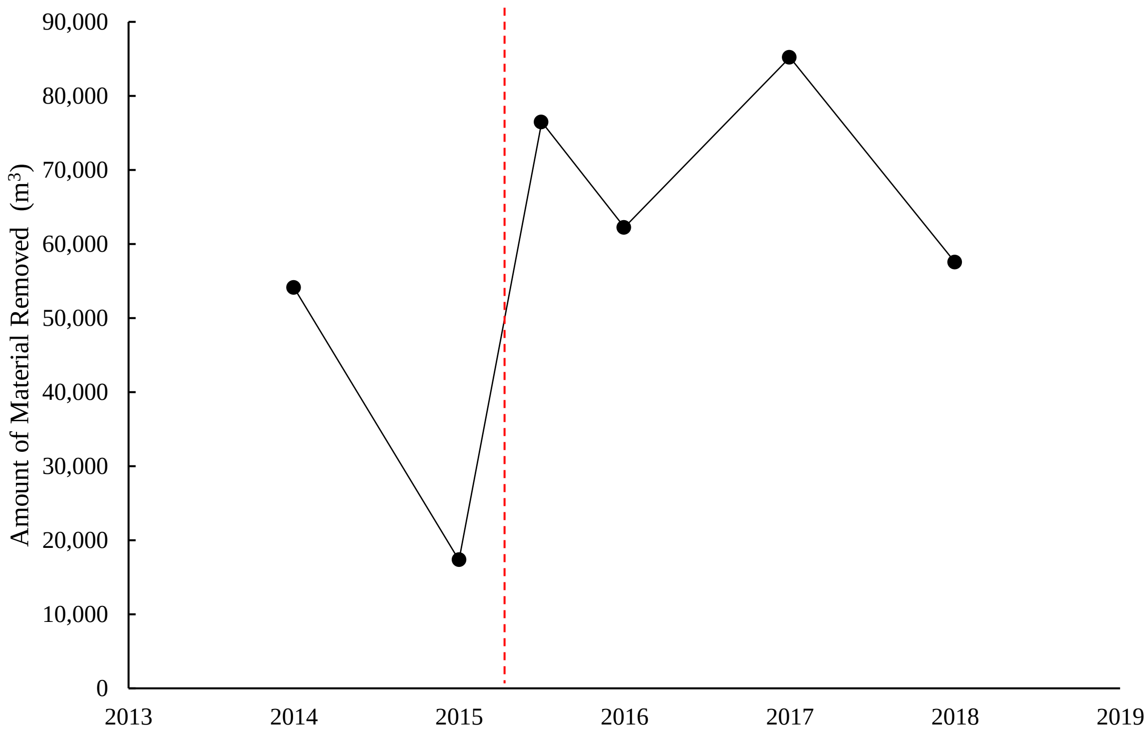

Figure 3.12: Amount of dredged material (in cubic metres) removed via the New Era dredge from the Otago Harbour between 2014 and 2018. Red line indicates the commencement of the capital dredging project in April 2015. (Note: figure only shows material removed from the harbour within the region of where sampling for the project took place). Data sourced from Port Otago Limited

Table 3.1: Two-way ANOVA of the mean percentage cover of sediment at low tide estimated at the six study sites by students over the three-year duration of a facilitated citizen science project ($n_{(2016)}$= 50, $n_{(2017)}$= 63, $n_{(2018)}$ = 46)

Factor	F value	df	p-value
Study site	11.2	5	<0.01
Year of project	1.37	1	0.248
Study site x Year	0.812	5	0.542

Table 3.2: Correlation coefficient and orthogonal regression confidence intervals for visual estimates recorded by scientists and students for six different substrate types (n = 115)

Substrate Type	Correlation	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Boulder	0.755	<0.001	0.495	1.01
Cobble	0.763	<0.001	0.602	1.06
Gravel	0.498	<0.01	-0.0230	1.71
Reef	0.805	<0.001	0.720	1.05
Sand	0.847	<0.001	-0.0411	2.43
Sediment	0.546	<0.05	-1.54	3.98

Table 3.3: Correlation coefficient and orthogonal regression confidence intervals for estimates recorded from photographs by scientists and students for six different substrate types (n = 117)

Substrate Type	**Correlation**	**p-value**	**Lower 95% Confidence Interval**	**Upper 95% Confidence Interval**
Boulder	0.524	<0.001	0.181	0.784
Cobble	0.523	<0.001	0.967	2.52
Gravel	0.596	<0.001	-0.264	3.49
Reef	0.505	<0.05	0.258	0.912
Sand	0.116	0.767	-	-
Sediment	0.561	<0.05	0.420	6.15

Table 3.4: Correlation coefficient and orthogonal regression confidence interval for the daily rate of sediment (in grams) accumulated from traps after five days collected by students and scientists (n = 72)

Substrate Type	**Correlation**	**p-value**	**Lower 95% Confidence Interval**	**Upper 95% Confidence Interval**
Sediment	0.528	<0.05	0.0835	0.578

Table 3.5: Correlations and regressions for the comparison between four methods (visual, photographs and sediment traps and photoQuad) used to estimate the mean amount of sediment (either percentage cover or weight of sediment collected in traps) at six study sites in the Otago Harbour ($n_{(photographs)}$ = 117, $n_{(visual)}$ = 115, $n_{(traps)}$ = 72, $n_{(photoQuad)}$ = 117)

Methods	Correlation	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Photographs vs Visual	0.152	0.773	-	-
Photographs vs Sediment traps	0.360	0.483	-	-
Visual vs Sediment traps	- 0.331	0.521	-	-
photoQuad vs Photographs	0.922	<0.01	0.440	0.992
photoQuad vs Visual	0.133	0.801	-	-
photoQuad vs Sediment traps	0.650	0.162	- 0.341	0.957

3.4 DISCUSSION

3.4.1 Sediment Accumulation Over Time

Mean percentage cover of sediment estimated by students differed significantly between study sites. Quarantine Island had the highest cover of sediment estimated over the course of monitoring compared to the other study sites. In 2017 Quarantine Island was estimated to have 60% mean sediment cover. This was the year in which the capital dredging project removed 82,500 m^3 from within the sampling area (the largest amount of material removed since the commencement of the project) (Fig 3.12). The amount of sediment estimated at Quarantine Island in 2018 was significantly lower to that estimated in 2017. Interestingly 2018 had the least amount of material dredged from the harbour since dredging project commenced in April 2015 due to technical issues with the primary dredging vessel and the completion of the first phase of the dredging in the lower harbour (R. McGrouther, personal communication, 26/01/2018). The changes seen at Quarantine Island (which is the site in closest proximity to the shipping channel) are similar to the changes in the amount of material dredged.

As one of the criteria to select sites, proximity to the shipping channel, where the dredging is being focussed, was considered. Quarantine Island, Rocky Point and Back Beach were the study sites closest to the port and the channel. During the data collections these locations were observed to have settled sediment on shallow subtidal macroalgae as well as along the intertidal. This was particularly apparent during sampling on Quarantine Island in 2017. Despite these observations at Back Beach (where sediment was clearly observed settling on macroalgae) there was low coverage of sediment estimated. Unlike Quarantine Island and Rocky Point, the shoreline at Back Beach was narrow and made of up predominantly boulders, therefore there may have been fewer places for sediment to settle and build up over time. In contrast, Portobello and Yellow Head – which were on the other side of the harbour – had similar trends in estimated mean sediment cover. The variability of estimated mean sediment cover between sites suggests that proximity to the shipping channel may influence sediment accumulation on the rocky intertidal however, this would need more monitoring and greater information on the hydrology in the harbour to further investigate this relationship.

3.4.2 Comparisons Between Visual and Photographic Estimates

Consistency between two groups of surveyors (students and scientists, henceforth referred to as ‘surveyors’) and between methods was used as a measure of accuracy as the absolute value of sediment accumulation on the rocky intertidal was not known. Scientists’ estimates of percentage cover of substrates were also not considered to be definitive/correct as it was acknowledged that scientist data was not without error. Therefore, comparisons between methods or between students and scientists were assessed on consistency.

There was no comparability between the average percentage cover of sediment estimated (by site) for photographs compared to visual surveys. Four out of six sites estimated more sediment using visual surveys compared to photographs. Visual estimates were also more variable as seen by the larger standard error surrounding the mean (with the exception of Yellow Head). When examining methods for consistency, it would appear that photographs (when compared to visual surveys) have less variability in estimating sediment.

Interestingly, comparisons between students and scientists indicated that visual surveys were more consistent between the two surveying groups. Visual estimates by students and scientists for all substrate types had the possibility of being equal (i.e. a 1:1 ratio) as seen in the confidence intervals. Additionally, confidence intervals for visual surveys were generally narrower. For photographs, only three out of six substrate types (sediment, gravel and cobble) demonstrated the possibility of equal substrate estimations between surveyors. Specifically looking at sediment, estimates by students were often higher than estimates by scientists yet comparisons between surveyors were still consistent. The width of the confidence interval for estimations of sediment was slightly larger for photographs compared to that of visual surveys suggesting there was more variability with estimations made using the photographs. Both the confidence intervals for sediment estimates made using visual surveys and photographs were the largest of all the substrates, suggesting that estimating sediment was more variable, and perhaps more difficult, then estimating other substrate types (with the exception of sand).

Sand was the least abundant substrate type identified in visual and photographs compared to the other remaining substrate types. But it was found there was a discrepancy in student and scientist estimates. This may be explained by the fact while in the field, students often distinguished sand and sediment by touch whereas on the photographs it was more difficult to separate sand and sediment. Therefore, there could have been less consensus on what was defined as sand, resulting in fewer quadrats where both students and scientists identified sand. If there had been greater incidents of identification of sand (by both groups of surveyors) then it is expected that the strength of the relationship could change.

3.4.3 Sediment Traps

The sediment traps were found to be highly variable in providing quantitative measurement of sediment between study sites in comparison to other methods. There was also no comparability between sediment traps and the other methods used to estimate sediment accumulation. Sediment traps were used to measure the volume of sediment accumulating (within the limits of the artificial turf) on the rocky intertidal whereas the other methods measured the surface cover of sediment. The different units used for measuring sediment may explain some of the differences between the sediment traps and the other methods.

Other research investigating sedimentation in subtidal environments opted for a cylindrical design of sediment traps (Airoldi et al., 1996; Anderson et al., 2004; Schiel et al., 2006; Storlazzi et al., 2011). However to deploy traps of this shape requires burying the base of the trap into the ground (Storlazzi et al., 2011) or holding it down with metal pins (Airoldi et al., 1996; Steiger et al., 2003). This design would not work on the rocky shore because it would be difficult to drive the trap into the ground (Steiger et al., 2003). Additionally, the fluctuating height of the water would be too shallow for the trap to stand up (previous work used cylinders around 50 cm) (Airoldi et al., 1996). Habitat constraints have been identified as a key control of the design, positioning and operation of sediment traps (Airoldi, 2003). Therefore, it was determined that a flat design would be most suitable for the rocky intertidal environment. Astroturf has been used to retain sediment in other research (Steiger et al., 2003) as it has been recognised to mimic turf algae (*Corallina* sp. in particular (Airoldi, 2003)).

3.4.4 Use of Photographs to Estimate Sediment

Portobello and Quarantine Island did not have any sediment identified when using photoQuad software. This was interesting as all other methods identified sediment at these locations, particularly at Quarantine Island, a site which was considered to have high sediment cover. With the exception of Yellow Head, the confidence intervals for this method were much narrower compared to the other methods. However the lack of statistical comparability with other methods, as well as no sediment being identified at two sites, suggests that photoQuad was a more inconsistent method than the visual or photographic methods. The purpose of analysing photographs using photoQuad software was to have a standard to compare the other three methods to as suggested by Pech et al. (2004). However, other studies that have found that digitising photographs and analysing them on computers is not as precise when compared to other methods (Dethier et al., 1993; Benedetti-Cecchi et al., 1996; Drummond & Connell, 2005).

The methodology for the photographic estimates were modified (in this study) from the wider literature (Pech et al., 2004; Drummond & Connell, 2005; Page et al., 2017). In order for this method to work in schools, printing photos on paper was thought to be more appropriate as opposed to digitising photographs to analyse electronically (which is what most research on the subject has focussed on). Students were asked to assess both the visual and photographic methods during the data entry sessions before selecting a method they preferred and indicating why. Most students chose visual surveys as their preferred method as they could use see and touch the different substrates. Therefore, they may be able to engage better with the task of estimating substrates on the shore which would assumedly make their data more accurate. As mentioned, measuring accuracy of substrate data is difficult as the true quantity of the substrate is not known.

Normally when using point-intercept analysis a portion of the photograph is analysed (Drummond & Connell, 2005), but it was thought that assigning substrate types to all areas of the photograph would help increase accuracy through iterative tasks (Kosmala et al., 2016). Using hard copy photographs was done for a number of reasons including limited time in the classroom and potential technical difficulties with the software. Although most software used for photo point analysis is free to download, there was uncertainty on whether it would work on Google Chromebooks (which is what all schools had). Using this software would also require schools to download and install the software prior to the data entry sessions with the scientists, so this task could be completed in the data entry session. However, whether this would be done by teachers could not be guaranteed. Finally, instructing students to complete the task using software was thought to be beyond their capabilities. Despite this, it would still be of interest to get students to use photographic analysis software.

3.4.5 Limitations

The fact that photographs had to be scaled down from 1 m^2 quadrats to A3 paper may have caused confusion for some students. In the New Zealand mathematics curriculum, working with scales and percentages is an achievement objective at the end of year five (when students are aged 9-10) (Ministry of Education New Zealand, 2014). Although in this facilitated citizen science project the average age of students was 9.8 years (± 0.2 years), as this project was in the first half of the year, these particular mathematics skills may not have been fully developed. Therefore, prior exposure with percentages and using scales and grids before commencing the project would be beneficial, and teachers could be asked to do this prior to the introduction sessions. As part of a citizen science project monitoring the rocky intertidal in California, teachers were required to attend a one-day workshop which explained the project objectives, methods and links into the curriculum (Freiwald et al., 2018). This workshop also provided tools and resources for teachers to implement in the classroom prior to commencing the project (Freiwald et al., 2018). Incorporating this into future projects would be worth considering however, this is dependent on the availability of teachers.

