Literature Review of Mussel Restoration and Sea Star Management in Ohiwa Harbour

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Cover Photo:
Sea star, Kura Paul-Burke

Executive Summary

This literature review has been carried out to address Phase Two options in the draft Working Mussel Action Plan that resulted from Section 2.1 of the Ōhiwa Harbour Strategy.

This literature review critically summarises and assesses the information available on mussel restoration and sea star management both nationally and internationally. The review identifies the different methods utilised in restoration programmes and sea star control programs and how successful they were. Although the resources reviewed have been conducted in many differing international geographical contexts, conclusions are drawn about the applicability to the restoration of the mussel beds and the predation by sea stars within Ōhiwa Harbour.

Some theories and reasons behind the mussel decline will also be briefly mentioned, alongside differing views on increased sea star populations worldwide, and potential uses of sea stars.

Recommendations made will argue the suitability of the methods for the Ōhiwa Harbour, and this literature review could lead to the construction of a Kutai Technical Design to help adapt a method for the Ōhiwa Harbour.

The primary objectives of this investigation are to analyse and critique existing literature surrounding mussel restoration and sea star management methods, so an appropriate method can be adapted and utilised, to improve the existing problem of mussel beds declining due to predation by sea stars in Ōhiwa Harbour, New Zealand.

The resources used and an analysis of the information they provide are listed in the annotated bibliography in Appendix 1.

Contents

Introduction

The Ōhiwa Harbour Strategy contains an action, 2.1, to investigate shellfish populations and advocate for sustainable shellfish management. This action has led to a proposal to build on investigations already carried out, into the state of the mussel beds in the Ōhiwa Harbour. Previous surveys of the western mussel beds found that mussels were in decline and were being heavily predated by sea stars. An action plan proposed by Kura Paul-Burke has been adopted by the Ōhiwa Harbour Strategy Coordination Group. This plan proposes a further survey of the western mussel beds, a survey of the eastern mussel beds, the state of which is currently unknown, and literature reviews of mussel bed restoration and management of sea star populations.

This report contains, in Section 1, a review of the current state of knowledge worldwide of mussel bed restoration as reported in the literature and in Section 2, a review of methods investigated to control sea star populations as reported in the literature. A brief assessment is also made for the possible application in Ōhiwa Harbour of the methods described.

Some commentary about the possible reasons for mussel decline and sea star population increase is also provided alongside potential uses of sea stars.

Section 1 - Mussel restoration

Introduction

Green-lipped mussels (*Perna canaliculus*) were once abundant in New Zealand. Extensive reefs on soft sediments environments all but disappeared throughout New Zealand, particularly in the Firth of Thames by the year 1980, due to increase in sediment input and overfishing (McLeod, 2009). Starfish predation is believed to be one of the leading causes of mussel declines within the Ōhiwa Harbour.

Mussels undertake many roles within their aquatic environments and are important as ecosystem engineers influencing nutrient cycling, water filtration, habitat structure, biodiversity and food web dynamics (McLeod, 2009).

A survey of the mussel populations in Ōhiwa Harbour from 2007, 2008 and 2009 observed an increase in size class but a reduction in abundance. There was an estimated 115 m mussels in 2007 and by 2013 it had decreased to 1.2 m. All the mussels present in 2013 were also juvenile. A predator, the eleven-armed sea star were not mentioned in the 2007 survey, yet by 2008 and 2009 they were present in such significance, that they formed a line across the entire width of a mussel bed. The sea star also mimicked the sizing of mussels and was mainly juvenile in 2013. In 2013 it was found that 88% of original mussel bed boundaries were no longer present and 98% of original mussel population had disappeared (Paul-Burke & Burke, 2013).

This section is split into Part 1: Caging, Part 2: Translocation/relocation and Part 3: Reef construction. The most commonly used methods to re-establish or re-populate mussel beds both nationally and internationally are introduced. The methods are explained using various projects that applied and adapted the method for their specific purposes. Although projects may have differing circumstances surrounding the conception, this section also details the alternative processes of each method. Providing a different way in which each method is employed is important, so we can adapt both the best suited method and processes. This section also includes materials, monitoring, results, discussion and possible application in Ōhiwa Harbour. Finally, a very brief look at potential causes of mussel declines is explored. This investigation is assumed in the hope of restoring the formerly abundant but now severely reduces reefs of green-lipped mussels within the Ōhiwa Harbour.

Part 1: Caging

Numerous reports have been produced cataloguing the variety of methods used to try and restore mussel populations worldwide, one such method is caging.

Method

McLeod, Parsons, Morrison, Taylor and Le Port (2011), Hua (2015), Gray & Kreeger (2014) applied caging of mussels to determine whether the habitat was suitable for restoration. McLeod et al (2011) designed a study in the Firth of Thames, New Zealand to test whether historical mussel reefs could still sustain adult mussels. After the reefs failed to recover 50 years after dredging was stopped, it was hypothesized that the muddy sediments that replaced the benthic environment was unsuitable habitat. Twenty five adult green-lipped mussels were transplanted into cages on the seafloor, at three sites within the Firth of Thames on the 15 September 2008.

Similarly, Hua (2015) assessed the habitat suitability in three sites in the Clinch and Powell Rivers in June 2008. Three differing types of release of juvenile wavy-rayed Lampmussel (*Lampsilis fasciola*), one of which was caging, was employed. Two cages placed into the substrate at the three sites had 100 Lampmussel placed within.

Gray & Kreeger (2014) surmised that caging of mussels was a good indication of stream capabilities to sustain mussel populations and was prudent to test, prior to investing in mussel reintroduction. Fourteen Eastern Elliptio Mussels (*Elliptio complanata*) were placed into four replicate cages 10 m below the substrate within five streams in Pennsylvania, West Branch Brandywine Creek, Red Clay Creek, East Branch White Clay Creek, Middle Branch White Clay Creek and Chester Creek in October 2007.

Brumbaugh, Beck, Coen, Craig and Hicks (2006) acknowledge that exclusion devices can limit the stress of predation on shellfish, so caging can enhance species particularly susceptible to this stress.

Tauranga Harbour

Caging has been used in the Tauranga Harbour, New Zealand, as a way to check levels of oil and metal contamination in water. Pacific Oysters have been caged and deployed throughout the harbour, collecting data to add to a five year sediment accumulation study (Bay of Plenty Regional Council, 2015).

Oysters are filter feeders, so if there’s pollution in the water column it will be absorbed into the oyster tissues. The oysters have been brought in from Ōhiwa Harbour and deployed at ten sites throughout the Tauranga Harbour. They’ll be retrieved in February for tissue sample analysis and compared with tissue samples from the Ōhiwa source population, as well as wild oysters which will also be collected from Tauranga Harbour (Bay of Plenty Regional Council, 2015).

Bait Snifter Berley Dispensers bought for $15 were the main cages, but they were also limited so cages had to be constructed using mesh net, cutting the wire into squares and rectangle cages held together by zip-ties. Ten oysters were placed within each cage and then zip-tied closed. Cages were attached to differing structures throughout the harbour, including channel markers and near the Kauri Point Jetty. They were secured using a combination of rope and zip-ties. A. Platt (personal communication, January 18, 2016).

Materials and process

McLeod et al (2011), Hua (2015) and Gray & Kreeger (2014) had various requirements when selecting sites to place cages for their respective research. All sites selected either had live mussels present, Hua (2015) or were acknowledged historical sites in which mussels were once present. Sites with a constant depth of 5 m were desired, so they were located at varying distances from the shore, McLeod et al (2011) whilst Hua (2015) based sites on habitat characteristics and conservation interests requiring flowing water reaches in a forested landscape with vegetated riverbanks.

Cages were constructed from varying materials but a desire to allow water flow through the cages without any unduly affect, saw McLeod et al (2011) Hua (2015) and Gray & Kreeger (2014) utilising mesh nets. Although McLeod et al (2011) completely utilised mesh net securing them with reinforced iron pegs, Hua (2015) had a plastic storage container with only the lid and bottom of the container replaced by two sheets of plastic mesh screening, secured by zip ties. Gray & Kreeger (2014) cages consisted of an industrial dishwashing tray with plastic netting covering the top, sides and bottom of the cage.

Mussels sourced from the same longline from a mussel farm found within the study confines, collected at a depth of 3 m and sizes ranged from 60 mm - 120 mm, McLeod et al (2011) and using nine month juvenile mussels propagated and cultured at the Freshwater Mollusk Conservation Centre, Hua (2015) eliminates unnecessary prejudice that could occur. Interestingly, Gray & Kreeger (2014) opted for using mussels of varying adult sizes from two differing source sites Ridley Creek and Brandywine Creek, although the latter provided the most. In doing so, results that occur could be influenced by the difference in conditions and factors between the two sites.

Mussels were cleaned, measured and some assigned a plastic identifying tag before release McLeod et al (2011), Hua (2015) and Gray & Kreeger (2014).

Additionally, both Hua (2015) and Gray & Kreeger (2014) added substrate to the bottom of the cages for the mussels and to help anchor cages. One half of the cage separated with a mesh divider was filled with dried mussel shell for alternate spat settlement for mussels, McLeod et al (2011).

Monitoring

McLeod et al (2011) had a monitoring regime of 500 days with sampling occurring three times. Whilst sampling occurred four times, in August and October of 2008, and June and September of 2010 respectively, Hua (2015) and during December 2007, March 2008, June 2008, and October 2008 Gray & Kreeger (2014).

Monitoring programmes involved counting the number of live mussels and recording the maximum length of all tagged mussels for growth analysis, McLeod et al (2011) whilst Hua (2015), did so to calculate survival and growth rates. Three untagged mussels were also randomly selected then removed for condition analysis, McLeod (2011). Gray & Kreeger (2014) collected three mussels per cage and transported them to the laboratory for total wet weight and shell height analysis. Tissue was also excised for further analysis.

Results

The experiment saw mussels grow an average of 19 mm in length with no significant difference among sites. Results suggested that adult mussels can survive and grow in the Firth of Thames despite the muddy seafloor that has replaced mussel reefs, and so the initial hypothesis was rejected, McLeod et al (2011).

Hua (2015) acknowledged that caging was the most effective method in determining site suitability for mussel restoration. This mark-recapture method concluded that Powell River was unsuitable habitat for mussels. Monitoring caged mussels was found to be a tool of value for evaluating the suitability of candidate streams for *E. complanata* Gray & Kreeger (2014).

Discussion

Caging is deemed a method that helps to validate a site for mussel restoration; it isn't a permanent restoration technique that is employed. Caging can indicate whether a site is suitable and then alternate methods are employed permanently. Caging was successful for both programs, obtaining results that helped immensely for future endeavours of the projects.

Considerations when looking into these reports is that Hua (2015) and Gray & Kreeger (2014) focused on freshwater mussels in streams, whereas McLeod et al (2011) is on soft sediment surfaces in the Firth of Thames. This is more similar and relatable to mussels in the Ōhiwa Harbour, with the same species focused on as well. McLeod et al (2011) insights are still limited due to their prioritisation of adult mussels only.

Losing cages is a recurring problem with cages unable to be located in all of the experiments commenced. Measures to prevent this would need to be prioritised as results are skewed and less accurate. Cages are a good method that ensures losses are attributed solely to mortality as opposed to emigration. They prove necessary to maintain mussels in a single site where they could be reliably relocated, as trials showed that mussels were highly mobile McLeod et al (2011).

Both Hua (2015) and McLeod et al (2011) disregarded prevention of predation as influencing the results. Although caging does inhibit predation on mussels, which is exactly what is needed within the Ōhiwa Harbour, during the monitoring programs undertaken, mussel predation was observed only once and so results can still be referenced to free-released mussels, Hua (2015).

An alternative interpretation of results suggesting that predation is restricting mussels from the FOT seafloor was overlooked, as only one starfish was observed close to the transplanted mussels. Snapper (*Pagrus auratus)* another prey species has also declined alongside the mussels, so excluding potential predators did not influence the results, McLeod et al (2011).

Possible application in Ōhiwa Harbour

The method of caging could have the desired outcome in Ōhiwa Harbour as it has proven successful for each individual study.

This method could prove cost effective also; ways in which to do so would be using easily accessible materials and products to build the cages. The problem of losing cages would be remedied using GPS devices imbedded in the cages, as a way to minimises costs of potentially replacing cages. Other such measures could include correctly placing the cages and fortifying them, so damages to the mussel beds will not occur, although it is still possible. Surveying will also need to be undertaken, to ascertain whether the cages are working and to maintain the cages. Caging is the only method uniquely suited to the situation in Ōhiwa Harbour, which is threats predominantly from predation. Prey species will be unable to access the mussels so they will have the change to grow. Considerations into sizing of caging would need to account for expected growth rates and increasing numbers of mussels; cages will also need to be built around existing mussels unlike the programs conducted.

Part 2: Translocation/relocation

Translocation and relocation is a recognised method in species restoration and has been adapted for mussel restoration. Relocation has been used as a conservation and management technique, as a way to recolonise areas that have been altered, polluted or have adversely affected species numbers.

Method

Carey, Jones, Butler and Hallerman (2015) focused on restoring endangered oyster mussels using a variety of methods, one of which was translocation.

Layzer & Scott (2006) relocated freshwater mussels aiming to re-establish populations. Harris, Babcock, Carls, Brodersen and Rice (1998) aimed to determine if manual restoration could effectively and practically accelerate the loss of petroleum hydrocarbons from mussels, after the Exxon Valdez crude oil spill in Prince William Sound, Alaska.

Dunn, Sietman and Kelner (1999) did a study evaluating relocations of Unionid (Bivalvia) whilst Cope, Hove, Waller, Hornbach, Bartsch, Cunningham, Dunn and Kapuscinski (2002), similarly discussed research into relocation of unionid mussels to in situ refugia, looking at the recovery and survival of four species.

Sheehan, Neves and Kitchel (1989) adapted translocation in a way similar to caging, as a way to assess if habitats can support mussels.

Kreeger & Thomas (2014) likewise undertook translocation as a way to ascertain whether there was a need for mussel restoration.

Clayton (2013) wrote a brief article on relocation in West Virginia Streams, distinguishing it as the easiest and most prominent method used in the region.

Carey et al (2015) undertook a study from 2005 to 2011 to reintroduce endangered oyster mussel *Epioblasma capsaeformis*, releasing a total of 1418 adult mussels into one site in the upper Clinch River, Virginia, using four release techniques. Mussel populations have severely declined due to habitat and water quality and various anthropogenic impacts. Success was measured based on the criteria of settlement of released individuals, post-release survival of individuals, and natural recruitment.

Layzer & Scott (2006) translocated 19,754 adult mussels of 19 species over three years between 1997 and 2000 into the French Broad River, Tennessee. Species selected have declined due to decades of operating dams along the river and its tributaries, as well as the introduction of zebra mussels *(Dreissena polymorph)* that established dense populations soon after their introduction, and extirpated local populations of native unionids in areas around North America.

Harris et al (1998) uniquely applied translocation as a way to clean up and reduce hydrocarbon concentrations in nine blue mussel *(Mytilus trossulus*) beds, in Prince William Sound.

Dunn et al (1999) evaluated seven translocation projects of unionid (Bivalvia). Three in St Croix River, the first in 1994 with 9,042 unionids translocated, 1995 saw 14,043 with the largest amount of 18,119 relocated in 1996. Meramec River had 4,514 unionids translocated in 1994, whilst there were only 202 translocated in Elk River, also in the year 1994. Wolf and Mississippi rivers had 26,337 and 644 translocated respectively in the years 1995 and 1997.

Cope et al (2002) studied species pimpleback *(Quadrula pustulosa pustulosa),* spike *(Elliptio dilatata),* Higgins eye *(Lampsilis higginsii)* and pocketbook *(Lampsilis cardium).* One hundred and fifty of each species were experimentally relocated to a control and situ refugia in two areas of the St Croix River of Minnesota and Wisconsin, United States of America (USA).

Sheehan et al (1989) selected seven sites within reaches in the Clinch and North Folk Holston River. Four large species were studied *Actinonaias ligamentina*, *A. pectorosa*, *Amblema plicata* and *Fusconaia subrotunda* and three small species *Villosa nebulosa*, *V. vanuxemensis* and *Medionidus conradicus*.

Kreeger & Thomas (2014) studied species *Elliptio complanata* and *Pygonodon cataracta* splitting them into six groups with a number of 13-19 of each species per group and an overall of approximately 33 mussels per group. They were released into six reaches of the Skippack Creek.

New Zealand

There are many news articles on mussel restoration currently occurring in New Zealand with translocation, a leading restoration effort.

In December 2013, as a part of the Revive, our Gulf Initiative of The Mussel Reef Restoration Trust focusing on the Hauraki Gulf, 7 t of green-lipped mussels were deposited off eastern Waiheke Island. Checks by divers confirmed their successful positioning on bare seafloor. The mussels were dropped by mussel barge and form seven, dense, “living room” size plots within an embayment. In March 2014, a survey showed the mussels had matted together over a once barren seafloor and been colonised by a range of marine species. Although some initial mortality and some expected predation by starfish and snapper, the mussels survived really well. There were approximately 580 live mussels per metre squared versus 18 dead mussels (Mussel Reef Restoration Trust, 2015).

In addition, millions of mussels rejected from supermarket supply due to not meeting size requirements, were then added to the previous restoration efforts, increasing the area ten-fold. Through a partnership with North Island’s mussels, two drops of 30 t - 40 t of mussels, three and a half million live adult mussels, were seeded over a period of two weeks in September 2014 (New Zealand Herald, 2014).

Likewise, Abadia (2014) wrote that Ngāti Whatua commenced their mussel restoration project by laying reef restoration beds of mussels in Auckland’s Okahu Bay in August 2014. A total of 40,000 mussels weighing 2 t were placed in the bay by Orakei Water Sports waka ama crew with help from about 60 volunteers. The mussels were donated by Westpac Mussels Distributors and Coromandel Mussel Kitchen in Ngati Paoa in Kaiaua.

Nordqvist (2014), a call from the putatara (shell trumpet) marked the start of the restoration efforts, as they attempt to enlist mussels to clean the popular stretch of water with aims of having self-generating mussel beds within 50 years.

Materials and process

Most translocations will occur in sites that either have live mussels present or did historically and they are either declining or virtually extinct.

Carey et al (2015) selected sites that were characterised by a diverse native-mussel community, darter fish hosts, suitable water quality and hydrological conditions and stable gravel substrates.

Layzer & Scott (2006) selected sites that would be a refuge for the mussels due to barge traffic, which zebra mussels utilise for transport, being restricted to the lower 3 kms of the French Broad River. The sites also had many of the mussel species selected already established within the river system, or were present historically. There was also a decision to introduce species that have never been present. Likewise Dunn et al (1999) selected sites that were not susceptible to zebra mussels, by using sites with established unionid populations present. Similarly, Cope et al (2002) focused on sites with large mussel densities already present, as a way to establish temporary refuges.

Harris et al (1998) selected beds that were polluted by the oil and had high concentrations of petroleum hydrocarbon within the sediments, underlying the mussel beds. Other factors also included the accessibility to the beds, whether substrate could be excavated or handled manually. Whether there were clean sediments nearby and a suitable area to disperse oiled sediments.

Sheehan et al (1989) selected sites that were previously polluted, and also looked at habitat characteristics, water quality, aiming for sites with depth ranging from 30 cm - 45 cm.

Kreeger & Thomas (2014) similarly based their sites on earlier observations of suitable habitat characteristics.

Carey et al (2015) translocated mussels from several healthy source populations in the Clinch River, Tennessee. In 2006, 201 mussels were translocated aged between four to five years, the oldest out of all the mussels, 2007 saw 197 mussels aged between three to four years translocated. In 2008, 218 mussels aged between three to four years were translocated, with 401 of the same age done in 2009. The year 2010 was identical to 2009. Mussels released annually ranged in sizes from 37.7 mm, 33.8 mm, 34.2 mm, 33.9 mm and 34.2 mm, respectively. In doing so, it could enable easier identification in sampling years, or was based purely on the availability of mussels. These methods prove interesting as the difference in variables, different ages, sizes, number of mussels and the source sites, could inadvertently influence results.