Although the protocol used in this study for collecting sediment from sediment traps was intended to be easy to use, the participants in this citizen science project struggled the most with this method of the three used in this study. Full supervision was required during the collection of sediment from the sediment traps, which was difficult with larger groups (of 20+ students). There were incidents where sediment collected from traps was poured out or knocked over resulting in partial or total loss of sediment in that particular sample. There was also one incident where a sediment trap had been removed from the water (assumedly by a member of the public) prior to collection. This likely impacted the results for the sediment traps and so a comprehensive assessment of sediment traps could not be made. Instead of being the primary method to monitor sediment, traps could provide a visualisation for students as a relative measure of sediment present in the rocky intertidal environment. Therefore, sediment traps could be used as an educational tool for explaining and demonstrating the impact of coastal sedimentation.

Younger students did not have the skills or understanding to complete some tasks, such as estimating percentage cover of substrates, without adult support. For example, Quarantine Island (assigned to the oldest group of students) was found to have the least variability between methods when estimating the average amount of sediment. Students at this site were able to complete their surveys on the rocky intertidal more independently in comparison to the younger students involved and often had less adult support (two to three teachers for the whole class of 25 students). This could prompt further investigation into factors that may influence the ability to complete tasks assigned in a monitoring project such as age of students and the amount of support provided from teachers. Therefore, future projects need simplification of some tasks to be more inclusive or more selective criteria for participants to be involved in future projects are needed. An example of simplifying tasks could be getting students to identify fewer squares using the photographic methods as opposed to all the squares. This would require less time and would be more comparable to other studies that use point-intercept analysis.

Finally, this study used descriptions for substrate that could be measured in relation to parts of the body (e.g. boulder = rocks the size of a child’s head or bigger but were not stable or continuous). Therefore, to improve the accuracy of assessments of substrate cover, using a more descriptive structure of substrate size classes could be used. This however, would require further training for scientists and students.

3.5 CONCLUSIONS

The impacts of sediment on the rocky shore have been well-described in the scientific literature, yet there are few studies that look at methods for monitoring sediment over time (Airoldi, 2003). The majority of sediment accumulation research on rocky shores has focussed on coral reefs (Rogers, 1990; Airoldi, 2003; Agardy et al., 2005; Storlazzi et al., 2011) with some additional work on subtidal organisms (Airoldi & Virgilio, 1998; Airoldi, 2003; Schiel et al., 2006; Walker, 2007; Onitsuka et al., 2008; Chew et al., 2013). On the whole, the rocky shore has been under-represented, despite the potential risks that sediment loading poses to this environment (Airoldi, 2003; Agardy et al., 2005; Halpern et al., 2008). Therefore, effective monitoring techniques are needed that are low-cost and can complement less frequent (and often more expensive) scientist-led monitoring projects. Research has investigated different methodologies to identify optimal ways (including the consideration of cost-benefit analysis) to best measure sediment over time, however, this has rarely been done in the intertidal zone (Drummond & Connell, 2005). This information can be applied to further monitoring of the current dredging project occurring in the Otago Harbour. This research compares three methods; visual (*in situ*) surveys, photographs (printed onto paper) and flat-bottomed sediment traps. Methods were selected as they have previously been used to estimate sedimentation (Asselman & Middelkoop, 1995; Airoldi, 2003; Storlazzi et al., 2011) yet they have not been compared to one another. Depending on the comparison, this study finds that visual surveys are the most consistent between students and scientists (for all substrate types). However, photographs are more consistent when comparing between methods to estimate sediment, therefore a combination of visual and photographic surveys is recommended. This research uniquely compares methods by incorporating tasks that are suitable for a citizen science project targeted for school-aged children. The comparison of these methods also combines a range of techniques used to estimate sediment change over time that have not been compared before.

CHAPTER FOUR

INVESTIGATION INTO SCIENCE-BASED SKILLS AND KNOWLEDGE DEVELOPED DURING A FACILITATED CITIZEN SCIENCE PROJECT

4.1 INTRODUCTION

4.1.1 Citizen Science History and Global Trends

Citizen science is a term that was first used by Alan Irwin in 1994 to describe the engagement of non-scientists in scientific investigations, usually assisting in data collection, while also asking questions or interpreting results (Follett & Strezov, 2015). Despite the recent rise in the profile of citizen science, there has been a long history of public participation in science (Shirk et al., 2012; Miller-Rushing et al., 2012; Dennis et al., 2017). Prior to science becoming a profession about 150 years ago, nearly all ecological data was collected by volunteers including farmers, naturalists and hunters (Devictor et al., 2010; Miller-Rushing et al., 2012; Bonney et al., 2016; Kobori et al., 2016). For example, in Japan the peak flowering times of cherry blossoms have been recorded for approximately 1,200 years, and this historic data has been used to help predict flowering times and investigate possible relationships with climate change (Miller-Rushing et al., 2012; Kobori et al., 2016).

Over the past 30 years there has been a growing resurgence in volunteer-collected data (or citizen science), as seen in the increase of scientific publications and the number of projects on citizen science (Sbrocchi, 2014; Follett & Strezov, 2015). The expansion of citizen science projects has been attributed to the advancement of technology (particularly with smartphones and apps) (Grey et al., 2016; Lorenz, 2016; Shah & Martinez, 2016; Kosmala et al., 2016; Fulton et al., 2018), the need for long-term and large-scale datasets (Dickinson et al., 2010; Conrad & Hilchey, 2011; Todd et al., 2016; Kosmala et al., 2016) and the growing emphasis on scientific outreach and education (Silvertown, 2009; Kosmala et al., 2016). The importance of citizen science has been recognised by many organisations in charge of funding for scientific research in the US and the UK – where most research involving citizen science takes place (Kobori et al., 2016) – and they now list scientific outreach and/or community engagement as requirements for grant holders (Silvertown, 2009; van der Velde et al., 2017). The benefits of collaborating with citizen scientists or incorporating citizen science collected data into scientific research are well-known (for a review see Chapter Two of the thesis). This is often determined through quantitative assessments (often validating data collected during citizen science projects), however these assessments often do not actually evaluate projects as a whole (Sbrocchi, 2014).

4.1.2 Evaluating Citizen Science

Evaluations are needed to assess the strengths and weaknesses of policy, progress, products, personnel, programmes and organisations in order to improve their overall effectiveness (Jordan et al., 2012). Regular evaluations of citizen science can help project managers improve project outcomes (Jordan et al., 2012; Hecker et al, 2018), reach new audiences and increase project longevity and impact (Jordan et al., 2012). Therefore, reviews (and other methods of assessment) are important to evaluating different aspects of citizen science projects (Phillips et al., 2018). Most citizen science projects have some kind of built-in tools for evaluation and adaptive management (Kobori et al., 2016) – for example surveys or interviews with participants by project leaders or external evaluators (Wiggins et al., 2018). Such evaluation tools can be particularly useful for assessing, creating or adapting project outcomes and can be used before, during or upon completion of a project (Bonney et al., 2009; Jordan et al., 2012; Kobori et al., 2016; McKinley et al., 2017) but are not always useful for completing cross-programmatic evaluations (Phillips et al., 2018). Evaluating outcomes across different citizen science projects could be useful for determining funding (Phillips et al., 2018) as well as ensuring that project organisers have outcomes that are realistic (Shirk et al., 2012). However, there are few frameworks or guidelines available to consistently assess and evaluate citizen science project outcomes (Bonney et al., 2016; Wiggins et al., 2018; Phillips et al., 2018).

4.1.3 Outcomes of Citizen Science

Outcomes are measurable elements that can be evaluated from the outputs of a specific project (Shirk et al., 2012). Shirk et al. (2012) classifies outcomes for citizen science projects into three categories; for science, for society (often in relation to policy) and for individuals. Originally citizen science was primarily focussed on science-based outcomes, however, there has been a recent shift to also include other outcomes aside from science (e.g. learning or behavioural outcomes) (Phillips et al., 2018). In earlier chapters of this thesis, outcomes for science have been addressed – including examining the validity and quality of data collected during a facilitated citizen science project. Outcomes used to measure value for socio-ecological change in the projects have included: stewardship, opportunities to deepen relationships with nature or other people/organisations and increased environmental awareness (Shirk et al., 2012). Individual learning outcomes to date have been based on knowledge and skills development, better understanding of the scientific process and increased scientific literacy (Shirk et al., 2012; Parrish et al., 2018; Phillips et al., 2018). However, benefits that relate to changes in social or learning behaviours are less researched as they are often more difficult to measure (Phillips et al., 2018), which can make it difficult to evaluate citizen science projects as a whole. However, this project had set learning objectives, which were based upon the 'Nature of Science' section in the New Zealand curriculum (Ministry of Education, 2007; Ministry of Education, 2014).

4.1.4 Citizen Science and the New Zealand Curriculum

Citizen science fits in well with modern school curricula across the globe (Bonney et al., 2016; Lewenstein, 2016). Due to the range of projects on offer, citizen science can easily be applied into classroom topics and also meet the requirements of the curriculum in different countries (Shah & Martinez, 2016; van der Velde et al., 2017; Freiwald et al., 2018). In the New Zealand curriculum, citizen science has links to mathematics, science and English (Peters, 2018). Citizen science was especially relevant to the five science capabilities (Ministry of Education, 2014) that provide structure to the 'Nature of Science' section in the science curriculum. The five science capabilities are: gather and interpret data, use evidence, critique evidence, interpret representations and engage with science (Ministry of Education, 2014). Using citizen science in schools can also meet broader concepts of the New Zealand curriculum that aim to produce confident, connected and actively involved life-long learners (Ministry of Education New Zealand, 2007). Citizen science can also be incorporated into learning and empowering Māori mātuaranga (traditional knowledge, understanding, wisdom and skill) through cultural-based monitoring (Peters, 2018).

The potential of citizen science as an education tool was recognised by central government in New Zealand through the establishment of the 'Unlocking Curious Minds' fund in 2014 as part of the national strategic plan for 'Science in Society' (Ministry of Business Enterprise and Employment et al., 2014; Peters, 2018). This funding initiative is focussed on engaging youth (aged 18 years or under) in ecologically-based science and technology projects and lists participatory science (defined as a method of undertaking scientific research where students can be meaningfully involved with the development and progression of locally relevant scientific research projects with science professionals) as one of its over-arching goals (Ministry of Business Enterprise and Employment et al., 2014; Peters, 2018).

4.1.5 Education and Citizen Science

Citizen science projects can provide exposure to a range of science skills including: logical/scientific thinking, data analysis and presentation, public speaking and data collection (Evans et al., 2005; Dickinson et al., 2012; Ballard et al., 2017; Dean et al., 2018). Furthermore, citizen science projects have also been recognised as promoting inquiry-based learning (Bonney et al., 2009; Jordan et al., 2012; Cigliano et al., 2015; Shah & Martinez, 2016; Ballard et al., 2017). Studies in the US have found that many students are not equipped with these kinds of skills that are needed to help prepare students for science classes at a tertiary level (Oberhauser & LeBuhn, 2012; Shah & Martinez, 2016). Exposure to these skills may encourage students to further pursue science in their academic career (Shah & Martinez, 2016; Ballard et al., 2017).

Although there has been some demonstration of projects achieving education-based outcomes (Bonney et al., 2016), documentation of robust learning, such as knowledge of science, increased inquiry skills, and increased interest in science is lacking (Phillips et al., 2018). Research investigating outcomes particularly associated with learning is limited due to the difficulty of collecting data, as this requires more time and expertise in conducting social science evaluations (Phillips et al., 2018), which can become expensive (Bonney et al., 2016). As a result, individual learning outcomes and examples of measurable science skills have not been well researched (Phillips et al., 2018). Therefore, non-conventional tools and techniques need to be investigated to assess changes in individual learning outcomes in citizen science over time. A possible useful tool to investigate this is mind maps as they have been used in social sciences and psychology (Salzberg-Ludwig, 2008), nursing (Tattersall et al., 2011; Rosciano, 2015; Kernan et al., 2018) and midwifery (Noonan, 2013).

4.1.6 Mind Maps in Education

A mind map is defined as a graphic representation of how the human brain thinks and generates ideas, thus fostering whole brain learning (Wright, 2011; Noonan, 2013). Although mind maps are often confused with concept maps, they are different from one another (Wheeldon & Faubert, 2009; Wright, 2011) as mind maps have a looser structure that is more akin to the process of brain-storming (Noonan, 2013). Mind maps also allow the user to record random ideas/thoughts without the need to link concepts together (Kernan et al., 2018), whereas concept maps follow a linear structure and have more rigid criteria (Wright, 2011; Kernan et al., 2018). Mind maps have been noted to encourage creative thinking (Salzberg-Ludwig, 2008; Wright, 2011; Noonan, 2013), aid in problem solving (Wright, 2011; Noonan, 2013; Hou et al., 2016; Kernan et al., 2018), develop writing skills (Wright, 2011), prompt visual learning (Budd, 2004; Wright, 2011) and aid memory (Croasdell et al., 2003; Salzberg-Ludwig, 2008; Kernan et al., 2018).

Research has found that students who use mind maps to study for examinations perform at a similar level to students using other methods of learning such as note taking (see Noonan 2013 for a summary) and most students were reported to respond positively to the use of mind maps (D’Antoni & Zipp, 2006; Kernan et al., 2018). Despite the success of mind maps as a teaching tool, there has been limited research dedicated to investigating them as a tool to evaluate and assess learning (Wright, 2011). Most evaluations on how mind maps affect student learning are done with accordance to a marking criterion based on complexity of ideas and branches, colour use and connections between ideas (Salzberg-Ludwig, 2008; Keleş, 2013) and there is little evaluation completed in relation to broader concepts such as educational curriculum or methodology (an example being the standard scientific protocol) (Phillips et al., 2018). Therefore, this presents an opportunity to assess development of scientific skills and evaluate them in relation to the curriculum using mind maps.