Harris et al (1998) involved mussels and sediments attached to byssal threads carefully removed with shovels or trowels, then transported into 20 litre buckets and spread out on sorbent pads. The sorbent pads were placed intertidally near each bed. To maximise stability when mussels were replaced, care was taken to avoid severing byssal threads connected to other mussels and substrate. After the beds were cleaned and oily sediments replaced, the mussels were repositioned as evenly as possible in original bed areas. Selected bed seizes ranged from 9 m^2 - 62 m^2. Mussels reattached to other mussels and the donor substrate after one high tide cycle.

Layzer & Scott (2006) collected mussels periodically from the lower Tennessee River. The mussels were than were placed in coolers, covered with wet burlap, and transported to the laboratory where they were hand scrubbed and then quarantined for 30 days. Rectangular plots were marked, measured and then delineated into a grid consisting of 1 m^2 plots.

Following quarantine, the mussels were again hand checked and then translocated to the French Broad River. In 1997, the mussels were inserted into the substrate of two plots. From 1998 through 2000, mussels were translocated to five rectangular plots. Plot sizes varied from 170 m^2 - 250 m^2.

Dunn et al (1999) removed mussels from an impact area and then transported them a short distance and placed them into existing unionid beds. Mirroring Layzer & Scott (2006) mussels were hand placed in the substrate in grids divided into one metre squared plots. They were distributed in a way that density wasn't increased more than twice,
Dunn et al (1999).

Sheehan et al (1989) sourced large mussel species ranging in size from 104 mm - 152 mm from Copper Creek whilst small species from 28 mm - 58 mm were sourced from Big Moccasin Creek. This distinction between difference source sites for different size classes is a much more suitable method compared to the unpredictability of methods operated by Carey et al (2015).

Mussels were transported on ice in coolers for up to four hours from the source sites to the translocation sites. Large mussels were worked into the substrate to properly orient them, whilst the smaller mussels were placed into mesh baskets that were flush against the river bottom. Fifty mussels were placed in each basket with translocations occurring in 1981, 1984 and 1985.

Kreeger & Thomas (2014) mussels were collected in 2012 from shallow sub-tidal habitats of the tidal freshwater zone of the Delaware River. They were then transferred by boat in coolers to the translocation sites where they were deployed.

Cope et al (2002) sourced mussels from the lower St Croix River for Site A whilst mussels for Site B were collected from a different part of the St Croix River. Grids sized 1 m^2 were again utilised like Dunn et al (1999) and Layzer & Scott (2006). There were five replicates with 10 mussels of each species hand placed within.

Most research projects involved mussels being tagged, identified and measured Carey et al (2015), Dunn et al (1999), Cope et al (2002) and Kreeger & Thomas (2014), which operated an electronic Passive Integrated Transponder or PIT. Additionally, Kreeger & Thomas (2014) and Cope et al (2002) scrubbed the mussels whilst the latter additionally weighed them. Dunn et al (1999) additionally aged the mussels translocated whilst Carey et al (2015) sexed the mussels.

Monitoring

Carey et al (2015) undertook sampling to estimate abundance and post-release survival. Sampling occurred in 2011 and 2012 and was a systematic sampling regime using a quadrat sized a quarter of a metre squared. Each quadrat was carefully hand excavated to a depth of 15 cm with the species found within, measured and sexed. Mussels found that had not previously been tagged, were tagged for identification, with age estimated and photographed. All mussels were then returned to their previous location.

Layzer & Scott (2006) utilised a stratified random sampling design evaluating mussels for survival rates annually. A random numbers table was used to generate sampling points and then a one metre squared quadrat was used in plots one and two and a quarter of a metre squared quadrat used for plots three to eight. Similarly to Carey et al (2015), the quadrats were placed on the substrate and then hand excavated, although the mussels were only identified and examined for marks before being returned, Layzer & Scott (2006).

Harris et al (1998) collected mussels for hydrocarbon analysis with mussel density populations estimated through 1995. Samples from 15-20 mussels from six to eight places were collected, cooled and frozen. Mussel densities were estimated by counting live mussels in two quarters of a quadrat sized a quarter of a metre squared at six randomly chosen locations. Mussel densities were estimated periodically through June 1996.

Dunn et al (1999) conducted the first monitoring a month after release, to determine if the unionids were buried and siphoning. Annual monitoring then occurred with selected grids sampled by disturbing the site up to 15 cm deep, collecting them, measuring and aging them before returning them. Interestingly, each site had a different amount of grids monitored during the first monitoring, whilst all the grids were measured in all sites during the second sampling period.

Cope et al (2002) did a quantitative assessment of mussel survival, recovery annually for two years in site A and for three years at Site B. All mussels within all cells were collected by the diver, placed into numbered dive bags, identified, enumerated, measured, weighed and replaced into their respective cells.

Sheehan et al (1989) monitoring occurred two weeks to estimate mortality and to ensure the mussels had properly established and then monitoring occurred annually in late summer or early fall. Monitoring or adult mussels were restricted to recording mortality in 1983 and 1984. The year 1985 saw random quadrat sampling occurring six times to count all living and dead specimens with the number of species, then averaged based on the results.

Kreeger & Thomas (2014) did monitoring twice. The first was started nine months after deployment in May 2013. The second monitoring occurred 15 months after in November 2013. Monitoring consisted of returning to each deployment location and sweeping the PIT tag reader, which can generate a return signal from the tag, if it is within 12" - 18" of the tag. When live mussels were detected, they were carefully removed from the bottom to confirm they were living, measured and then returned to the creek bottom.

Results

Carey et al (2015) found that among the four reintroduction techniques implemented, the translocation of adults and release of laboratory-propagated sub-adults (LPSA) were the most effective techniques for re-establishing populations of *Epioblasma capsaeformis*. Settlement, survival, and recruitment were observed only at site one where translocated adults and LPSAs were released.

Layzer & Scott (2006) found that based on the results, future attempts to re-establish mussels in other streams will be most successful if translocations occur at sites of existing or historical beds. Over 30 species of mussels can be re-established, but it is unlikely that 16 species can be re-established under the existing discharge regime within the area.

Harris et al (1998) concluded that manual restoration of mussel beds contaminated by oil was partially successful in reducing hydrocarbon concentrations. A significant decline in mussel density after restoration was reported also, but may have been due to regional declines rather than the restoration efforts.

Dunn et al (1999) concluded that resident unionids were abundant and recruitment was apparent in all relocation areas.

Cope et al (2002) found that based on results in the study, in situ refugia may be a viable tool for protecting and conserving populations of unionid mussels. The relocation of mussels to in situ refugia in the St Croix River was successful, based on the recovery and survival of mussels after two and three years of monitoring.

Sheehan et al (1989) results were not ideal, as the fate of most translocated mussels were unaccounted for. Large declines were recorded, believed to be caused by mortality.

Kreeger & Thomas (2014) summarised that two species of freshwater mussels were successfully reintroduced to Skippack Creek and to well in areas that are less prone to stormwater associated erosion. The water quality and food resources in Skippack Creek appeared capable of supporting freshwater mussels.

Discussion

Relocation or translocation is a way to re-establish mussel populations with the successes varying and susceptible to many factors. The method proved successful more so for some over others. Regardless, the results obtained are beneficial for other researchers or for future projects in the area.

Mussels in the Hauraki Gulf that were translocated and restored attracted predators but mussels are still surviving in acceptable numbers. This method could also prove very cost effective with many organisations happily donating free mussels for projects. Considerations when looking into these reports is that, not including the brief New Zealand section, they are all focused on freshwater mussels and not within New Zealand.

One problem with this method is that movement is not confined to the translocation plots, Layzer & Scott (2006), had to undertake monitoring in the substrate downstream of each plot on several occasions identifying active movement of the mussels. Dunn et al (1999) likewise identified movement as a problem, particularly in one site. Similarly to Cope et al (2002) who stated that low recovery in site B was due to the greater rate of movement of mussels into and out of the grid areas.

Kreeger & Thomas (2014) found that only about 10% of mussels were found to be still living in the exact deployment locations more than a year later. Due to the extensive time it takes to carefully cover the stream bottom, it was not feasible in the study to extend the search area farther downstream, in cases where mussels had possibly washed or moved out of the immediate deployment area.

Sheehan et al (1989) found that movement was not a problem in the study undertaken.

Cope et al (2002) studies showed that doubling or tripling the density of mussels at an existing mussel bed does not adversely affect survival of mussels in the natural or relocated populations. This is an advancement found in translocation methods as Dunn et al (1999) avoided doubling the density of mussels.

Sheehan et al (1989) acknowledged that using both adult and juvenile species was the method that would provide more insight and success for future studies, whilst Clayton (2013) stated the easiest method to restore mussel populations is relocating adult individuals from an existing population. This provides sexually mature individuals which naturally repopulate the new area. Biologists believe that stocking adult mussels, also improves the stream bottom for juvenile mussels.

Carey et al (2015) recommends that restoration efforts should focus on the release of larger individuals to accelerate augmenting and reintroducing populations and increase the probability for recovery of mussels.

Kreeger & Thomas (2014) used PIT tags but they were found to not be 100% accurate, since at least a few mussels were missed in earlier sampling periods, that were then found in later ones.

Layzer & Scott (2006) noted that choosing a suitable site is very problematic and recommended that one in which mussels are present or were historically, is the most successful.

Brumbaugh et al (2006) acknowledge that areas where reefs or target shellfish populations historically existed, would be ideal, as data on historic distributions can be obtained from published accounts, fishing records, and navigation charts or other bottom surveys. It is predicted that these sites are the most likely to be able to further support shellfish. It is noted that restoring the bottom may be necessary, like removing excess sediments or other debris in which Harris et al (1998) undertook.

Possible application in Ōhiwa Harbour

Translocation and relocation is the leading mussel restoration method in New Zealand and the most occurring around the world. The method has proven successful in the Hauraki Gulf which has a similar climate and substrate as the Ōhiwa Harbour and involved the same species, validating potential success if applied in Ōhiwa Harbour. It could prove cost effective if mussels were donated and could greatly enhance mussels and other species within the harbour. Re-establishing historical mussel beds in the Ōhiwa Harbour could be viable using this method, and it's appropriate to assume the higher abundance, the more likely they will survive in the face of predation. The method has proven successful both nationally and internationally.

Obtaining enough mussels to successfully undertake a project would be expensive if funding or organisations donating unneeded mussels weren't forthcoming.

Although there are mussels already present in Ōhiwa Harbour, they are highly susceptible to predation and have diminished significantly. Translocation from the current distribution to another part of the harbour could be considered, although it is assumed that sea stars would prove problematic throughout the harbour. If mussels were to disappear completely or decline to a degree where they cannot be sustained naturally, then translocation or relocation would also prove a useful method to successfully re-establish them. Translocation could also be considered to boost mussel numbers with the existing beds providing a good comparison. If viable habitat was found in Ōhiwa Harbour, free of predation by sea stars, the method of translocation to in situ refugia could be applied using mussels from the existing bed.

Similarly refugia could be created within the harbour where predator species are actively removed or where they are unable to reach mussels.

Part 3: Reef construction

Construction of three-dimensional reefs has become a widely used approach for enhancing the recruitment of and survival of shellfish and their associated reef communities.

Method

Schulte, Burke, Lipcius (2009) initiated studies into reconstructing oyster populations by using reef reconstruction, after native oyster populations collapsed worldwide due to overfishing and habitat destruction.

Luckenbach, Coen, Ross, Stephen (2005) discuss two different studies that utilised reef construction in oyster restoration.

Schulte et al (2009) focused on declined native oysters (*Crassostrea virginica*) and conducted a 35 ha field experiment by constructing native oyster reefs of three differing types, in nine protected sanctuaries throughout the Great Wicomico River in Virginia, United States in 2004.

Luckenbach et al (2005) conducted one study at four sites in the lower portion of the Rappahannock River, Virginia, USA, which is a mesohaline sub-estuary of the Chesapeake Bay. This study aims to address the role of spatial scale (ranging from a few meters to several kilometres) and the implications on the development of oyster populations and associated fauna. Whereas the other study compared the development of oyster populations and associated assemblages on constructed reefs to adjacent natural intertidal reefs over a six year period between 1995 and 2001. Conducted along the central coast of South Carolina, in Inlet Creek, a tributary adjacent to Charleston Harbour, three experimental reefs were constructed.

Materials and process

When considering which sites to carry out research, Luckenbach et al (2005) selected in Rappahannock River, an area that historically had highly productive oyster harvest sites and extensive reefs. The second area selected for study was located in the upper reaches of Inlet Creek, a tidal creek, which is relatively pristine with extensive oyster habitat present, a large marsh buffer and relatively little adjacent development.

Schulte et al (2009) selected the Wicomico River as one of the first sites in the region that would attempt restoration of a complete estuarine system as a single unit, rather than employ sequential additions of reefs within a system over an extended number of years.

Reefs were constructed various ways; Luckenbach et al (2005) constructed reef bases in August 2000 in Rappahannock River, by placing shell piles in arrays. Core material for individual mounds was comprised of surf clam (*Spisula solidissima*) shell that was covered with a layer (generally 10 cm - 20 cm) of clean oyster shell. Materials were barged to the four reef sites and deployed via a crane and bucket rig, creating "upside-down egg carton" shaped subtidal reefs elevated approximately 3 m above seabed and 1 m – 2 m below the water surface at low tide. Reef sizes ranged from 400 m^2 - 800 m^2 and were classes as small, medium and large reefs. In Inlet Creek, three artificially constructed reefs were created in 1994, next to three natural oyster reefs. Constructed reefs were approximately 24 m^2, the size of the natural oyster reefs in the area within a minimum distance of 5 m between them. Reef design had perforated plastic trays lined with fiberglass window screening, each filled with approximately 8 kgs of washed oyster shell to a standard height of 0.11 m. Each reef consisted of 26 rows of six trays placed end to end. Over 8.66 t of material (shell and trays), were used.

Schulte et al (2009) collected dredged and washed oyster shells removed from the lower James River, which historically was the world's largest oyster seed-producing river system. The field experiment involved two restoration treatments, a high-relief reef and low-relief reef and a control treatment of unrestored bottom spread over each of the reef complexes.

In contrast to Luckenbach et al (2005), the utilised methodology was less orderly influencing the results of the study, Schulte et al (2009). Water cannons were used to blow dredged shells from a barge, over the area to be restored. Due to the inherent difficulties in deploying shells off a barge via water cannon, to create shell beds of uniform thickness, some areas intended to receive shells did not, and some areas outside the restoration area did.

Monitoring

Luckenbach et al (2005) collected samples in July and October 2001 and in July 2002 in Rappahannock River whilst Schulte (2009) sampled in 2007 and 2009.

Luckenbach et (2005) in contrast, the study carried out in Inlet Creek had a more thorough sampling regime, as more frequent sampling allowed for better initial resolution as reefs began to receive both oyster and resident recruits. The natural reefs' initial monitoring began in March 1995 and constructed reefs from late spring to early summer of the same year. Sampling then occurred bimonthly for the first year and quarterly during the second year. From 1997–1999, sampling was reduced to summer and winter samples. For 2000-2001, samples were collected only during the winter.

Luckenbach et al (2005) collected samples from reefs at Rappahannock River to estimate standing stock of oysters. A random sampling regime was used with a quarter of a metre squared quadrat, haphazardly placed onto randomly selected mounds within ten reefs. One sample was collected from each mound, as mounds were treated as replicates within a reef treatment. All reef material was excavated to a depth of 10 cm by divers and transported to the surface in fine mesh bags. All live oysters in each sample were counted and measured. A sub-sample of 132 oysters was measured for dry tissue biomass from the October 2001 sample.

Inlet Creek saw oysters on experimental reefs sampled by removing three randomly selected trays, which posed as quadrats. The material was rinsed and put through a half a millimetre sieve and all organisms caught, retained. All oyster shell was thoroughly sorted and all live oysters counted and measured. For the oyster on the natural reefs, they were sampled using quadrats randomly placed with all organisms, including oysters, excavated to a depth of 11 cm and removed.

Schulte et al (2009) utilise a patent tong survey method as well as filming. Underwater video was used to document the reef condition and appearance at various locations during the patent tong survey. The filming occurred immediately adjacent to the patent tong sample sites. The patent tong survey, along with associated underwater video, sampled the three reef types in 2007 and 2009. In 2007, 85 1 m^2 plots were sampled, allocated randomly across the three treatments in the nine reef complexes. Further samples in the reefs during March 2009 were to verify long-term persistence of the reefs.

Results

Luckenbach et al (2005) found two years after construction, reefs at the four sites in the Rappahannock River differed both in abundance and size structure of oyster populations. However, no significant differences were observed between individual reefs. No oysters were found on the reef substrate in the summer of 2001. By the summer 2002, two age classes of oysters were evident on all of the reefs at densities ranging from 77-277 oysters per metre squared. At the time of final sampling, reefs did not yet support any market-sized oysters due to the age of the reefs. However, they did support resident and transient community assemblages, many of which were positively correlated with the abundance and size (shell height or biomass) of oysters on the reefs.

Luckenbach et al (2005) during the study in Inlet Creek collected over 87 resident and 60 transient species associated with the reefs. Oyster abundance on the experimental reefs at Inlet Creek increased during the period from January 1997 through January 2001. Oyster size frequency distributions were similar on the experimental and natural reefs, with natural reefs at inlet having more oysters above 75 mm in size.

Schulte et al (2009) reported an unparalleled restoration of a *Crassostrea virginica* oyster metapopulation, comprising 185m oysters of four dominant year classes. The re-established metapopulation is the largest of any native oyster worldwide. In 2007, the metapopulation on the nine reefs consists of an estimated 184.5m oysters, comprising 119.2m adults of two age classes and 65.3m juveniles of the 2007 year class, indicative of prolonged survival of settled individuals to adulthood and recruitment of larvae to the reefs.

Discussion

Reef construction is a widely used restoration technique that has its advantages and has proven successful in projects undertaken. Mussels in their early stages, planktonic larvae expelled from mussels drift with tides and currents, attaching to algae, seaweed and other marine organisms. As they grow into spat (juvenile mussels) they move on to firm surfaces - gravel or rock or the shell of adult mussels - to settle Cumming (2013).

The two studies outlined were each designed with different specific goals in mind Luckenbach et al (2005). In Rappahannock River, it was concluded that larval supply may play a significant role in restoration success. In contrast, Inlet Creek restoration success appears to be simply the result of the addition of the limiting substrate, oyster shell. The experimental reefs in Inlet Creek did have extensive natural reefs for comparison, and over the time period from 1995 to 2000, although they failed to converge with the natural reefs, they are persisting with slowly increasing oyster populations.

Schulte et al (2009) found success was majorly attributed to reef height, which drove abundance and density across the reef complexes. Oyster density was fivefold greater on high-relief than low-relief reef. This restoration project deviated significantly from prior restoration attempts in the Chesapeake Bay by building oyster reefs of high vertical relief at a broad spatial scale in large sanctuaries protected from fishery exploitation. Most projects had only created reefs on low-relief explaining the success of this project.

Despite these projects focusing on oysters, translocations undertaken in New Zealand, particularly in the Hauraki Gulf have made great successes. Perhaps the method could be mimicked using dead or remnant mussel shell, essentially making the method reef construction. Although dropping mussels by barge is easier and cost effective, there would be merit in mimicking Luckenbach et al (2005) methods for Inlet Creek, as monitoring would prove easier and efficient with greater insights found.

Possible application in Ōhiwa Harbour

Reef construction is a useful technique and could be employed within New Zealand. Mussels in the Hauraki Gulf that were translocated could easily be substituted for dead or remnant mussel shells, therefore constructing a hard surface for mussels to potentially repopulate. Although the method hasn't been tried essentially, the translocation occurring in the Hauraki Gulf is very similar to this method. If live mussels become sparse or unavailable, collection of old shells may prove a potential course of action.

The more orderly method of the projects investigated, although it would prove more costly, would ensure more detailed and accurate sampling regimes. The two ways, in which reef construction was employed, could be the first study carried out. Determining which is best suited for Ōhiwa Harbour by doing both on a small scale could prove necessary, particularly if there was no prominent difference between the two or if one didn't take at all. The more cost efficient or the most successful would then be implemented.

Causes of mussel declines

Although not the focus of this review, some causes are briefly explored from some sources.