4.1.7 Mind Maps as a Tool to Measure Outcomes

Assessment of improvement in scientific knowledge or skills is often done in the forms of pre- and post- surveys, in-depth interviews and self-evaluations (Bonney et al., 2009; Phillips et al., 2018). Mind maps were incorporated into this study because they allow freedom in students' thinking (Goodnough & Woods, 2002; Crowe & Sheppard 2012). Criteria to code answers were developed to investigate whether this facilitated citizen science project was meeting set learning outcomes, particularly surrounding science education, development of knowledge of the scientific process and providing hands-on learning. Mind maps were also thought to encourage team-work and peer-to-peer discussion (Rosciano, 2015; Kernan et al., 2018; Stokhof et al., 2018), allowed for the collection of a wide range of ideas in a short amount of time (Salzberg-Ludwig, 2008; Kernan et al., 2018) and prompted creative problem solving and thinking (Salzberg-Ludwig, 2008; Keleş, 2013; Noonan, 2013). The use of mind maps to evaluate outcomes also provides flexibility as the central idea of the mind map can be adapted to measure or assess aspects or outcomes (Crowe & Sheppard, 2012). Mind maps provide a unique way of collecting evaluation data and it is thought to be the first time they have been used in the context of citizen science.

4.1.8 Aims and Objectives

This chapter aims to assess the skills and knowledge developed in school-aged students (aged five to fourteen years) during one year of a facilitated citizen science project. Skills of science inquiry (defined by Phillips et al. (2018) as observable practices, such as species identification, that can be applicable to daily life) were based on students' ability to correctly identify five common intertidal snails by completing pre- and post-tests. Although direct species identification (i.e. scientist is present when citizen scientists are identifying species) have been completed in other citizen science projects, there have often been only two species to identify (as opposed to five in this project) (Delaney et al., 2008), larger organisms are used (such as trees) (Bloniarz & Ryan, 1996) or a recording is used (for example amphibian calls) (Miller et al., 2012). As most students encountered all the snail species during two data collections along with the introductory classroom session, it was expected that the post-test results will demonstrate an increase in the percentage of correct identifications.

Knowledge of the process of science (i.e. the scientific method) was assessed using mind maps (also in pre- and post-test format). Mind maps were coded using criteria based on the scientific method as well as the science capabilities as set by the New Zealand Ministry of Education (Ministry of Education, 2014). The central question was changed between pre- and post-test mind maps to see if the understanding of the scientific process was applicable to different environments. It was expected that there would be an increase in the students' number of ideas relating to results, analysis and conclusions.

4.2 METHODS

4.2.1 Student Age Demographics

Six schools were involved in the project in 2018 with students ranging in age from five to fourteen years. There were 150 students (17% secondary students, 83% primary school student) involved in this year of the project and the average age of students was was 9.8 years (± 0.2 years) (Fig 4.1).

Figure 4.1: Age demographics for students involved in the 2018 year of the facilitated citizen science project (n = 150)

4.2.2 Identification of Rocky Intertidal Snail Species

This activity was completed to investigate whether students' identification of intertidal species improved over the course of a facilitated citizen science project. Five intertidal snail species were selected for the assessment of students' identification skills. The species were; turret snail (*Maoricolpus roseus*), spotted top snail (*Diloma aethiops*), horn snail (*Zeacumantus subcarinatus*), lined whelk (*Buccinulum* sp.) and cats eye snail (*Lunella smaragda*) (Fig 4.2). Six individuals of each species were presented to the students during the introduction sessions – the pre-test (March 2018) and the summary sessions – the post-test

(August 2018). This was completed using a mix and match survey. There were no identification resources available to students for this activity. At the end of the activity in both sessions the correct identification of each snail was revealed to students.

The five species were chosen as they are commonly found along the rocky intertidal and students would be very likely to encounter them at some point during the project. In order to really test students' identification skills, snails were also selected to have similar appearances e.g. similar colours, sizes and shapes.

Figure 4.2: Images of the five common rocky shore snails used to assess students' identification skills (answers are in black). Numbers correlate to the tray number snails were on. Answers were shown to students once they had completed the identification assessment

Prior to students beginning the exercise, six individuals from each species were laid out on five plain, dry white trays (18 inches x 26 inches) which were placed around the classroom (Fig 4.3). Students were provided with a piece of paper that had the common names of the snails in a random order on the right side and the tray number on the left (Fig 4.4). Students were given five minutes to visit all five trays (which were placed around the classroom) and match the common name of the snail to the appropriate tray number. Students were encouraged not to handle or remove snails from the trays. It was emphasised that this was an individual activity and students were encouraged to do their best.

Figure 4.3: Example of snails laid out on white tray with tray number (on yellow post-it note) in the top left corner. Pictured here are six lined whelks (*Buccinulum* sp.)

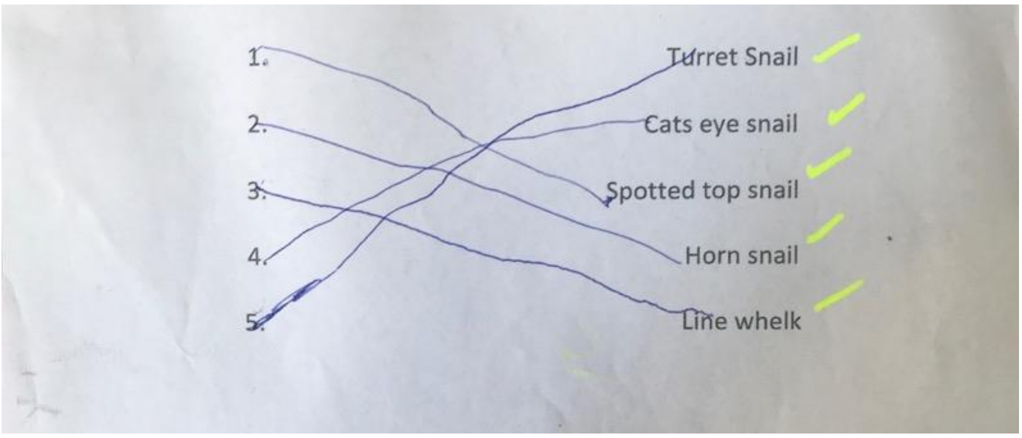

Figure 4.4: Exemplar of a completed pre-assessment snail identification answer sheet completed by a student (age nine) in the introduction session. Yellow ticks are by scientists indicating that the student correctly identified all snail species

4.2.2 Identification of Rocky Shore Snails Analysis

Data were entered into Microsoft Excel (version 16.18). Paired t-tests were run using RStudio to see if there were differences in correct identifications of snails between the pre- and post-tests (version 1.1.414, RStudio Team 2016) (Table 4.1). To investigate whether there were differences between the pre- and post-tests within the individual snail species, the average percentage of correct identification for each snail species was calculated for each of the six schools to standardise effort. The average percentage of correct identification for each snail species was then compared between pre- and post-tests using individual paired t-tests completed on RStudio (Fig 4.8; Table 4.2). In order to account for multiple testings, p-values were adjusted using the Holm correction method (significance set to a level of $\alpha = 0.05$) (Table 4.2). The number of students achieving 100% identification was also compared between pre- and post-tests and the identification ability of primary school students to secondary school students using a two-way ANOVA, which was completed using RStudio (Table 4.3).

4.2.3 Mind Maps Assessment

Students worked in groups (ranging between three and seven students) and groups had ten-minutes to record all their ideas relating to marine-focussed issues on a mind map. This was completed in both the introduction and summary sessions in a pre- and post-test format. Although there was parent and teacher support while students were collecting data on the rocky intertidal, there was no support during the two assessment tasks which were completed at the beginning and end of the project. There was an exception for younger students (aged five and six) who had some assistance with writing from either their teacher or the scientist. The amount of contact time with the scientist/educator was consistent across schools (eight hours over six sessions – see Chapter One for further detail) and the same basic information was presented to each school. However, students and the teachers at times directed the discussion toward different topics through comments, questions or from their experiences on the seashore. Some classes had done additional in-depth inquiry into the intertidal and marine environment as directed by the teacher without the educator present. The effect of this was thought to be too difficult to test in the study and was thought not to create any bias between schools.

4.2.3.1 Introduction Session

Prior to the mind map activity, a brief overview of the dredging project – including defining what dredging is – was provided using Microsoft PowerPoint (version 16.18) (Fig 4.5). The scientists were also introduced as were the study sites to be included in the project. Students were then put into groups of four to seven pupils and had ten-minutes to answer the following question: “As a scientist, how could we investigate the impact of dredging and sediment disturbance on rocky shore life in Otago Harbour?”

Any students that had been a part of the project before (only eight students or two groups of four students from one school) were placed together into two groups. As this was a small proportion of the total students involved (eight out of one hundred and fifty), there was no analysis completed on assessing whether prior involvement had any effect on the mind map.

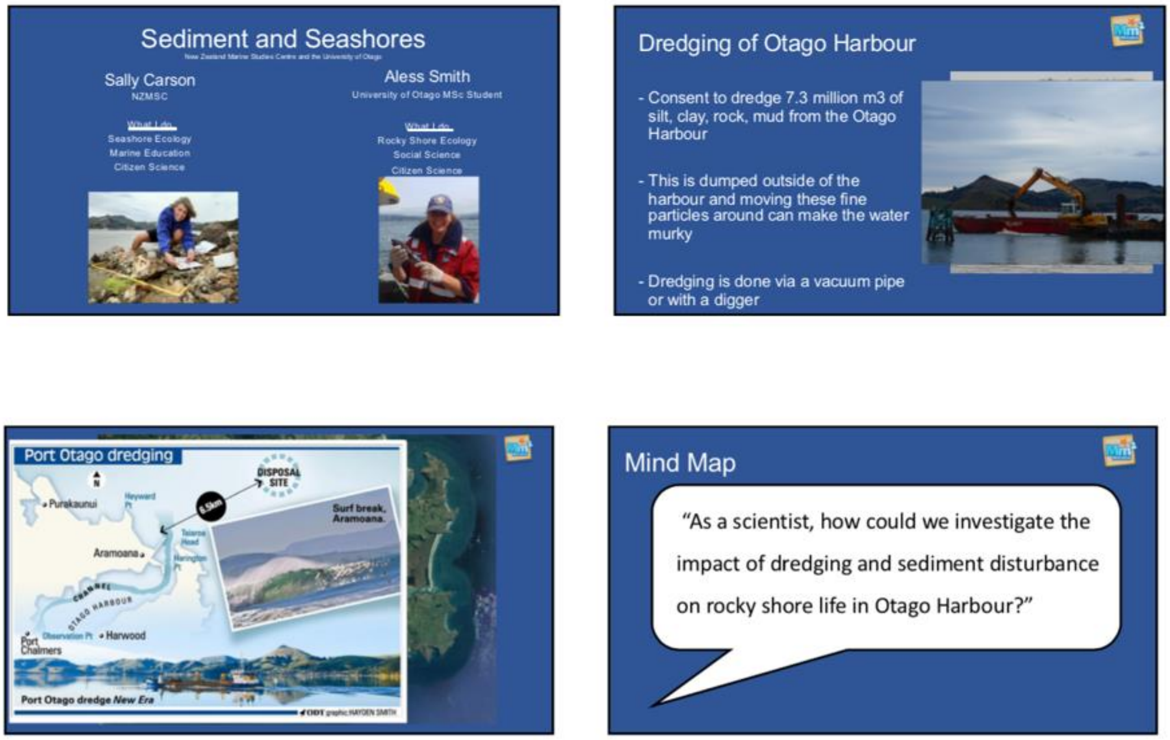

Figure 4.5: Screenshots from the introduction PowerPoint presentation providing background information on the dredging in the Otago Harbour

4.2.3.2 Summary Session

After the completion of the snail identification activity, summary sessions commenced with a recap discussion about the project prompted by the following questions that students were encouraged to investigate (and were regularly bought up in discussion with scientists) throughout the duration of the project

- Why should we be concerned about increased sediment in the Otago Harbour?

- How does sediment affect the seashore?
- What are some of the causes of sediment on the seashore?
- What species are most at risk? What plants and animals are most sensitive to sediment?
- What about other areas of the Otago Harbour (i.e. outside of the six study locations)?

Students also reviewed a summary of the data they collected over the year and compared their data with other locations being monitored in Otago Harbour. This included some examples of species that had varying densities over the duration of the three years of monitoring.

To see if students could apply their science skills to a new challenge and environment, the central question for the post-test mind map was modified to: "As a scientist, how could we investigate the impact of dredging and sediment disturbance on subtidal life in Otago Harbour?" The subtidal was defined to students as the marine environment that is below the low-tide mark on the shore (i.e. always underwater).

Prior to commencing the mind map activity, a 19 second underwater film of Otago Harbour (recorded by a scientist on a GoPro Hero 4+ camera) was played through twice to 'set the scene' and introduce students to the subtidal environment (Fig 4.6). Students worked in the same groups (of three to seven students) as in the introduction sessions with minor adjustments due to student absences.

Figure 4.6: Screenshot of a still from the video introducing the subtidal shown in summary session PowerPoint presentation

4.2.4 Mind Map Analysis

Mind maps produced by students in both the introduction and summary sessions were coded using criteria based on the standard scientific method and the science capabilities as set by the New Zealand Ministry of Education (Ministry of Education, 2014) (Fig 4.7). Criteria were broken down into eight categories (each with a range of sub-categories) (Appendix 4.1). Categories were: gathering background information, asking additional questions, predicting outcomes from the dredging, methods, data analysis, critiquing data/reviewing methods, ideas for future investigations and irrelevant ideas (Appendix 4.1). The total number of ideas (defined as the number of possible coded answers) as well as the number of branches (the number of singular points stemming from the central question) were also recorded. Each branch was coded and could have multiple codes per branch. Coding was completed by two scientists and the coded answers were reviewed when there were discrepancies between the reviewers. In all cases, consensus was reached.