McLeod (2009) explains some theories for why mussels are declining in the Firth of Thames. Declines are due to overfishing as well as the overall decline in conditions of coastal waters through impacts such as sedimentation, habitat disturbance, and eutrophication. Seabed habitat degradation has been attributed to mobile bottom fishing gear, with the method of dredging for shellfish the most damaging to benthic organisms and substrate.

Many reefs that have been mined by fishing and dredging activities have then been silted over impacting the abilities of larvae to settle and survive to adulthood. The impact of sedimentation on bivalves includes the clogging of gills, impairing their feeding ability, and smothering hard surfaces their larvae need to settle on, McLeod (2009).

Coastal and urban development, farming, and deforestation are contributing to increase sediment loads into coastal environments so juvenile or adult mussels are not surviving on the seafloor, possibly due to environmental conditions, McLeod (2009).

Other factors that may affect mussel reef recovery include insufficient mussel spat and a lack of settlement substrate for mussel larvae. Despite no dredging occurring in the Firth of Thames for over four decades, the mussel reefs have not recovered. Recent surveys of Hauraki Gulf soft sediments showed that areas where mussels were previously abundant are now dominated by bare soft sediments, with relatively little three-dimensional structure, McLeod (2009).

Gray & Kreeger (2014) detail overharvesting, construction of dams, habitat degradation, pollution and introduction of invasive species, as the reasoning behind the decline of freshwater mussels in North America.

Hua (2015) similarly states these causes and threats, as the control program is also focused on freshwater mussels, additionally sedimentation, coal mining, over-exploitation and other anthropogenic disturbances are highlighted.

These views are supported by those who undertook restoration efforts for freshwater mussels and are acknowledged as leading threats to the species.

Oyster reef construction occurred due to the worldwide collapse of the populations due to overfishing and habitat destruction, Schulte et al (2009) Luckenbach et al (2005).

Section 2: Sea star management

Introduction

The eleven-armed sea star (*Coscinasterias muricata)* is the most common and largest sea star found in temperate waters around Aotearoa, New Zealand. Within subtidal areas and sheltered bays, this sea star is an important predator; it is large and proves extremely insatiable, although typically occurs in low densities (Paul-Burke, 2015). Green-lipped mussels are the preferred prey of the eleven-armed sea star. Observed within soft sediment environments, Ōhiwa Harbour and Firth of Thames, preying on the green-lipped mussel populations, the sea star is acknowledged as likely important predators of the species within these particular environments, (Paul-Burke, 2015). Sea stars are considered to be keystone species, organisms that with their abundance, have with considerate effect on its surrounding environment. The feeding activities of sea stars control the distribution of associated species within an ecosystem (Paul-Burke, 2015).

Alongside the eleven-armed sea star, the cushion star (*Patiriella regularis*) has also been observed in the Ōhiwa Harbour near mussel beds, although in less numbers. Surveys conducted in harbour have shown decreases of mussel populations correlating with increased presence of the eleven armed starfish.

Starfish predation is surmised to be one of the leading causes of mussel declines within the Ōhiwa Harbour.

This section is split into Part 1: Removal, Part 2: Chemical control Part 3: Traps and Part 4: Other methods. The methods are explained using various projects in which applied the method for their purposes. Although projects may have differing circumstances surrounding the conception, this section also details the alternative processes of each method. Providing a different way in which each method is employed is equally as important, so we can adapt both the method and processes best suited to achieve the required results. This section includes the materials used, monitoring aspects of the program, results, discussions and recommendations. Finally, a very brief look at potential causes of increased sea star abundance is explored. This investigation into different options for control, is assumed in the hope of minimising effects that prey starfish have on declining green-lipped mussels within the Ōhiwa Harbour.

Part 1: Removal

Removing sea stars is a very common method in control programs, although there are various techniques of how they are removed.

Method

Yamaguchi (1986) noted that intensive control programs used the method of hand collecting starfish and disposing them on land, as a way to minimise coral predation.

Lee (1951) implemented two methods of removal to minimise oyster predation by starfish, mopping and dredging, whilst Calderwood, O'Connor, Roberts (2015) examined the efficiency of a starfish mop.

Paine (1971) researched the effects of single-species removals on community composition and overt appearance by hand removal of a sea star species.

Yamaguchi (1986) summarises and analyses past control efforts undertaken from 1970 to 1983 in Ryukyu archipelago, which have been susceptible to *Acanthaster* planci infestations since 1969. Most areas outside the Ryukyu where luxurious coral assemblages developed are designated national parks and are protected by law. Control programs have been undertaken in three of such areas: Ashizuri-Uwakai at the southwest part of Shikoku, Kushimoto at the southern end of Kii Peninsula and Miyake Island in the Izu Islands.

Lee (1951) examines control methods used in Long Island Sound by the oystermen of the region. The common sea star (*Asterias forbesi*) plagues the oysters and the men have no choice but to pay for control methods, lest the starfish overtake the oysters and wipe out their stock.

Similarly, Galtsoff & Loosanoff (1939) also detailed methods of starfish control focusing on the sea star *Asterias forbesi* in Long Island Sound.

Calderwood et al (2015) filmed and catalogued the use of a starfish mop on subtidal mussel beds at Belfast Lough on the east coast of Northern Ireland. The work was carried out on an area licensed for benthic mussel culture where the starfish (*Asterias rubens)*, preys on mussels (*Mytilus edulis)*.

Barkhouse, Niles, Davidson (2007) states the dredge can be used to control sea stars during harvesting of target species, with the dredge’s primary function being to collect scallops, oysters or mussels from the sea bottom; however, the dredge also catches sea stars.

Methods administered by Lee (1951) were also briefly highlighted by Flimlin & Beal (1993) as methods to successfully control starfish.

Flimlin & Beal (1993) states destruction of captured starfish by removal from the water is beneficial.

Paine (1971) removed forcipulate starfish, *Stichaster australis*, whose primary prey is the mussel, *Perna canaliculus*, manually and kept removed from a stretch of shore for a period of nine months (September 1968 through May 1969). The investigation occurred on a rocky promontory forming the northern boundary of a beach at Anawhata, a few miles north of Piha in the vicinity of Auckland, New Zealand.

Joint Standing Committee on Conservation/Standing Committee on Fisheries and Aquaculture National Taskforce on the Prevention and Management of Marine Pest Incursions (referred to as SCC/SCFA) (1999) stated that physical removal is the only method currently available for reducing sea star numbers in near shore coastal environments in Australia. A variety of techniques can be employed, involving ‘mops’, hand collection, and traps.

In Maketū, New Zealand efforts to control starfish the 11 arm starfish *Coscinasterias calamaria*, proved successful with consistent culling efforts. The sea stars were found taking over the main mussel-growing areas in the harbour, despite locals stating there hadn’t been starfish in the area 15 years prior. Initially, a trial they first opted to cut up the starfish and throw them overboard until it was found each piece grew into a new starfish. They were then killed by lethal bleach injection, but this was stopped when it was feared the bleach harmed other aquatic life. Then it was decided that the cullers, usually marine studies students from Tauranga, would fill sacks and removed them by hand to be used in gardens as fertiliser. Over three years they removed approximately three or four tonnes of sea stars. No take limits had been placed on the cull. Another incentive in the program was sometimes people were offered a 50 c bounty for every starfish they caught (Whakatane Beacon, 2012).

Materials and process

When conducting research, there were some requirements when selecting a suitable site. Yamaguchi (1986) focused on shallow areas due to limited funds to buy breathing apparatus. But sites with the most luxurious coral assemblages within the Ryukyu Islands had focus on deep waters because of the importance of these areas.

Calderwood et al (2015) selected an area that consisted of numerous individual mussel beds with mussels at all stages of the cultivation process, from point of relaying of seed mussels to mussels ready for harvest.

In Yamaguchi (1986) the control programs were commenced by local fishermen. In some areas, SCUBA was used but most diving was done without underwater breathing apparatus. The numbers of starfish were estimated by counting numbers of baskets in which the starfish were emptied into, which may have contained a certain average number. This was done by a member of Government as pay was based on the number of starfish caught. In areas protected by law, local diving associations were the main contractors involved and they worked in rather deep waters by using SCUBA.

Lee (1951) explains several methods used in Long Island Sound. Mopping is the most used method due to little damage caused and its suitability for effectively and thoroughly cleaning areas where few sea stars are located. It is a long bar with six to twelve short lengths of chain secured at regular intervals. A ‘mop’ or bunches of string or twine is tied to each chain. This mop is dragged slowly over the bottom at the end of a dredge cable. Starfish become entwined and the mop is hauled up at intervals to remove starfish. Starfish can be handpicked from the mops, but the mops are usually placed in tanks of water of a degree so hot that the starfish die, softening and falling from the mops. Two mops aboard the boat allow for the mops to be working continually with only two minutes required in the hot water, covering a more extensive area.

Galtsoff & Loosanoff (1939) further added that in some cases where the bottom is too rocky or uneven, the regular mop cannot be used. A special frame created consists of two pieces of heavy sheet iron, the largest of two by five feet, was attached by four large rings to the triangular smaller piece. This arrangement permits independence of movement of the two parts, the mop used is the same but it is attached by chains to the five foot side of the larger piece of sheet iron. The apparatus slides easily over rocks and the mop falls between them to reach the starfish.

Galtsoff & Loosanoff (1939) noted that during the oyster dredging, starfish captured are killed. This practise is in general use in Narragansett Bay and is sometimes preferred over mops.

Lee (1951) the flower suction dredge utilises the principle of a vacuum cleaner, a wide funnel shaped collector was carried on wheels at a short distance above the bottom. A large centrifugal suction pump discharged this mixture into a conveyor.

Lassig (1995) stated that string sharpened sticks, hooked steel rods and barbeque tongs are best for pulling starfish out from under corals. The starfish can then be transferred to land to be buried.