Data was entered in Microsoft Excel. The average number of ideas for each category was calculated and a paired t-test was run on RStudio to compare the pre-test and post-test mind maps (Table 4.4). To investigate whether there were any differences between the two mind maps (pre and post) within the individual categories, the average number of ideas per group was calculated for each of the six schools (to standardise effort). Paired t-tests were run in RStudio for each category (as well as the average number of ideas per mind map) (Fig 4.9-Fig 4.10; Table 4.5). In order to account for multiple testings, p-values were adjusted using the Holm correction method (significance set to a level of $\alpha = 0.05$) (Table 4.5).

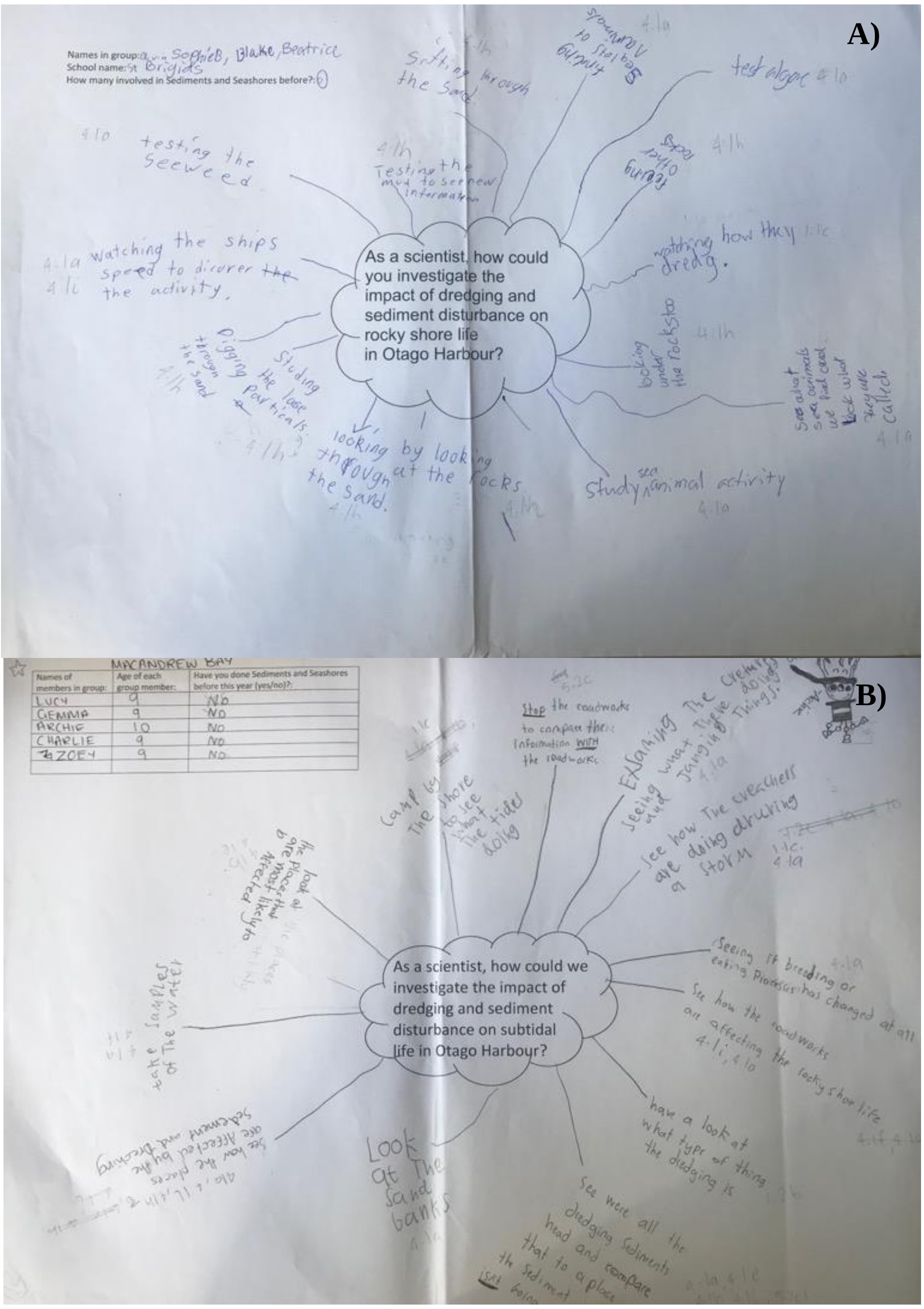

Figure 4.7: Exemplars of completed mind maps by two different groups of students from different schools in the same age (9-10 years). Map A was completed by four students in the introduction session (pre-test mind map) and map B was completed by five students in the summary session (post-test mind map). NB: Numbers and letters in pencil relate to coding by scientists

4.2.5 Teacher Evaluations

After the completion of the project, all teachers involved (n = 7) were asked to anonymously answer a nine question survey made using Survey Monkey™ (www.surveymonkey.com) surrounding the educational values of the project. Questions were either in short-form answers or matrix system. As part of this, teachers were asked to rank how valuable the project was in terms of relating to the science capabilities as set by the Ministry of Education (Ministry of Education, 2014).

4.3 RESULTS

4.3.1 Identification of Rocky Shore Snail Species

There was a significant difference between the percentage of correctly identified snail species between the pre- and post-tests (Fig 4.8, Table 4.1). The average percentage of correct identification for all snails (regardless of species) increased from 28% (pre-test) to 48% (post-test). Comparing pre- and post-tests between the individual snail species results were more variable (Fig 4.8). There were statistically significant increases in the identification of horn snails (*Z. subcarinatus*) and lined whelks (*Buccinulum* sp.) ($p < 0.05$; Fig 4.8; Table 4.2). The average percentage of correct identifications for these two species rose from 21% to 41% (*Z. subcarinatus*) and from 19% to 43% (*Buccinulum* sp.) between pre- and post- surveys respectively (Fig 4.8). Although other species also showed increases in the percentage of correct identification, these results were not significant (Fig 4.8; Table 4.1). The number of students achieving 100% correct identification rose from 2 in the pre-test to 19 in the post-test, which was significant (Two-way ANOVA $F_{(3,8)} = 13.29$, p-value <0.01) (Table 4.3). There was also a significant difference between the number of primary students (five to eleven years) and secondary students (thirteen to fourteen years) achieving 100% correct identification of all snail species where more primary students achieved 100% than secondary students (Two-way ANOVA $F_{(3,8)} = 13.29$, p-value <0.05) (Table 4.3). There was a difference with the interaction of school level of the students and their performance in the pre- and post- tests (p-value <0.01) however only secondary students had a significant increase between the pre- and post-test (p-value <0.05 for Tukey's HSD) (Table 4.3).

4.3.2 Mind Maps Assessment

Overall, there were no significant differences in the average number of ideas per group between pre- and post-test mind maps (p-value = 0.255, Fig 4.9; Table 4.4). When investigating the average number of ideas per group for each individual category, it was found that 'future work', 'methods' as well as the average number of ideas recorded all had significant increases between pre- and post- mind maps (p-value <0.05)(Fig 4.9-4.10; Table 4.5). The remaining all decreased between pre- and post-test mind maps but were not significant (Fig 4.9). The average number of ideas for these categories was low (often less than one) except for the categories predicting outcomes and irrelevant ideas (Fig 4.9). These categories had the largest decreases in this study – predicting outcomes from 1.19 to 0.04 and irrelevant ideas 0.84 to 0.42 – but these were found to not be significantly different (Fig 4.9; Table 4.5).

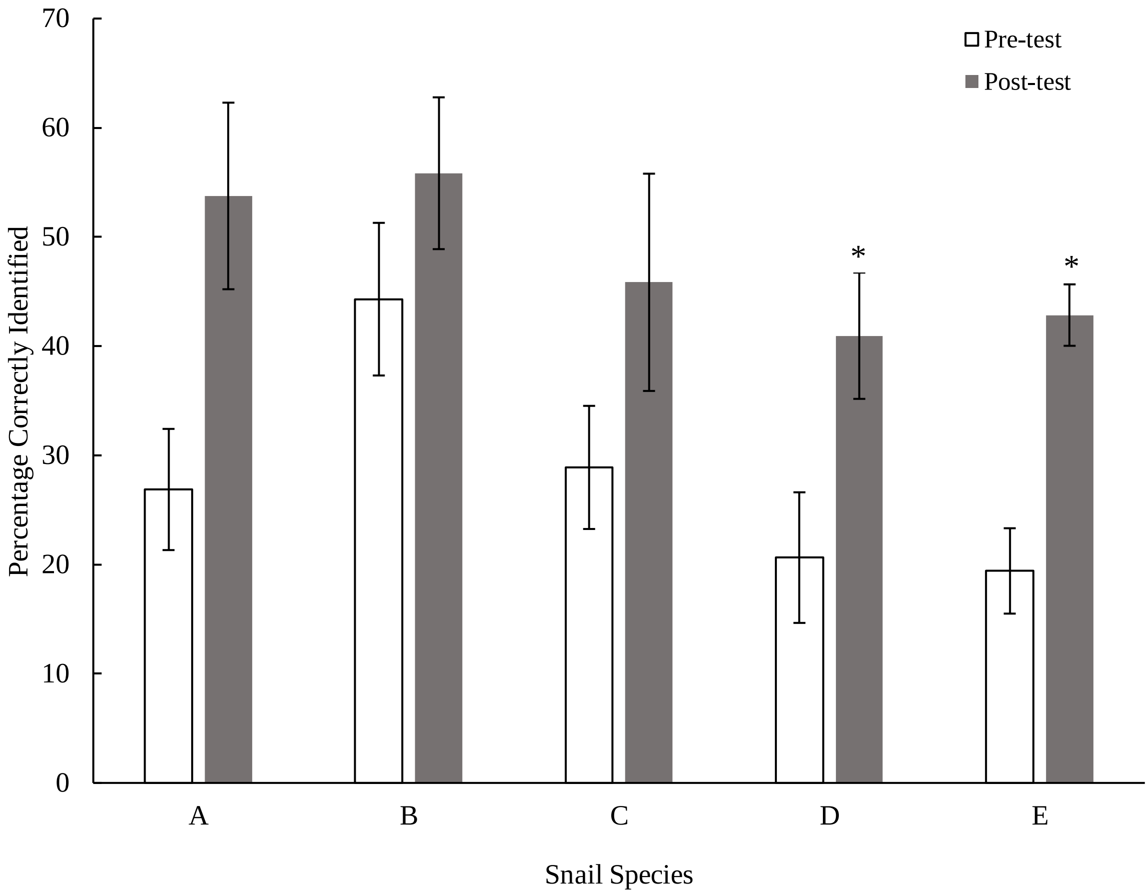

Figure 4.8: Average percentage of correctly identified rocky shore snails from pre-test survey (white bars) and post-test survey (grey bars) ± SE ($n_{(pre\text{-}test)}$ = 130, $n_{(post\text{-}test)}$ = 126). The snails are in the following order; A – Turret Snail (*Maoricolpus roseus*), B – Cats Eye Snail (*Lunella smaragda*), C – Spotted Top Snail (*Diloma aethiops*), D – Horn Snail (*Zeacumantus subcarinatus*) and E – Lined Whelk (*Buccinulum* sp.). Asterisks indicate significant difference between pre- and post- surveys

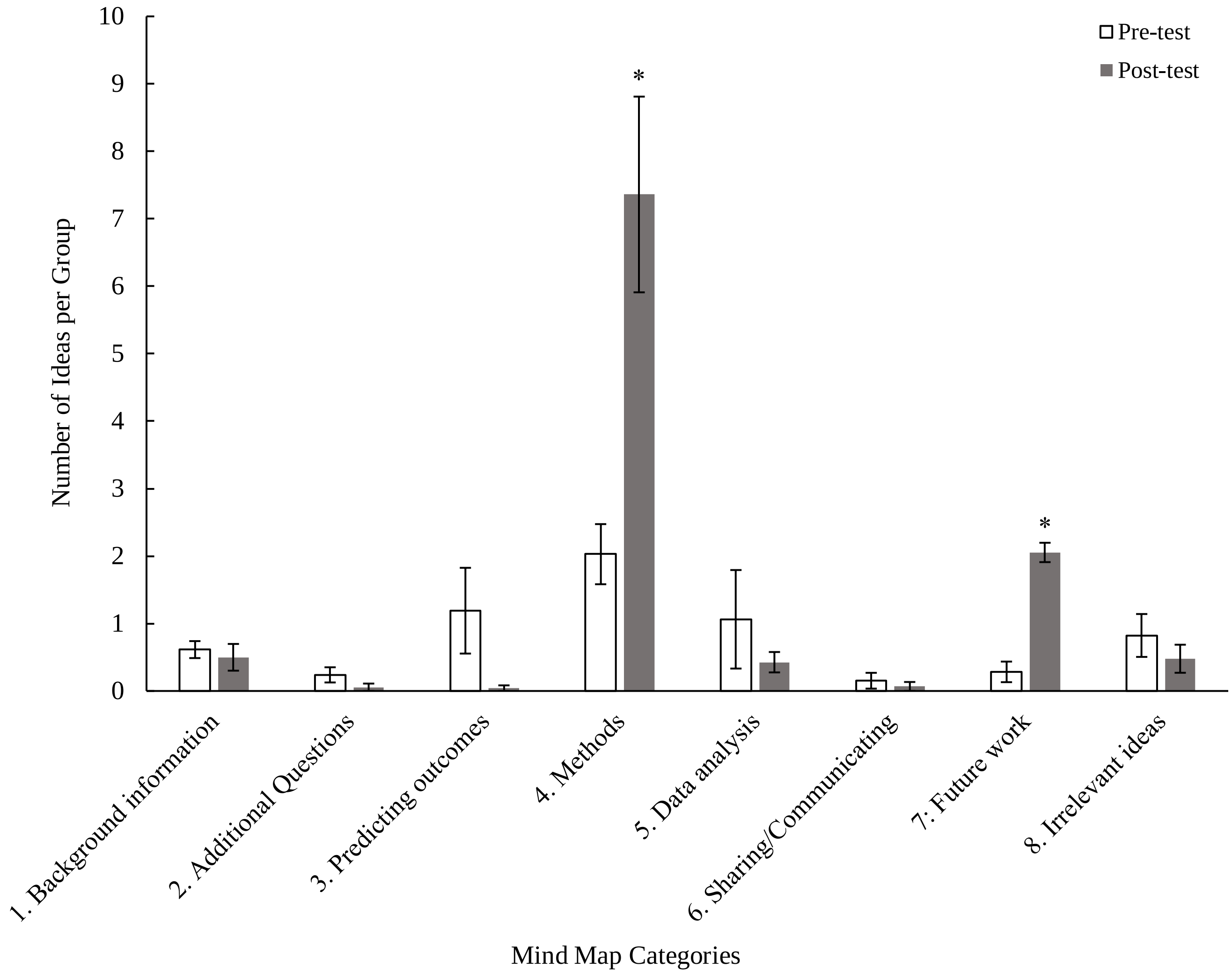

Figure 4.9: Average number of ideas per group for the eight mind map categories for pre-test (white bars) and post-test (grey bars) mind maps ± SE ($n_{(pre\text{-}test)}$ = 130, $n_{(post\text{-}test)}$ = 126). Asterisks indicate significant difference between pre- and post- mind maps