Calderwood et al (2015) had nine sampling events within an area of approximately 30 ha across, with an average depth of 4.5 m. The work was conducted on board a commercial mussel dredger operating within Belfast Lough. Sampling took place between October 2013 and December 2014, and was dependent on when the dredger was scheduled to mop for starfish. When mopping for starfish was monitored, two mops consisting of a 6 m long dredge bar, from which 40 lengths of chain (2 m in length), positioned at 15 cm intervals and to which lengths of frayed rope are attached, were towed alternatively from each side of the ship in a to and fro manner across the mussel bed. The length of tows ranged from 400 m - 900 m with the mussel dredger travelling at a mean speed of 1.75 knots whilst mopping. A GoPro™ camera was attached to the apex of the starfish mop deployed from the starboard side of the ship, with the camera orientated towards the direction of the travel of the mop so that it could view the area of seabed about to be mopped. When the mop was lowered to the seabed, the camera was at a height of approximately 28 cm above the sea bed, providing a 75 cm wide view along the bottom edge of recorded footage. When the mops were back on board, the starfish were removed by hand.

Monitoring

Yamaguchi (1986) had no regime as control efforts within the report were poorly documented. Unfortunately, only limited information is available from repeated surveys about the condition of reefs after *Acanthaster* infestations. Most of the information gathered pertains to the number of starfish collected.

Yamaguchi (1986) where the infestation was first detected in Okinawa Island, only small numbers of starfish, 240 and 60, were removed in 1969 and 1970. Much larger numbers were collected in the two years following (8,000 and 23,000). Approximately half of the total number approximately 6.1m out of 13m starfish were removed from Okinawa Island.

Calderwood et al (2015) monitoring did not occur during some sampling events due to time restraints and some monitoring was unable to be analysed owing to high water turbidity and reduced visibility.

The monitoring regime included determining starfish densities using videos from a total of 31 tows, counting and recording the number of starfish collected and measuring the length of the longest arm of every fifth starfish using callipers.

To assess the population structure of the starfish on mussel beds, the abundance and size of starfish collected by mops was recorded from a total of 81 tows, including the additional tows where recorded video footage was not suitable for analysis. Twenty starfish were selected randomly from mop tows at each sampling date and the longest arm length and biomass of each starfish were recorded.

Results

The Yamaguchi (1986) control programs had a total removal of around 13m starfish. Despite this impressive number, most reefs where control programs were employed due to *Acanthaster* aggregations did not survive the heavy infestations. Reefs were devastated with it now hard to find any reef with significant coral cover, except for a few recently recovering areas.

In Yamaguchi (1986) because the programs were on a bounty system spanning a fiscal year, budgets were allocated to areas where infestations were at their height or in their final phases. This resulted in *Acanthaster* aggregations being left well-fed and undisturbed for at least one breeding season prior to the partial removal of the population. This might in turn have helped them to breed more efficiently by reducing the population density, when they were faced with reduced amounts of coral food.

In Calderwood et al (2015), starfish mops are commonly used today in areas where starfish are known to be abundant. Despite the widespread use of this predator removal technique within mussel fisheries, little work has been conducted to assess how effective it is at removing starfish from mussel beds. The efficiency of mops showed considerable variation with the percentage of starfish removed by mops compared to those viewed on video footage. This highlights the need for the adoption of predator removal techniques year round to reduce predatory pressures that may be placed on mussels by these starfish populations. They found seasonal variation in the effectiveness of mops at removing starfish from mussel beds as the density of *A. rubens* observed in videos increased. There was also a slight trend towards mops displaying greater effectiveness at removing starfish from beds with smaller sized mussels. This may be as a result of starfish being protected from mopping actions, when they are within the structural matrix created by larger mussels compared to smaller mussels.

Paine (1971) found the manipulation of removing the sea star resulted in the mussel *Perna canaliculus,* extending its vertical distribution by 40% of the available range, and a decrease in the species richness of the invaded area from 20 to 14 species. The second manipulation involved the removal of both Stichaster and a large brown alga, *Durxl'illea antarctica*, from two areas. Within 15 months, 68% of the available space in one area, and 78% in the other, was occupied by mussels, to the almost total exclusion of other fauna or flora.

Cost

Yamaguchi (1986), the total cost of the control programs may be well over five hundred million yen for the Ryukyu’s from 1970 to 1983 fiscal year.

A private foundation and Local Governments contributed funds for a bounty system (twenty yen per starfish). This system was maintained from 1970 to 1975 and was administered by the Okinawa Tourism Development Corporation. The Environment Agency and the Fisheries Agency of the Japanese Government acted as the main funding sources, by contributing funds matching those from the Local Governments, starting in 1974 and 1976, respectively. They differed in their methods of administering the budgets: compensating for labour and expenses in the former case and using bounty systems (twenty five yen per starfish in Okinawa, Miyako and Yaeyama and ninety yen in Amami) in the latter case.

Barkhouse et al (2007) example of costing for mopping was taken from a trial done in the Magdalen Islands. Operational cost of the mop varies but it involves the cost of running the boat, labour wages and wear on the mop. In one trial, the performed longevity of the cotton bundles was low and they needed to be replaced periodically (approximately every three days). The initial cost to equip a fishing boat with a boiler system was estimated at about $10,000 per system. They stated an estimated cost of $43,000 to cover a 4 km squared area over 16 days. In the long run, the longevity of the frame is also a consideration.

Discussion

Lassig (1995) stated that removal is an ineffective method due to the time it takes and the risk to the collectors of getting spiked.

Barkhouse et al (2007) states that in shallow waters, sea stars may also be collected from the sea bottom by hand, either with or without the help of diving equipment. However, it was suggested that the amount collected is not likely to make a big impact on total sea star densities. Furthermore, collection by hand is extremely labour intensive.

Barkhouse et al (2007) there has been some concern over the impact of mopping on local flora and fauna, however, in general, the mop is considered to cause little disturbance to the sea bottom. The mop is best used on areas of a medium scale with high densities of sea stars.

Barkhouse et al (2007) found the mop offers the most efficient sea star control method for bottom culture, but the significant initial investment required and its adaptation to open water conditions need to be considered. The dredge presents the unique advantage of being able to concomitantly remove sea stars during regular fishing activities and should be encouraged. Meanwhile, this method may target species of sea stars that are not of concern to shellfish culture.

Calderwood et al (2015) recognise that it would be beneficial to collect further information with regard to mopping operations, to allow for the construction of a model, to determine the exact effect that mopping has mussel yields and the economic output of such fisheries. If mopping operations were optimised further, however, this technique could be used to effectively remove larger numbers of starfish from mussel cultivation sites. With little seasonal variation being noted in the number of starfish recorded on beds, it is important for mussel producers in Belfast Lough to continue mopping operations year round if starfish numbers are to be kept to a minimum. Additionally, mopping practices should be optimised by towing mops over shorter distances when high densities of *A. rubens* are encountered. Mops would then be recovered prior to becoming saturated with starfish, thus, maintaining mopping efficiencies throughout the entire length of tows.

Possible application in Ōhiwa Harbour

Removal can be an easy and cost effective method to implement in Ōhiwa Harbour. Due to the cultural significance of Ōhiwa Harbour, it should be relatively simple to rally residents, descendants, whānau, hapū and the community into participating in the removal of sea stars. Safety cautions will also be considered during these community based programs. If the employment of a mop or other such device was warranted, costing towards materials to build or buying the contraption will be another concession. It’s also prudent to request volunteers bring their own breathing apparatus to eliminate further costs.

There are several restrictions to this method, the main one being that the daily starfish take limit under normal conditions is 15 (Whakatane Beacon, 2012). Ministry of Primary Industries are able to sanction a massacre as they are able to issue permits under Section 97 of the Fisheries Act 1996 to eradicate unwanted aquatic life. A culling applicant would need to design a suitable research project for assessment by the ministry and supply information to support the culling; the first proposal in the case of the starfish might be a trial eradication programme (Whakatane Beacon, 2012).

Other restrictions include the time of the control effort which would have to be timed specifically in relation to when sea stars spawn. Also, once an area is cleared of starfish it is easily repopulated so considerations into how to keep sea stars out of recently cleared sites will need to be acknowledged. There are such exclusion techniques like fencing off an area that could be further researched.

Quantifying the amount of sea stars to be removed without the integrity of the ecosystem being jeopardised will also need to be highlighted, as the sea stars are native keystone species and will alter the current ecosystem. The sea stars in Ōhiwa Harbour will not be able to be eradicated, only removed to a suitable number and this will require further research, as this knowledge is not known.

Part 2: Chemical control

Numerous reports have been produced cataloguing the variety of methods used to try and control sea star populations, one such method is chemical control which is largely implemented through injection.

Method

Johnson, Moran, Driml (1990) decided the method of injection of saturated copper sulphate would best achieve the aims of protecting existing coral cover from predatory starfish.

Loosanoff & Engle (1942) Lee (1951) utilised calcium oxide or quicklime for combating starfish that plagued the oyster and scallop industry.

Kenchington & Pearson (1981) found differing reasons to test out chemical control of starfish ranging from the need to protect a reef important for coral viewing, research and tourism, to concern with the predation of algae and living coral.

Grand, Rivera-Posada, Pratchett, Aguilar, Caballes (2014) enhanced chemical control by a single-shot lethal injection of bite salts to help limit the problem of predator sea stars.

Many programs were similarly conducted within the Great Barrier Reef focusing on the crown-of-thorn starfish (*Acanthaster planci*).

Johnson et al (1990) implements a control program conducted on Grub Reef, Great Barrier Reef, Australia in July 1986, to ascertain whether control programmes are efficient. This region is susceptible to outbreaks of the crown-of-thorn starfish (*Acanthaster planci*) and continuous destructive outbreaks have led to controversy surrounding the effectiveness of control programs.

Kenchington & Pearson (1981) discusses an experiment done in Green Island, Great Barrier Reef, Australia, where a series of trials was conducted to test out chemicals best injected to control predatory crown-of-thorn starfish.

Grand et al (2014) tests the feasibility of bile derivatives to be used as a single-shot lethal injection method for killing crown-of-thorn sea stars at Lizard Island, northern Great Barrier Reef.

In contrast, others focused on the forbes sea star (*Asterias forbesi*) found within Long Island Sound.

Loosanoff & Engle (1942) details the development and use of quicklime as a method to control starfish in Long Island Sound. The Forbes sea star, one of the most destructive enemies of shellfish in the Atlantic coast of North America spurred investigations into more efficient control methods in the 1940's, as costs of ineffective programs and losses from damaged stock increased. Field experiments occurred in the year 1938 after various years of research and lab testing occurred.