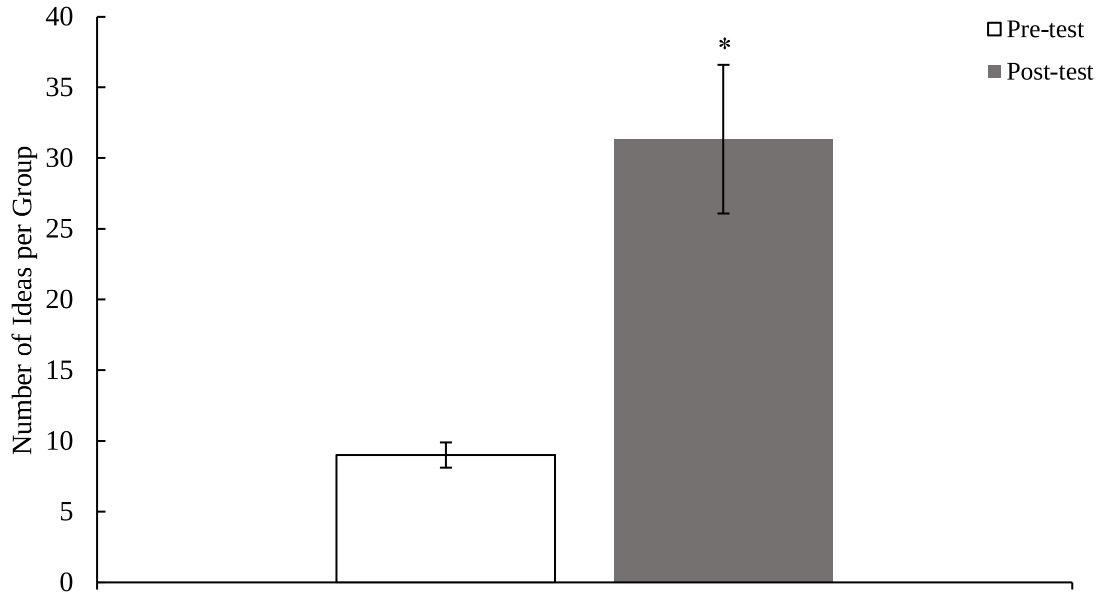

Figure 4.10: Average number of ideas recorded per group on pre- and post- test mind maps ± SE ($n_{(pre\text{-}test)}$ = 130, $n_{(post\text{-}test)}$ = 126). Asterisk indicates significant difference between pre- and post- mind maps

Table 4.1: t-test results for the average percentage of correct identification for five rocky shore snail species between the pre-test and post-test ($n_{(pre-test)}$ = 130, $n_{(post-test)}$ = 126)

Factor	t stat	df	p-value
Pre-test vs Post-test	6.16	4	<0.01

Table 4.2: t-test results for the average percentage of correct identification for five rocky shore snail species between the pre-test and post-test with adjusted p-value using the Holm method ($n_{(pre-test)}$ = 130, $n_{(post-test)}$ = 126)

Snail Species	t stat	df	Adjusted p-value (Holm method)
Cats Eye Snail (*L. smaragda*)	1.50	5	0.386
Turret Snail (*M. roseus*)	2.98	5	0.092
Horn Snail (*Z. subcarinatus*)	6.90	5	<0.01
Spotted Top Snail (*D. aethiops*)	1.39	5	0.386
Lined Whelk (*Buccinulum* sp.)	6.30	5	<0.01

Table 4.3: Two-way ANOVA results for the number of students achieving 100% identification of rocky shore snails in the pre-tests and post-tests ($n_{(pre-test)}$ = 130, $n_{(post-test)}$ = 126)

Factor	df	F	p-value
Secondary school age vs Primary school age	1	7.00	<0.05
Pre-test vs Post-test	1	22.94	<0.001
Age x Test	1	9.92	<0.01

Table 4.4: t-test results for the average number of ideas per group between pre-test mind maps and post-test mind maps ($n_{(pre-test)}$ = 31, $n_{(post-test)}$ = 31)

Factor	t stat	df	p-value
Pre-test mind map vs Post-test mind map	1.23	8	0.255

Table 4.5: t-test results for the average number of ideas per group for eight mind map categories as well as average number of ideas per mind map between the pre-test and post-test with adjusted p-value using the Holm method ($n_{(pre-test)}$ = 130, $n_{(post-test)}$ = 126)

Mind Map Category	t stat	df	Adjusted p-value (Holm method)
1. Background information	-0.506	5	1.00
2. Asking additional questions	-1.58	5	0.877
3. Predicting outcomes	-1.79	5	0.804
4. Methods	4.62	5	0.046
5. Data analysis	-0.89	5	1.00
6. Reporting back	-0.66	5	1.00
7. Future work	6.92	5	<0.01
8. Irrelevant ideas	-1.05	5	1.00
Average number of ideas	4.48	5	0.046

4.4 DISCUSSION

4.4.1 Assessment of Scientific Skill Development Using Species Identification

Species identification has been tested in some citizen science projects (Bloniarz & Ryan, 1996; Delaney et al., 2008; Ratnieks et al., 2016), however this has not been done with multiple or small organisms nor completed in the presence of a scientist in these studied. As was expected, the correct identification of common rocky shore snail species increased significantly over the course of the project. A significant increase in the rate of correct identification between pre- and post-test was observed in *Z. subcarinatus* (horn snails) and *Buccinulum* sp. (lined whelks). Correct identification of these species was relatively low (around 20%) in the pre-test and increased by at least two-fold in the post-test. This improvement was positive as students often had some difficulty identifying these species on the shore (pers. observation). It was thought that there would be a significant different between the pre- and post-test identifications of turret snails (*Maoricolpus roseus)* because *M. roseus* have a distinctive, conical shape as well as their ecological importance was discussed in the classroom as *M. roseus* is less common on the rocky shore compared to the other snails in this exercise as it prefers sandy and muddy shore environments (Carson & Morris, 2017). Despite not being statistically different, there was still a large increase in the percentage of correct identifications of turret snails from 26.87% (pre-test) to 53.75% (post-test).

It was predicted that age would influence the percentage of correct identifications. This was because of the large age range of participants involved (the difference in students' ages was a maximum of 11 years), which assumed that students would have a range of abilities that could make the task more or less difficult for them. There were differences in the proportion of students achieving 100% correct identification between primary school (aged five to eleven) and secondary school (aged thirteen to fourteen) students. This may be due to the fact that there were fewer secondary school students involved in the project and all students were of similar ages. However, research by Delaney et al. (2008) found slightly contrasting results in comparison to this research, where students aged seven to eight and thirteen to fourteen years of age had the ability to differentiate two crab species with 80% and 95% accuracy respectively. Although not significant, the results from the primary aged students in this study showed that they have the ability to learn new information and complete tasks well (including identifying and collecting data on the rocky intertidal).

There was also an increase in the number of students that were able to identify all five species correctly which rose from two in the pre-survey to nineteen in the post-survey. Despite this increase, the proportion of students being able to identify all five snails correctly is relatively low. Overall, the post-test results for the percentage of correct identification of snail species was on average 47%. Although this result shows improvement in students' ability to identify common rocky intertidal snails, it is much lower than expected.

It should be noted that species identification assessed students individually, unlike during data collection when students worked in groups (of at least three) and had an accompanying adult, identification resources available and could query if the group was struggling to identify a particular organism on the shore. This exercise accurately assessed how much the students had learnt throughout the project (without resources present). If guides were available and students able to clarify their answers with adults or other students (as they did in the field) then it is expected that the percentage of correct identification would increase.

The identification assessment of selected snail species also demonstrates retention of knowledge learnt during the project. The summary sessions were held in August, at least five weeks (including a two-week holiday) after the last time the students encountered snails as part of the study in June. This highlights the importance of practical learning when retaining knowledge for species identification. It would be of interest to complete this assessment again in future with less time between data collection sessions and the species identification assessment.

Nonetheless, the change in the students' ability to identify five species of snails reflects an increase in their knowledge about individual species. This knowledge contributes to the students' ability to collect accurate/relevant data and reflects positively on the quality of the training that they received. This also highlights the importance of training (including prior exposure to targeted species) to citizen science.

4.4.2 Assessment of Science Knowledge Developed with the Use of Mind Maps

Although there were no statistical differences between pre- and post-test mind maps, there was a noticeable shift in the distribution of the students' ideas. At the beginning of the project, student responses were focussed on planning the project (background information, asking additional questions, predicting outcomes from the dredging). At the end of the project, students' ideas shifted to more specific thinking on how they would answer the question (i.e. the resources, equipment and techniques they may need to complete their research). This was shown by the students' focuses surrounding ideas relating to the categories 'methods' and 'future work' – both of which showed significant increases between pre- and post -mind maps. In terms of the New Zealand curriculum, this study applies three of the five science capabilities: gathering and interpreting data, engaging with science and using evidence (Ministry of Education, 2014). The patterns in the responses given by the students demonstrate their ability to plan to carry out their own research project as prompted by the question; "As a scientist, how could we investigate the impact of dredging and sediment disturbance on rocky shore life (pre-test) or subtidal life (post-test) in Otago Harbour?" This was shown by the increase in ideas relating to methods/how they could collect data. The students' responses demonstrated that they are able to transfer their learning of science and the scientific method into collecting data in a different context and identify aspects of the scientific method. It was expected that there would be an increase in the average number of ideas for data analysis and sharing/communicating ideas between the two sessions, however no significant change was observed and the average number of ideas per group for these two categories remained low (less than one). This shows that in future, these areas of the project need further support and perhaps exercises that could engage students more in analysing and sharing the data.

Although pre- and post-tests surveys were used to evaluate education outcomes in other studies (for example Bonney et al., 2009), the application of mind maps in citizen science to assess skill development and understanding, to our knowledge, has not been done before. A Norwegian study by Stokhof et al. (2018) used pre- and post-test mind maps to measure individual and collective learning outcomes (in relation to core concepts of the national curriculum) for students aged eight to twelve years. This study found that the majority of students progressed in learning the core curriculum and were able to add more examples, ideas and associations to the curriculum (Stokhof et al., 2018). Other investigations that used mind maps to evaluate student learning found similar results such as children with learning impairments had improved recollection on a focus topic over time (Salzberg-Ludwig, 2008) and college students had improvements in their knowledge of geography, tourism and history (Hou et al., 2016).

Students generated significantly more solutions to the question provided in their post-test mind maps. The average number of ideas per mind map rose three-fold between the pre- and post-test assessments. Although one teacher voiced concern over the equality of contributions of students within groups (M. Direen, personal communication, 16/10/2018), many groups provided evidence that most students participated in the activity. This was shown by colour-coding of answers (i.e. one colour represented one student), students' initials were placed next to branches and different hand-writing was observed.

4.4.3 Teacher Evaluation of the Science Capabilities

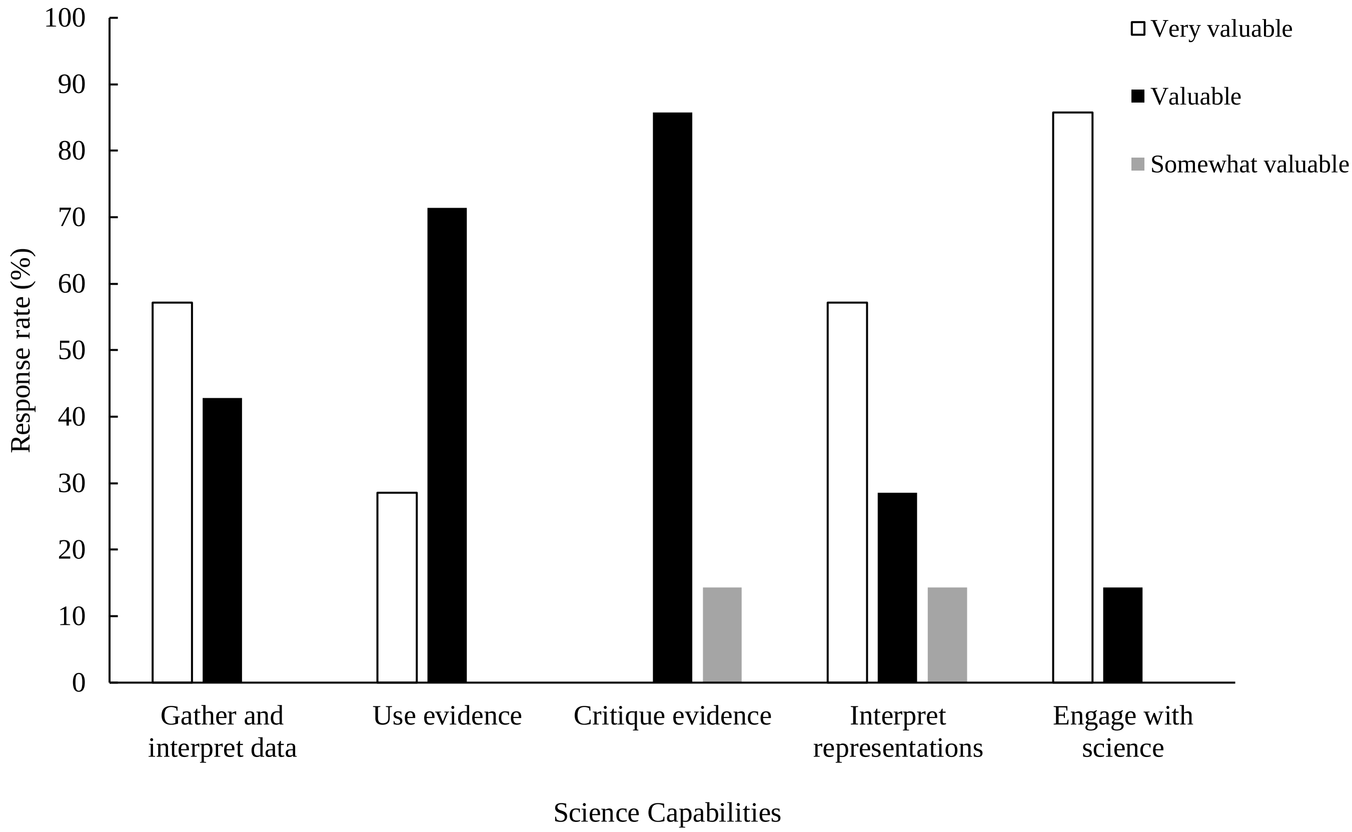

Figure 4.11: Anonymous responses from teachers involved in the facilitated citizen science project in 2018 rating how valuable they though the project was in developing science capabilities (from the 'Nature of Science' section in the New Zealand Curriculum) (n = 7)

Teachers rated how valuable they thought the project was in terms of developing the science capabilities under the topic 'Nature of Science' (Fig 4.11). These capabilities are described as "the weaving strand" through the science curriculum in New Zealand (Ministry of Education, 2007). Most teachers thought this project was 'valuable' or 'very valuable' in meeting the five capabilities, with 'engaging with science' being the most highly-rated science capability being met by the project (Fig 4.11). Participating and engaging in science with support of practicing scientists has been identified as areas that are in need of development for the future of science education in New Zealand (Gluckman, 2011). Therefore, facilitated citizen science projects could be useful for addressing this issue by providing insight into potential science-based careers or opportunities by doing relevant science with the support of scientists. Citizen science projects offer an educational opportunity which allows students to 'be scientists' collecting data in a real-world setting (Evans et al., 2005; Shah & Martinez, 2016). This has been identified as motivating for some students in reviews of different citizen science programs on the West Coast of the US (Ballard et al., 2017).

Other valuable learning areas for students (as commented on by teachers) were; "local understanding", "link to work in mathematics that extended and supported learning in statistics and percentages", "developing observation skills", "seeing the connection between human activities and habitats" and "developing an understanding of how important all areas of marine life are". Having a "hands-on" experience with a "local project" was also repeatedly mentioned as being a valuable learning aspect for both students and teachers. There was one response that listed the project as "somewhat valuable" in meeting the science capabilities "interpret representations" and "critique evidence", however this was for the school that had the youngest students involved. This may be a less relevant area of the curriculum to younger students as there may be other skills that take priority instead.

In a previous review of New Zealand science education, the need for more inquiry-based learning and open investigation as well as providing in-depth reasoning as to why students are completing specific tasks is described (Haigh et al., 2005). Scientific inquiry has been noted as an under-developed skill in undergraduate science students (Oberhauser & LeBuhn, 2012; Shah & Martinez, 2016; Mitchell et al., 2017) and so earlier familiarity with this kind of learning is needed (Oberhauser & LeBuhn, 2012). This study supports the view that citizen science could provide opportunities for science skills and understanding to be developed (as well as other areas in the curriculum).

4.4.4 Future Directions

In future, it would be of interest to assess the identification of a wider range of species groups (i.e. not just snails) that include commonly misidentified species (see Chapter Two in this thesis for further suggestions). As aforementioned, the identification assessment should also be completed much sooner (ideally one week after the student's final data collection as opposed to five weeks after). It would also be interesting to try to quantify how much the teachers extended the learning in the classroom, as although teachers were encouraged to extend learning in the classroom this did not always happen. Extending concepts outside of the time allocated with the scientists would likely contribute to the students' level of learning. However, quantifying this would be difficult as problems with standardising performance across all schools could arise as the extended context was not controlled by the scientists. Obtaining feedback from teachers on how valuable they thought the mind maps were as an assessment tool and how useful they think mind maps could be in the future would be helpful.

The low level of change in comments around 'data analysis' and 'reporting back' in the pre- and post-mind map activity may be due to the fact that although the students were actively involved in data entry and preliminary analysis, they were instructed on what to do. In future, students may benefit from the opportunity to take a more active role in the development of the assessment criteria or techniques for data analysis and have further opportunity to develop these skills. This could be achieved through increased support from scientists, possibly in the form of longer data entry sessions, with the additional time used to facilitate discussion about what the data can show us (prior to the summary sessions).

Teachers also commented that students struggled when entering data into the database and that more time, support and explanation for the data entry session would be beneficial. Furthermore, teachers suggested it would be helpful if they knew in advance what mathematical knowledge students would require so they could cover this in class. Teachers also noted in their anonymous surveys that entering and analysing the data collected was where students learnt the most science skills including; “data input/entry”, “repetitive analysis”, “graphing skills” and “interpretation of data” and “critical thinking”.

Scientists’ knowledge of science and the marine environment was known although this was not the case for the parents and teachers involved. Therefore, it would be of interest to investigate the prior knowledge that the teachers and parents have with respect to the marine environment. This information could be used to answer whether their knowledge of has impact on the quality of the data. Alternatively, it would also be interesting to investigate the engagement level, quality of the data collected and learning outcomes with reduced scientific presence and reduced community support throughout the project. Investigation into the impact of group size on both data quality and learning outcomes as well as comparing age (with a greater sample size of older students) would also be worthwhile.

4.5 CONCLUSIONS

Evaluation is crucial to assessing the outcomes of a project. In citizen science, most science-led projects look at science outcomes, meaning that learning and education outcomes are viewed as less important. This may also be affected by the difficulties associated with investigating learning outcomes in-depth. This study looked at two unique ways to assess knowledge of the science process and identification skills using mind maps and a mix and match survey, respectively, in school-aged students (aged five to fourteen). The ability of the students' to correctly identify five common rocky intertidal snail species improved after participating in the facilitated citizen science project. There was a significant difference in the pre- and post-tests for two species of snail – horn snail (*Z. subcarinatus*) and lined whelk (*Buccinulum* sp.). Pre and post-test mind maps demonstrated a shift in students' focus from preparing to conduct their own investigation (background information and planning) to how they would carry out their investigation (methods and future directions). The mind maps highlighted that analysing and reporting data were two areas that students need more experience with, which is supported by comments from teachers. The skill identification assessment showed that students can, with proper training and support, learn to accurately identify different species, which contributes to collection of quality data. Furthermore, involving students in real research assists the development of knowledge of the science process. These findings show that the educational outcomes of this project are being met and identifies where extra support should be allocated. This information will be useful for future marine education and citizen science projects.

CHAPTER FIVE
GENERAL DISCUSSION

This thesis set out to assess the strengths and weaknesses of the scientific and educational outcomes of a facilitated citizen science project. A three-year facilitated citizen science project investigating the potential impacts of sediment (disturbed from a capital dredging project) on the rocky intertidal was used as a case study. The key findings from this thesis show that students (aged seven to fifteen) were able to identify a similar number of species per m^2 as scientists, with the exception of the small, sessile species that are found in large aggregations. It was also found that visual and photographic methods were the most consistent between students and scientists when quantifying sediment accumulation. Although the equipment used to estimate sediment accumulation was fairly basic, the methodology used to collect sediment may have been too complex for the students involved. Finally, students (aged five to fourteen) demonstrated improvement and retention of identification skills after participating in the project as well as showed development in their knowledge of planning future investigations.

5.1 Applicability of Citizen Science

Citizen science has the potential to partially the gaps left open by insufficient environmental management as volunteers have the ability to collect data on a scale that is otherwise unattainable to scientists (Hochachka et al., 2012; Mitchell et al., 2017; Parrish et al., 2018). This can be particularly applicable for routine monitoring that requires broad scale data to be collected, such as natural resource management (Sbrocchi, 2014). Engaging with citizen scientists would be particularly useful for developing long-term data sets that monitor change over time (Dennis et al., 2017), impacts of restoration (Peters et al., 2015b; Peters et al., 2016), climate change (Aceves-Bueno et al., 2017) and gathering baseline data for future activities (Peters et al., 2015a; Peters et al., 2016). If coupled with education and/or policy, this can open up more opportunities for engagement with the general public as well as support and involvement from other stakeholders (aside from scientists and volunteers). The importance of including a range of stakeholders is shown in this case study, which collaborated with local and national government as well as the general public. Although gathering information on the overall state of the harbour was a priority, there were also educational and social benefits, of the project which assisted in getting groups involved in the facilitated citizen science project. By having a diverse support network, this has allowed the operation of the project to run relatively smoothly and set itself up for on-going monitoring.

Citizen science is in no way a full replacement for professionally collected data but rather can complement and enhance scientific research (Koss et al., 2009; Dickinson et al., 2010; Dennis et al., 2017; Freiwald et al., 2018). As stable funding for long-term scientific research projects is highly difficult to obtain (and often rare) (Lovett et al., 2007; Müller et al., 2010), citizen science can assist in collecting data at broad and fine spatiotemporal scales, which is needed for addressing large scale conservation issues (Burgess et al., 2017). Sometimes having a more simplistic monitoring approach that can be sustained over time will provide data that is more beneficial for resource managers in the long run. Ideally, resource managers would adopt the combination of consistently collected data with regular periods of intensive monitoring. This approach would work well in the continuation of monitoring the intertidal in Otago Harbour.

Although citizen science covers a range of subjects and scales (Theobald et al., 2015), not all projects will be applicable for environmental monitoring. Caution is advised when using data from citizen science (Kamp et al., 2016; Dennis et al., 2017), as goals and outcomes for citizen science projects may not seek out to achieve exclusively science outcomes or science outcomes at all (Parrish et al., 2018: Phillips et al., 2018). Therefore, citizen science projects need to be assessed on the fitness to the intended purpose/use of the data collected (Wiggins et al., 2011; Parrish et al., 2018; Guerrini et al., 2018). This should be determined by the specific objectives and outcomes of the citizen science project. Outcomes also should be used to determine what standard the data quality should be held to – for example, if a project has scientific outcomes then data should assumedly be acceptable if standards are within scientific ranges (Wiggins et al., 2018; Parrish et al., 2018). Not all citizen science projects will achieve their set scientific outcomes (Shirk et al., 2012; Freiwald et al., 2018) or some projects will choose to prioritize different outcomes above scientific rigour (Shirk et al., 2012). Therefore, project design, particularly the strength and replicability of the methodology, should also be assessed when considering the application of citizen science collected data for environmental monitoring.

There are few frameworks or guides available that can objectively assess citizen science projects depending on their general outcomes. Assessments surrounding scientific outcomes are often simplistic or limited in their applicability (Wiggins et al., 2018) and there are few in-depth assessments for measuring other outcomes such as education and learning (Wiggins et al., 2018; Phillips et al., 2018) or evaluating personal development of participants (Wiggins et al., 2018). Firstly, projects need to become more transparent in their objectives (Grey et al., 2016) so that assessments for their applicability to the broader outcome categories (as described by Shirk et al., 2012) can be completed more effectively. This could then allow for the development of a more intricate framework to assess citizen science projects independently.

5.2 Roles in Citizen Science

In other research validating citizen science collected data, participants have undergone training prior to collecting data (Delaney et al., 2008; Edgar & Stuart-Smith 2009: Koss et al., 2009; Cox et al., 2012; Gillet et al., 2012). Training prior to collecting data has been identified as an important factor to ensure data quality (Ahrends et al., 2011; Ratnieks et al., 2016; Ellwood et al., 2017). A review of citizen science papers found that around 75% of citizen science projects (from 63 papers) provided training prior to volunteers collecting data (Aceves-Bueno et al., 2017). Most project organisers invest their time and funding into training volunteers and producing training resources. Direct training coupled with informative training material is the most effective way to teach accurate identification of different insect species to volunteers (Ratnieks et al., 2016). Other researchers have identified that well-designed resources and training from scientists can also assist in improving the quality of data collected by volunteers (Kosmala et al., 2016; Burgess et al., 2017). Investing time into training and preparing the students to collect data made up a large proportion of this case study and it is likely to be a contributing factor to the quality of the data collected during the citizen science project. However, as the size of citizen science projects grow, online training for projects focussed on species identification is now becoming more commonly used and thought to be as effective as in-person training (Parrish et al., 2018).

Online training could be a worthwhile investment for the future of this case study. It would reduce the scientist’s time in the project but more importantly, online training would provide a resource for teachers to refer back to in the classroom. This could encourage schools to continue monitoring with less assistance from the scientists. One of the issues with this project is that it may have been ‘too facilitated’ and so teachers may not feel confident enough to lead any aspect of the project without the scientists present. This could potentially be an issue to the longevity of this particular citizen science project, which no longer has a source of secure funding, and so will rely on the initiative of teachers and schools to contact the scientists co-ordinating the project if they wish to continue monitoring.