Similarly, Lee (1951) explains using quicklime not long after Loosanoff & Engle (1942) within the same area and for the same purposes. Among other methods, this was used by the oystermen in the region with some changes made.

Barkhouse et al (2007) reviewed brine, a saturated salt solution that has been used to remove settled sea stars from mussel collectors. Osmotic stress on the sea stars causes them to detach from the collectors, while the mussels remain unharmed.

Barkhouse et al (2007) also reviewed lime to remove sea stars from mussel spat. Despite broadcast application of lime not practiced in recent years due to its potential harmful effects on other non-target organisms.

Lassig (1995) believes the injection of poisons is the most efficient technique, taking just a few seconds to inject an individual starfish.

Lisa Boström-Einarsson has discovered advancement in the chemical control of crown-of-thorn starfish as she researched the use of vinegar. The current eradication practice is to inject the starfish with ox bile which is much harder to come by, more expensive and could cause quarantine issues as it is an animal by-product. Her research has shown that injecting vinegar has a 100% mortality rate with starfish dying within 48 hours. She said the next step was large scale field testing to ensure process was safe for other marine life, Roe & Calderwood (2015).

Researchers from Queensland University of Technology are also close to finishing trials on a robot which will be primed to find and kill the starfish. The mechanical hit man, known as COTS bot, uses GPS and a series of thrusters to cruise a metre from the seafloor. Once it spots a crown-of-thorns starfish, it uses an extended arm to administer a fatal dose of bile salts, Australian Associated Press (2015).

Materials and process

There were several considerations when deciding where to undertake their respective research, Johnson et al (1990) chose a site that had reasonably high levels of both live coral and starfish. It was also easily accessible with areas that could be dived during bad weather conditions without difficulty. Similarly, Loosanoff & Engle (1942) utilised a site occupied by the species preyed upon choosing natural oyster beds.

Johnson et al (1990) had a control area of approximately 0.64 km^2 with 53 patch reefs and a 10 m – 30 m depth of predominantly sandy substrate. Carried out by 15 Royal Australian Navy divers over a period of 15 days, starfish were injected with 5 ml – 10 ml of saturated copper sulphate using “Dupont” agricultural injection guns. Each patch reef was searched by a squad of five divers. The divers were spaced about 5 m apart and searched to a depth of 20 m, injecting all starfish observed. To avoid repeated injections, starfish were marked by a cut from a knife. The exercise was repeated on all 53 reefs with the final two days of the control exercise used to inject starfish, on adjacent patch reefs to the north and west of the control site. Each patch reef was mapped, marked and numbered for location.

In Grand et al (2014) a total of 220 sea stars, ranging in size from 30 cm to 42 cm diameter were collected from back reef environments at Lizard Island. Specimens were immediately transported to the Lizard Island Research Station and kept in large holding tanks with constant flow of ambient seawater. All sea stars were left to acclimatise for three days. Weak or injured individuals were discarded.

Field experiments followed with two adjacent patch reefs across the Lizard Island Reefs, with an area of less than 100 m^2 each and separated by a stretch of sand, selected to separately test the efficacy of bile salts and dry acid injections. To simulate outbreak densities on these small reef patches, 50 sea stars, collected from nearby reefs the previous day, were placed on each patch and allowed one hour to re-orient and disperse, prior to the commencement of the field trial. Control divers used SCUBA gear to inject the sea stars, while free-diving snorkelers helped locate the sea stars. Divers administered one 10 ml injection of 8 g l^{-1} solution of Bile Salts No. 3 into the base of the arm of each sea star using the prototype metal injection gun. Out of the 50 sea stars dropped on the first reef, they were accounted for and injected in less than 12 minutes. Sea stars on the second reef were injected using the DuPont Velpar Spotgun. Each sea star was injected six to fifteen times with 10 ml doses of sodium bisulphate at 140g l^{-1}. All 50 were easily located but injections took over 35 minutes.

Moreover, the 4-l sodium bisulphate solution in the bladder was completely spent after injecting about 35 individuals.

Loosanoff & Engle (1942) had two sites, Lot A and B, sized one acre in area and 500 feet apart from each other and located in 25 feet of water as part of the Stratford natural oyster bed. There was no such equipment at the time of the experiment readily available to disperse quicklime over the oyster beds in a precise and methodical manner. Lime was either shovelled or washed overboard with a strong jet of water. On March 11 1938, 840 lbs of granulated lime was spread on Lot A with the same quantity of coarse material deposited on Lot B.

Another experiment commenced on March 14 of the same year near Charles Island. Two lots C and D, now further apart with the same size area but at depths of 18' were treated with lime. Lot C received 840 lbs and Lot D received 280 lbs of granulated lime. To try and maintain a more precise and uniform distribution of the lime, the release occurred luring slack-water periods.

The last experiment occurred on a larger scale on seed oyster grounds located in New Haven Harbour on 22 March. Three oyster lots were treated with granulated lime. Lot 1 was twenty five acres at a depth of 17' and received 320 lbs per acre. Lot 2 of the same size and depth received 480 lbs per acre whilst Lot 3 was fifteen acres in size located at 25' was treated with 640 lbs per acre.

Lee (1951) shovelled lump lime over the boat rail to be disintegrated and dispersed as it settles to the bottom. An apparatus later developed by Loosanoff and Engle, for distributing a lime suspension immediately over the bottom, involves a stream of water from a centrifugal pump picking up the fine lime and the suspension was forced through a hose line to a distributor pipe which was carried a short distance above the bottom on a pair of wheels.

Kenchington & Pearson (1981) injected starfish with a range of chemicals and kept them in cages to be monitored. They also tested injection of compressed air, although it was unsuccessful.

Monitoring

Johnson et al (1990) had a biological survey conducted two weeks prior to the beginning of the program in June 1986, and then monitored twice, one month and six months after completion of the project.

Johnson et al (1990) had monitoring programs estimating the relative cover of live and dead corals and the number of crown-of-thorn starfish observed within the reef perimeter and patches to the west of the main section, whilst Loosanoff & Engle (1942) detailed the state the starfish was found in.

Johnson et al (1990) employed three methods within their monitoring regime to find these measures. The first of which was a manta tow technique which towed an observer behind a small inflatable boat at around two knots, stopping every two minutes and noting the observations. Technique two was having half the reef patches searched extensively by SCUBA divers. Selected at random in the beginning, the same reefs were done throughout the three surveys. Two divers swam around the sides and across the top of the patch reefs recording the observations. The last technique was utilising a 50 m line transect laid along the crest of five reef patches with the highest coral cover, with observations noted.

Loosanoff & Engle (1942) had a somewhat haphazard monitoring regime and doesn't note distinct ways in which they monitored the experiments. Samples were collected numerous times, with sampling times for the first experiment occurring the first day after and eight more times spanning two months. The second experiment saw the samples collected six times over the course of a month. The last experiment was sampled nine times spanning two months.

Grand et al (2014) opted to monitor using cameras. Three hours after all injections, video cameras were placed on each reef at strategic locations to monitor the activity of injected *A. planci* and its interactions with other organisms in the vicinity. Aggregations of decomposing sea stars were individually marked using bright-coloured flag tapes. Mortality rates and decomposition rates were recorded. Cameras were changed twice daily for four days. Further video monitoring was conducted once every week for one month. Three replicate permanent transects (10 x 1 m) on each reef patch were also established within the immediate vicinity of decomposing *A. planci*. These transects were very small relative to normal sampling protocols for coral reef fishes, but this was sufficient given the very small area of impact. All decomposing sea star were within an area measuring approximately 10 m x 6 m. The injected were mostly hyperactive up to an hour after injection, but subsequently remain stationary prior to death. A video recording of the entire length of each permanent transect was done on day one, day seven, and day 14 to monitor fish and macro-invertebrate populations. In addition, 20 colonies of branching corals (*Acropora, Pocillopora, Seriatopora* and *Stylophora*) were individually tagged and then photographed at regular intervals (every one to five days) to test for any new incidences of coral disease. These colonies were located at distances of 0 m – 4 m from the *A. planci* aggregations.

Results

Loosanoff & Engle (1942) found in the first experiment that after a day, no starfish had died but there were small lesions and scars reported. Next sampling saw 58% and 84% in Lot A and B respectively affected with many either dead or dying. The third sampling concluded that all starfish severely impacted had died and the starfish now only had small contusions. Starfish with scars were found two months after also.

The second experiment showed 88% and 74% at Lot C and D respectively was found to be impacted. The last experiment showed Lot 2 had the best results with 81% affected.
Sea stars that didn't die within a few days were wounded but still found for a long time afterwards.

Results found that the method was largely successful. The efficiency of the method could be further improved by deployment methods but the method was largely tried through the area by various people with favourable results Loosanoff & Engle (1942).

Johnson et al (1990) saw a total of 3175 starfish injected in the program with 251 hrs of dive time catalogued. Manta tow surveys recorded approximately half as many starfish around the perimeter of the reef after the control program had been completed. The SCUBA swim counts and the line transect coral cover data were analysed. The number of starfish showed significant differences between surveys, but the percentage of live coral cover and dead coral cover between surveys were non-significant. The SCUBA swim estimates of live and dead coral cover, for each of the 26 patch reefs were similar for all three surveys and consistent with the more quantitative findings from the line transects.

Johnson et al (1990) the findings of the biological surveys indicate that the control program was largely unsuccessful. Despite the fact that numerous starfish were injected and that a decline in the starfish population was subsequently recorded, a reasonably large number of starfish were still present in the control area six months after the program had ceased. Despite this, an appreciable increase in coral mortality was not recorded after the control had finished.

Kenchington & Pearson (1981) conducted a trial using copper sulphate injections where two divers worked for a total of 35 days injecting crown-of-thorns in an area of approximately four hectares. In all, 25,850 starfish were killed. Trials found copper sulphate to be the most effective chemical in terms of costs, unit dose, ease and safety with the highest recording of kills per hour being 132.

Grand et al (2014) found that all crown-of-thorns injected with Bile Salts No. 3 experienced 100% mortality regardless of the concentration and site of injection. This was significantly higher compared to sea stars injected with Oxgall, which only experienced 80% mortality after 48 hours. Among the sea stars injected in the central disk, those injected with Bile Salts No. 3 died more rapidly, compared to those injected with Oxgall.