As this was a facilitated citizen science project, scientists were involved in every step of the project and were in charge of managing the participants as well as maintaining quality of the data collected. Quality control was completed by consistently reviewing the data collected by students through the project from data collection to final analysis. Prior to entering the data into a database, scientists manually went through the students’ data sheets to check for potential errors such as questionable identification (i.e. species unlikely to be found on the rocky shore) and spelling mistakes. Scientists also checked the online database after students had entered their data to ensure the correct species had been selected. Towards the end of the project, two scientists were tasked with identifying inconsistencies across the three years of the project so that the data could be standardised in order to create one large dataset (which was made up of approximately 20,000 individual data points). This process also required an in-depth understanding of the data, particularly the metadata, which was often used to distinguish surveys from one another. Standardising the data took a significant amount of the scientists’ time as well as required refined statistical knowledge and skills to filter through the dataset. For every hour spent with the schools, the lead scientist spent approximately three to four hours sorting through and analysing the data. Navigating a dataset of this size was highly complex and without access to people with these skill sets analysis of this data would have been exceptionally difficult, which demonstrates the necessity of the role of the scientist.

Citizen science often goes beyond just collecting data (Parrish et al., 2018). Many citizen science projects stem from members of the general public expressing concern about observed changes over time in their community and/or local environment (Parrish et al., 2018). Therefore, their interest actually lies in using the science for action (e.g. management or policy). If participants can see their contributions being used for a purpose, this may encourage further engagement from individuals or communities. To influence policy development and management decisions, it is recommended that managers are also engaged with citizen science projects from the beginning so they can provide input of a robust project design from a management point of view.

However, using citizen science collected data is difficult as resource managers are unlikely to accept non-validated citizen science data (Delaney et al., 2008; Conrad & Hilchey, 2011; Sbrocchi, 2014). Similar circumstances would be likely to occur if citizen science data were to be used for legal action. Though there are examples of using citizen science for legislation (Conrad & Hilchey, 2011), this requires substantial effort by the public, scientists, managers and policy makers (Sbrocchi, 2014). This highlights the importance of collaboration between different groups for monitoring to be effective and worthwhile for all involved.

5.3 Challenges in Citizen Science

As mentioned, one of the most difficult things regarding larger citizen science projects (particularly ones collecting broad-scale data) is the significant size and complexity of datasets that are produced. Often the data manipulation requires the employment of someone with the right skillset and statistical knowledge to help organise and structure the data for statistical analysis, which often falls to the scientists. Many community groups cannot do this kind of work themselves and this can be a barrier to using the data in official reports or sharing it with resource managers and scientists (Peters et al., 2015a). Even if community groups provide unprocessed datasets to managers, they may be put off using the data because the dataset is unfamiliar to them (hence they may not totally understand it). If the dataset has not been cleaned it may be ignored as unstructured citizen science collected databases may present high levels of observer bias (Kamp et al., 2016) and be difficult to interpret.

Working in or around the marine environment comes with extra challenges (Theobald et al., 2015; Cigliano et al., 2015; Chatzigeorgiou et al., 2016), which is likely why marine-focussed projects have been under represented in citizen science (Theobald et al., 2015). However, due to the importance of the marine environment to a broad range of people (Martin et al., 2016b; Pearson et al., 2016) there is great potential to engage them with citizen science. This has been recognised in Australia and has been reflected in the increasing number of marine-focussed citizen science projects (Martin et al., 2016b). Marine citizen science projects do rely on some creativity to get participants involved, but the best way to engage people in citizen science is to incorporate the skills, jobs and hobbies that marine users already have (Martin et al., 2016a). Research has found that those who engage with marine citizen science often already have an interest in science, therefore the true challenge lies in engaging users that distance themselves from science (Martin et al., 2016b).

Citizen science, although considered less expensive than professional scientific research, is not cost-free (Chandler et al., 2017). Long-term monitoring, regardless of who does it, still requires some level of financial support (Sergeant et al., 2012). However, funding is one of the main limiting factors for ongoing monitoring projects (Hays et al., 2005; Cox et al., 2012). Funding for citizen science is also very competitive (Koss et al., 2009; Peters et al., 2015b; McKinley et al., 2017) and there are few guaranteed multi-year funding opportunities in place. Funding is particularly needed in the early stages of projects (Hyder et al., 2015) where time and resources are required to engage with the first wave of volunteers, setting up data management systems and prompting projects and associated events. For schools, funding is extremely important as it is required to train and support teachers, transport students to study sites, provide scientific equipment and provide a platform for engagement with other organisations. Therefore, a lack of financial support can reduce opportunities to expose children (and their wider communities) to hands-on science and monitoring their own areas.

5.4 Future of Citizen Science in New Zealand

Despite the potential of citizen science being recognised by central government in New Zealand (Ministry of Business Enterprise and Employment et al., 2014; Peters 2018), citizen science is very much still at a grass roots/community-based level (Peters et al., 2015a). A study in New Zealand identified challenging areas for community environmental monitoring groups as; a lack of technical skills, uncertainty of setting up monitoring programs and limited funding (Peters et al., 2016), implying that there needs to be more support available to monitoring groups. Therefore, the development of a long-term budget and strategic plan for the future of citizen science in New Zealand is needed (Peters et al., 2016; Storey et al., 2016). Having a source of secure funding would allow for projects to plan for more than one cycle of routine monitoring. Monitoring groups would then be able to invest in better project planning and the development of training and supporting resources, resulting in a more robust study design. Additionally, a national framework or strategy could create a more aligned network of projects in New Zealand. This could enhance collaboration and communication between not only citizen science groups in New Zealand but also national and regional partners. As of 2019, there has been progress to develop a strategic plan for citizen science in New Zealand, as prompted by the Citizen Science Symposium in Wellington in April 2018 (pers. observation). When developing this strategic plan, it is suggested that the representatives from the national education sector are also included in order to advance the incorporation of citizen science into classrooms around the country. Including central government organisations/groups tasked with natural resource management would also be recommended so that issues where citizen science could be applied can be identified. By including these two stakeholders in the planning process, this may open up opportunities to support regular citizen science monitoring in the future.

Citizen science in New Zealand is not as advanced as in other areas of the world that have national/regional organisations including Europe, the United States and Australia. Asian and Ibero-American (excluding European nations) regions are also in the process of establishing regional citizen science networks. This is something that New Zealand could strive towards. Increasing connectivity between monitoring groups, scientific organisations and governments both nationally and regionally should be made a priority. Greater connectivity would assist in increasing engagement of individuals and organisations and hopefully encourage collaboration between groups, thus growing citizen science in New Zealand. Examples of robust citizen science are uncommon in New Zealand and so the research presented in this thesis could be used as an example of positive engagement, from both scientists and the community, as well as demonstrating ways to assess projects and aid in quality control of the data.

Technology is an important part of society and should be utilised to increase the number of people engaging with citizen science by making it more accessible. Funding opportunities should be provided to assist in the development and maintenance of both apps and websites. Incorporating technology – particularly apps and smartphones – into citizen science has been highly recommended in other research (Shah & Martinez, 2016; Hecker et al., 2018; Peters, 2018). Examples of using robust automatic techniques to assess quality of data entered online by citizen scientists includes flagging systems for unexpected data (e.g. invasive species, species out of normal range) (Dickinson et al., 2012; Bonter & Cooper, 2012) or verification of photographs by other members in the online community (Parrish et al., 2018). There have also been discussions on the potential of automatic photo recognition technology (Wiggins et al., 2011). Adopting these mechanisms (or similar) for online citizen science projects could greatly reduce the reliance upon the scientists to complete quality control measures. Therefore, improvement and further development of the technology used in this case study is highly recommended and could reduce the time and costs to engage scientists over the long term.

Further investigation and detail into how citizen science fits into the curriculum is needed to further connect the classroom with hands-on science. Opportunities in education to learn and practice using the scientific method (and 'being a scientist') are limited and costly, yet students need to engage with real-world examples to be global citizens and contribute to society through engaging with meaningful science. Schools provide an excellent opportunity to engage with under-represented groups in citizen science through both students and their parents whilst providing unique yet relevant educational experiences. The relationship of age and task complexity should be explored. This study found that students as young as five were capable of collecting species abundance data and assessing substrate cover (given support from adults). Comparable data quality has been found between younger students and scientists in research by Delaney et al. (2008) (identifying and sexing crab species) and van der Velde et al. (2017) (identifying and classifying marine debris). Other studies have suggested placing entry restrictions on age and skill-level for citizen science (Freiwald et al., 2018) but this again will vary based on the desired outcomes of the project. Selectivity of participants may come at a cost and create bias by turning the public away from engaging with science as well as reducing the diversity of participants.

5.5 Summary

This facilitated citizen science project has succeeded in collecting scientifically validated data, engaging multiple stakeholders into a monitoring project and demonstrated educational links to the national curriculum. This project is a strong case study of not only facilitated citizen science in New Zealand but also of a marine facilitated citizen science project. The regular monitoring of this project has contributed three years' worth of regular monitoring of the rocky intertidal that otherwise would not have been collected (as scientists gathering data as required by the consent for the dredging project only assess the rocky intertidal every three years) (Port Otago Limited, 2010). Information from the project not only provides more detail on the fluctuations of sediment in the intertidal (and the short-term effects of this) but also contributes to knowledge of the ecology of the Otago Harbour for both scientists and the wider public involved. This project also had the opportunity to bring multiple stakeholders together – local government, the Port, scientists, and the wider community – which over time eased tensions surrounding the issue of the dredging. Support for on-going monitoring for schools that have previously been involved is available, however, this will not be possible at the same intensity as provided in the first three years of the facilitated citizen science project. This is due to lack of funding as well as reduced availability of the lead scientist.

The applicability of citizen science projects to environmental monitoring is determined by the outcomes of the project as well as the robustness of the study design. Evaluation of projects is thus needed to measure results and assess if they meet the outcomes (as that will be what determines success). Outcomes and project design will determine whether citizen science is appropriate for environmental monitoring. In terms of this research, citizen science could be a useful tool to monitor the environmental impacts of a capital dredging project on the rocky shore – provided there is adequate training and available resources as well as on-going support. Continued monitoring of the rocky intertidal within the harbour is highly recommended as it has both scientific and educational benefits. By evaluating the case study used in this thesis, strengths and weaknesses of the project have been identified which can improve future approaches to not only this facilitated citizen science project but also be used as a case study for other citizen science projects in a similar context. Collaboration is a huge part of taking citizen science beyond collecting data and to engaging with management and this will be the key to unlocking the potential that citizen science holds for natural resource management.

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APPENDICES

Appendix 2.1: List of species identified by scientists and students on the rocky intertidal in Otago Harbour during a three-year facilitated citizen science project. NB: Scientists did not use the same database as students therefore species classifications may be different (n = 199)

SCIENTIFIC NAME	COMMON NAME
ALLOSTICHASTER INSIGNIS	Sea Star, Three and Three
ACANTHOCHITONA ZELANDICA	Chiton, Hairy
PETROLISTHES ELONGATUS	Crab, Half
HORMOSIRA BANKSII	Seaweed - Brown, Neptunes Necklace
POLYSIPHONIA SP	Seaweed - Red, Filamentous (*Polysiphonia*)
TETHYA BURTONI	Sponge, Golf Ball (*T. burtoni*)
ISCHNOCHITON MAORIANUS	Chiton, Brown
MACROCYSTIS PYRIFERA	Seaweed - Brown, Bladder Kelp
DILOMA ARIDA	Snail, Black Top-Shell (*Diloma arida)*
OPHIOMYXA BREVIRIMA	Sea Star, Brittle (*Ophiomyxa brevirima*)
LUNELLA SMARAGDA	Snail, Cats Eye
SCUTUS BREVICULUS	Limpet, Duck's Bill
ZEACUMANTUS SUBCARINATUS	Snail, Horn-Shell
OSTREA CHILENSIS	Oyster, Bluff: Oyster Rock (*Ostrea chilensis*)
SPIROBRANCHUS CARINIFERUS	Worm, Blue Tube
CODIUM FRAGILE NOVAE-ZELANDIAE	Seaweed - Green, Branching Velvet Weed
HALICHONDRIA SP	Sponge, Encrusting
ISOCLADUS ARMATUS	Isopod, Sea Slater
ELZERINA BINDERI	Bryozoan, Flexible
HAUSTRUM LACUNOSUM	Snail, White Whelk (*Haustrum lacunosum*)
ANONYMUS KAIKOURENSIS	Worm, Flat
CYSTOPHORA SPP	Seaweed - Brown, Zig-zag
CORALLINA SP	Seaweed - Red, Encrusting Coralline
COSCINASTERIAS MURICATA	Sea Star, Spiny
MYTILUS GALLOPROVINCIALIS	Mussel, Blue
TETHYA BERGQUISTAE	Sponge, Golf Ball (*T. bergquistae*)
AUSTROVENUS STUTCHBURYI	Cockle
HEMIPLAX HIRTIPES	Crab, Stalk Eyed Mud
EPOPELLA PLICATUS	Barnacle, Plicate
BUCCINULUM LINEA	Snail, Lined Whelk
HEMIGRAPSUS SEXDENTATUS	Crab, Common Shore
NOTOPLAX VIOLACEA	Chiton, Girdle
CHITON GLAUCUS	Chiton, Green
CORALLINA OFFICINALIS	Seaweed - Red, Erect Coralline (*Corallina oficinalis*)
CELLANA ORNATA	Limpet, Ornate
DISTAPLIA SP	Sea Squirt, Colonial Ascidian (*Distaplia* sp.)
UNDARIA PINNATIFIDA	Seaweed - Brown, Wakame

ADENOCYSTIS UTRICULARIS	Seaweed - Brown, Sea Sack
XENOSTROBUS NEOZELANICUS	Mussel, Little Black
DILOMA AETHIOPS	Snail, Spotted Top-Shell
CHAMAESIPHO COLUMNA	Barnacle, Columnar
ZOSTERA MUELLERI	Plant, Eelgrass
APLYSIA DACTYLOMELA	Sea Slug, Sea Hare (*A. dactylomela*)
BENHAMINA OBLIQUATA	Limpet, Pulmonate
BOSTRYCHIA ARBUSCULA	Seaweed - Red, Moss
DENDRODORIS CITRINA	Sea Slug, Lemon Nudibranch
CYCLOGRAPSUS LAVAUXI	Crab, Smooth Shore
AULACOMYA MAORIANA	Mussel, Ribbed
FAMILY NEREIDIDAE	Worm, Rag
XIPHOPHORA GLADIATA	Seaweed - Brown, Strap (*X.gladiata*)
BOTRYLLOIDES SP	Sea Squirt, Colonial Ascidian, (*Botrylloides* sp.)
AUSTROLITTORINA ANTIPODUM	Snail, Blue-banded Periwinkle
XIPHOPHORA CHONDROPHYLLA	Seaweed - Brown, Strap (*X. chondrophylla*)
HALICARCINUS SP	Crab, Pill Box (*Halicarcinus* sp)
HAUSTRUM SCOBINA	Snail, Oyster Borer
MAORICOLPUS ROSEUS	Snail, Turret
SIPHONARIA AUSTRALIS	Limpet, Common Pulmonate
CELLANA RADIANS	Limpet, Radiate
FORSTERYGION LAPILLUM	Fish, Common Triplefin
SYPHAROCHITON PELLISERPENTIS	Chiton, Snakeskin
HEMIGRAPSUS CRENULATUS	Crab, Hairy Handed
ISACTINIA OLIVACEA	Anemone, Olive
ANTHOPLEURA ROSEA	Anemone, Rock Pool
PYURA PACHYDERMATINA	Sea Squirt, Sea Tulip Ascidian
GALEOLARIA HYSTRIX	Worm, Red Tube
CORELLA EUMYOTA	Sea Squirt, Transparent
SEPIOLOIDEA PACIFICA	Squid, Bobtail
AUSTROMINIUS MODESTUS	Barnacle, beaked
AUSTROLITTORINA CINCTA	Snail, Brown Periwinkle
SIGAPATELLA NOVAEZELANDIAE	Limpet, Circular Slipper
GRACILARIA CHILENSIS	Seaweed - Red (*Gracilaria*)
ATALACMEA FRAGILIS	Limpet, Fragile
ASTEROCARPA COERULEA	Sea Squirt, Solitary Ascidian (*Asterocarpa coerulea*)
CALLORIA INCONSPICUA	Brachiopod, Lampshell (*Calloria inconspicua*)
ECTOCARPUS SP	Seaweed - Brown, Filamentous
DIDEMNUM SP	Sea Squirt, Colonial Ascidian (*Didemnum* sp.)
PAPHIES AUSTRALIS	Clam, Pipi
FORSTERYGION NIGRIPENNE	Fish, Estuarine Triplefin
CYANOBACTERIA	Algae, Blue-Green
ULVA SP	Seaweed - Green, Sea lettuce
ANTHOPLEURA AUREORADIATA	Anemone, Mudflat : Anemone, Tidepool
DORIS WELLINGTONENSIS	Sea Slug, Warty Nudibranch
PERNA CANALICULUS	Mussel, Green-Lipped
ANTHOTHOE ALBOCINCTA	Anemone, White Striped
ACTINIA TENEBROSA	Anemone, Red Beadlet
FAMILY: SERPULIDAE	Worm, Spiral Tube

LEPAS ANATIFERA	Barnacle, Pelagic
GASTROSCYPHUS HECTORIS	Fish, Cling
SCYTOSIPHON LOMENTARIA	Seaweed - Brown (*Scytosiphon lomentaria*)
ACANTHOCLINUS FUSCUS	Fish, Olive Rock
ULVA INTESTINALIS	Seaweed - Green, Intestine weed
EUIDOTEA STRICTA	Isopod, Sea Centipede
COMINELLA GLANDIFORMIS	Snail, Mudflat Whelk
ALLOSTICHASTER POLYPLAX	Sea Star, Four and Four
ASTEROCARPA HUMILIS	Sea Squirt, Waxy Sea Squirt
FAMILY MEMBRANIPORIDAE	Bryozoan, Rock Encrusting
PATIRIELLA SP.	Sea Star, Cushion
CRYPTOCONCHUS POROSUS	Chiton, Butterfly
RHODYMENIA SP	Seaweed - Red (*Rhodymenia*)
PACHYMENIA DICHOTOMA	Seaweed - Red (*Pachymenia*)
AMPHIPODA GAMMARIDAE	Amphipod, Sandhopper (*Amphipoda gammaridae*)
SARCOTHALIA LIVIDA	Seaweed - Red, Carrageenan Weed (*S. livida*)
ASTEROCARPA SP.	Sea Squirt, Solitary Ascidian (*Asterocarpa* sp.)
PLAXIPHORA CAELATA	Chiton, Zigzag
DIPLODONTIAS MILIARIS	Sea Star, Common Toothed
PYROPIA SP	Seaweed - Red, Karengo
DILOMA SUBROSTRATA	Snail, Mudflat Top-Shell (*D. substrata*)
PENTAGONASTER PULCHELLUS	Sea Star, Biscuit
BATEDOTEA ELONGATA	Isopod, Sea Centipede (*Batedotea elongata*)
CELLANA STRIGILIS	Limpet, Striated
CALANTICA VILLOSA	Barnacle, Gooseneck
PLEUROBRACHIA PILEUS	Jellyfish, Comb
PHYLUM NEMERTEA	Worm, Ribbon
CALLIOSTOMA PUNCTULATUM	Snail, Beaded Top-Shell
ASTROSTOLE SCABRA	Sea Star, Seven Armed
APLIDIUM SP.	Sea Squirt, Orange Colonial Ascidian
CHAETOMORPHA COLIFORMIS	Seaweed - Green, Sea Emerald
MACOMONA LILIANA	Clam, Wedge
COMINELLA MACULOSA	Snail, Spotted Whelk
RHIZOCLONIUM IMPLEXUM	Seaweed - Green, Filamentous (Rhizoclonium)
ADAMSIELLA CHAUVINII	Seaweed - Red, Shredded paper algae
DICTYOTA KUNTHII	Seaweed - Brown
CODIUM CONVOLUTUM	Seaweed - Green, Encrusting Velvet (*C. convolutum*)
METACARCINUS NOVAEZELANDIAE	Crab, Cancer
CODIUM DIMORPHUM	Seaweed - Green, Encrusting Velvet (*C. dimorphum*)
NOTOACMEA ELONGATA	Limpet, Green
MICRELENCHUS HUTTONII	Snail, Top-Shell (*Micrelenchus huttonii*)
TAENIOGYRUS DUNEDINENSIS	Sea Cucumber, Burrowing
CARPOPHYLLUM PLUMOSUM	Seaweed - Brown, Featherweed
PELICARIA VERMIS	Snail, Ostrich Foot
MUSCULUS IMPACTUS	Mussel, Nesting
PHASCOLOSOMA ANNULATUM	Peanut Worm (Sipunculid)
FISH EGGS, TRIPLEFIN	Fish Eggs, Triplefin
SPLACHNIDIUM RUGOSUM	Seaweed - Brown, Gummy Weed
MEMBRANIPORA MEMBRANACEA	Bryozoan, Seaweed Encrusting

FAMILY ORBINIIDAE	Worm, Orbiniid Polychaete
GIGARTINA CLAVIFERA	Seaweed - Red, Carrageenan Weed (*G. clavifera*)
SCYTOTHAMNUS AUSTRALIS	Seaweed - Brown (*Scytothamnus australis*)
COLPOMENIA SP	Seaweed - Brown, Sac
OCTOPUS HUTTONI	Octopus, Midget
BRYOPSIS SP	Seaweed - Green, Fern
EUPHIONE SQUAMOSA	Worm, Sea Mouse
LEUKOMA CRASSICOSTA	Clam, Ribbed Venus
PAGURUS NOVAEZELANDIAE	Crab, Hermit (*Pagurus novaezelandiae*)
ALCITHOE ARABICA	Snail, Arabic Volute
ALLOIODORIS LANUGINATA	Nudibranch, Dorid
ATAGEMA CRINATA	Nudibranch, white (*Atagema carinata*)
CNEMIDOCARPA BICORNUTA	Sea Squirt, Orange Ascidian (*Cnemidocarpa bicornuta*)
CORYNACTIS AUSTRALIS	Anemone, Jewel
DILOMA SP.	Snail, Black Top-Shell (*Diloma* sp.)
EPIACTIS THOMPSONI	Anemone, Striped
EULALIA MICROPHYLLA	Worm, Paddle (*Eulalia microphylla*)
EURYSTOMELLA SP.	Bryozoan, Orange Encrusting
FAMILY AMPHIURIDAE	Sea star, brittle (Family Amphiuridae)
FAMILY GLYCERIDAE	Worm, Blood
FAMILY MALDANIDAE	Worm, Bamboo
FAMILY MURICIDAE	Snail, Whelk Egg Cases (*Ambiguous* sp.)
FAMILY OWENIIDAE	Worm, Oweniid
FAMILY TEREBELLIDAE	Worm, Spaghetti
HALICARCINUS INNOMINATUS	Crab, Pill-box (*H. innominatus*)
LAMILLARIA CEREBROIDES	Lamellaria
MICRELENCHUS TENEBROSUS	Snail, Small Black Top-Shell (*Micrelenchus tenebrosus*)
MICRELENCHUS TESSELATUS	Snail, Top, Black and Yellow Spotted
NOTOMITHRAX SP.	Crab, Camouflage (*Notomithrax* sp.)
ONITHOCHITON NEGLECTUS	Chiton, Etched
OPHIONEREIS FASCIATA	Sea Star, Mottled Brittle
ORDER AMPHIPODA	Amphipod, Sandhopper
ORDER NEOGASTROPODA	Snails, Whelk (juveniles)
PAGURUS SP.	Crab, Hermit (*Pagurus* sp.)
PHYLUM BRYOZOA	Bryozoan, Encrusting
SALPA SPP.	Salp, Barrel
TETHYA SP	Sponge, Golf Ball
THEMISTE (LAGANOPSIS) MINOR HUTTONI	Worm, Peanut (Themiste)
VENERUPIS LARGILLIERTI	Clam, Oblong Venus
XYMENE AMBIGUUS	Snail, Whelk , Ambiguous Trophon
ACA	Seaweed - Red, Erect Coralline
CYSTOPHORA SCALARIS	Seaweed - Brown, Zig-zag (*C. scalaris)*
CYSTOPHORA TORULOSA	Seaweed - Brown, Zig-zag (*C. torulosa*)
LICHINA PYGMAEA	Lichen, Black Seaweed
SARCOTHALIA CIRCUMCINCTA	Seaweed - Red, Turkish Bath Towel
SIPHONARIA OBLIQUATA (EGGS)	*Siphonaria obliquata* (Eggs)
AUSTRIVENUS STUTCHBURYI	Cockle/Clam, Little-neck
HAUSTRUM ALBOMARGINATUM	Snail, Oyster Borer (*Haustrum albomarginatum*)
	Limpet, Small

CANTHARIDUS HUTTONII	Snail, Top-Shell (*Cantharidus huttonii)*
	Colonial Diatoms
CAPITELLA CAPITATA	Worm, Rag (*Capitella capitata*)
LINUCULA HARTVIGIANA	Clam, Nut
	Snail, Small Top
GOLFINGIA MARGARITACEA	Worm, Peanut (Golfingia)
GYMNOGONGRUS TORULOSUS	Red Seaweed

Appendix 4.1: Criteria used for coding student pre- and post-test mind maps

Section 1: Background Information

1.1 Own Resources

- 1.1a Own research (using technology/resource)
- 1.1b Own experiences/prior knowledge of environmental issues
- 1.1c Own observations

1.2 Asking others for information

- 1.2a Asking the community
- 1.2b Asking authorities (e.g. Port Otago, councils)
- 1.2c Asking scientists
- 1.2d Asking teachers/parents

Section 2: Additional Questions

2.1 Surrounding animal response/s

2.2 Surround plant response/s

2.3 Surrounding environmental parameters and the environment

Section 3: Predicting outcomes (from the dredging)

Section 4: Methods

4.1 Study design

- 4.1a Collecting data (counting, observing, collecting samples etc.)
- 4.1b Make a plan (When/where to go and how)
- 4.1c More than one sampling trip to the same site
- 4.1d Replication of quadrats
- 4.1e Multiple sites to investigate
- 4.1f Measure environmental parameters (e.g. temp, salinity, clarity)
- 4.1g Counting number of species (biodiversity)
- 4.1h Investigating substrate
- 4.1i Measuring human activity in the harbour

4.1j Monitoring species over time

4.1k Experimental manipulation

4.1l Follow set protocol

4.2 equipment

4.2a Equipment used during S&S

4.2b Equipment not used during S&S

Section 5: Data analysis

5.1 Enter the data onto a website/database

5.2 Data analysis

5.2a Statistical analysis

5.2b Graphs/visual displays

5.2c Compare data

5.2c1 Compare data (one parameter)

5.2c2 Compare data (multiple parameters)

5.3 Pooling data

Section 6: Sharing/communicating

6.1 Target audience (for reporting back)

6.1a The school

6.1b Wider community/public

6.1c Authorities (e.g. council, Port Otago)

6.1d With the scientists

6.2 Methods used for reporting

6.2a One method

6.2b Multiple methods

6.3 Type of information reported

6.3a Conclusions based on data collected

6.3b Research justification

6.3c Best practice methods

Section 7: Other conclusions

7.1 Critiquing data

7.1a Got data, needs expansion

7.1b Accuracy of their own work

7.2 Ideas for action

7.2a Related to dredging

7.2b Related to the environment

7.2c Related to animal care

Section 8: Irrelevant ideas