Barkhouse et al (2007) found treatment using brine was found to double mussel yield. The effectiveness of brine is dependent on the strength of the solution, as well as submersion time.

Barkhouse et al (2007) also found lime to be effective in removing sea stars in some trials however; it was recommended that hydrated lime be used rather than quicklime due to safety reasons. Using one boat, a crew of two can treat 20 lines per day.

Cost

The direct outlay required for the program with the biological surveys was $38,000 and the direct outlay for ship time, transport, equipment and consumables for the control exercise, was $29,435. The total cost for repeating the exercise, including the salaries and overheads of management and scientific staff and divers would be around $111,600. Not only was the program unsuccessful, it also proved costly. The total cost of the program was $35 per starfish, Johnson et al (1990).

Loosanoff & Engle (1942) experiments resulted in mortalities as high as 70% using two hundred pounds worth of quicklime per acre.

Barkhouse et al (2007) states costing in commercial trials using brine at two mussel farms, could cost approximately $4000 for each farm but that brine treatments could increase the seed harvest by 12 t - 16 t. Depending on the farm scenario and mussel price, this could translate into profits of between $10,000 and $33,000 for market-size mussels.

Barkhouse et al (2007) operational costs for the lime trials were estimated at between $20 and $100 per line of collectors. Depending on the size of the farm and the extent of infestation by sea stars, annual costs vary from $600 to $20,000.

Discussion

The method of chemical control is highly successful and has been used throughout the world. Due to advancements in technology and research, this method could easily be adapted for use within the Ōhiwa Harbour. Although the species and location conditions are different, research into the *Coscinasterias muricata* found in the Ōhiwa Harbour could be explored as well as the easier and newly recognised methods.

Chemical control had varying successes in the programs conducted. Considerations when looking into these reports is the different chemicals used, the varying quantities and associated costs.

Grand et al (2014) concluded that ox bile provides a relatively effective medium, requiring only a single injection.

Lassig (1995) wrote that copper sulfate was the most recommended poison due to it being effective, inexspensive, readily available and safe if handled correctly. Problems with copper sulfate include the potential for heavy metal pollution resulting in harm to reefs, animals or death. Other chemicals used including formalin, aqua ammonia solution and hydrochloric acid have been found to damage injection guns. There are also factors around getting the correct dosage and the safety of these methods. Research has found that ‘Dry Acid’ or sodium bisulphate is now the chemical of choice, as it is inexpensive, widely available and breaks down in seawater causing no harm to other forms of life.

Kenchington & Pearson (1981) found locally intensive control program as well as widespread control unfeasible.

Johnson et al (1990) highlighted the use of surveys with their use in the present study of fundamental importance, in assessing whether the objectives of the program had been achieved. In future, more detailed surveys could also be used to provide valuable insights into the timing, methodology and likely achievements of proposed control programs. Findings from this study also indicated the need to maintain detailed records of costs. Attempts at control are likely to be ineffective if they are implemented on a single "once off" basis.

Loosanoff & Engle (1942) needed more well suited and adapted methods to achieve the best outcome. The method allowed for an abundance of starfish to evade the control effort was highly ineffective and a waste of resources, due to currents moving limes away from selected sites. Fortunately, this method was found to cause no death or injury to oysters, clams or other molluscs. The method was still concluded as cheap, effective and relatively harmless.

Possible application in Ōhiwa Harbour

The method of chemical control could have the desired outcome in Ōhiwa Harbour. Vinegar is the cheapest, readily accessible chemical to use and should be adapted for the harbour. Although sea trials are yet to be undertaken, this chemical only needs to be administered once with a 100% kill rate. The chemical used must cause no harm to mussels or other species as it would defeat the purpose of the control programme, this can be tested using vinegar in which there is no reason to believe it may harm other aquatic species. Ongoing and extensive programs would need to be considered, as the permanent removal of the sea star within the Ōhiwa Harbour would decrease species’ diversity and isn’t a viable option. Instead of looking at controlling the species at a number where it isn’t detrimental to mussel abundance, should be examined and implemented. Research into the New Zealand eleven-armed sea stars needs to be conducted with trials of how they react to the chemical as they have not been a species of focus in a control program. An ongoing program with comprehensive surveys undertaken, that is both cheap and effective whilst being safe, needs to be adapted for the Ōhiwa Harbour. Another issue is the fisheries regulations of only 15 starfish allowed to be taken daily. Permits can be granted by the Ministry of Fisheries to allow the eradication of an unwanted aquatic species but a clear plan to justify the need will have to be submitted. With the advancements in techniques, this should be simpler and as the most widely used method could prove the most successful.

Part 3: Traps

Trapping is a method that can be utilised, although not very well practised.

Method

Andrews, Whayman, Edgar (1996) evaluated trapping to see if it was an effective method for minimising infestations of starfish on shellfish farms, and to objectively assess the value of sea star traps when used in commercial applications.

Andrews et al (1996) completed an experiment within Ralphs Bay, in the lower Derwent Estuary in 1995. This was done to test the efficiency of the locally produced Whayman-Holdsworth trap in controlling *Asterias amurensis.*

Barkhouse et al (2007) explains two types of traps that are used to control starfish and looked at the Whayman-Holdsworth sea star traps also.

The Joint Standing Committee on Conservation/Standing Committee on Fisheries and Aquaculture National Taskforce on the Prevention and Management of Marine Pest Incursions (1999) detailed the method trapping, as a means to reduce sea star numbers, and was tested in the years 1994 and 1996 by the Tasmanian Department of Primary Industry and Fisheries. The potential for using traps to control the migration of sea stars was tested by trapping at the perimeter of an area which was cleared of sea stars by divers.

Materials and process

Andrews et al (1996) were very specific when selecting sites to achieve the objectives of the control project. Location needed to be in the lower Derwent Estuary or northern D'Entrecasteaux Channel, have varying densities of *Asterias amurensis* ranging from moderate to high. The substrate also had to be sand/silt with homogeneity and similar bathymetry and currents. The sites also had to be readily accessible at all tides from a small craft, and pose no disruptions to boat traffic or shipping operations.

Andrews et al (1996) the trap is shaped in the form of a truncated cone. The bottom and sides are covered in 26 mm synthetic mesh with the top, circular in nature without covering. The frame of the trap is made of 10 mm mild steel rod, with a base diameter of 100 cm, a top or entrance diameter of 60 cm and an overall height of 12 cm. A plastic bait holder fits within the mild steel ring located in the centre trap entrance and is retained by a short length of synthetic cord tied to the top frame. Three 80 cm lengths of polypropylene rope are spliced to the trap opening at three evenly spaced points around its circumference, and the loose rope ends are in turn spliced together forming a three point harness, terminating in a large stainless steel shark clip. A small polystyrene net buoy mounted below the shark clip holds the harness above the entrance when the trap is submerged.

Andrews et al (1996) the Whayman-Holdsworth sea star trap was assessed at four sites, each approximately 10,000 m^2 in area. The first phase of trap assessment had two main study areas, one with moderate and the other with high densities of *Asterias amurensi*. The low to moderate density site was located 400 m east of Huxley's Beach. The high density site was located west of Richardson's Beach. A further two control sites were also used.

Andrews et al (1996), approximately 250 sea stars were collected randomly with the maximum arm length measured.

Forty nine sea star traps were baited with approximately 250 g of Atlantic salmon frames and deployed at each site. The traps were baited between 24 and 336 hours with traps arranged in a regular array, with seven rows and seven columns of traps, spaced 15 m apart.

Traps were fastened to each longline with a large stainless steel shark clip whilst railway iron weights anchored the ends of the longline. Buoys marked the line position.

Barkhouse et al (2007) mentioned two traps - one is a modified crab trap with a mesh size of approximately 15 mm, and the other is a domed shaped trap with opening on the top.

Monitoring

Andrews et al (1996) implemented before the experiment on the 1 August 1995, surveys to quantify the density at the low and high density sites. This was established using diver censuses, control sites were designated alongside them with density measured also. This was done by counting all sea stars along six 100 m by one metre transects, varying between four and six transects in the control areas.

Andrews et al (1996) had a program that implemented the mark recapture trial that varied depending on the weather. Traps were pulled, emptied, re-baited and reset 14 times over a period of 51 days.

Andrews et al (1996), *A. amurensi* collected in each trap were packed into bags and labelled, identifying the position of the trap, the array of the trapping and the date of retrieval. The bags were then taken to the Department of Primary Industry and Fisheries Marine Research Laboratories, where the starfish were counted and the associated by-catch identified. On 18 September, the sites were again surveyed for starfish density by divers.

Results

Andrews et al (1996) saw a total of 97,972 sea stars caught over the 51 days, 53,365 from the low density areas and 44,607 from the high density area. Numbers of sea star per trap declined throughout the trial, few species were caught as by-catch. It was found that the predicted reduction did not occur. Surprisingly, there was also no significant difference between high and low densities despite the large difference between the numbers of sea stars at the two sites. Significant differences between catch rates of traps immersed for differing periods of time was evident, with more sea stars caught within the first two days with traps later becoming saturated.

The Joint Standing Committee on Conservation/Standing Committee on Fisheries and Aquaculture National Taskforce on the Prevention and Management of Marine Pest Incursions (1999) found perimeter trapping, even with traps spaced only 2½ m apart, not effective in preventing sea stars entering the cleared area. Despite these problems, trapping was judged as the best available control method for chronic infestations, regardless of density or depth.

Cost

Andrews et al (1996), there were trials to ascertain whether trapping was more cost efficient than chemical control methods. There seems to be little difference between the cost efficiency at low densities. At higher densities traps become the more economical method.

Barkhouse et al (2007), the cost of using sea star traps includes the cost of each cage (approximately $65 each), fuel to travel to and from the traps and wages for labour and bait. An additional cost to be taken into consideration is the cost of replacement cages from being broken or lost.

Discussion

Andrews et al (1996), the Whayman-Holdsworth trap is concluded as the best method to control chronic sea star infestations regardless of density or depth. Traps are robust, easy to maintain and remove target species with very limited by-catch, although they are only suitable for long term control programs. Intensive trapping is known to attract sea stars to the area.

Barkhouse et al (2007) found using cages for large scale removal of sea stars is impractical due to the high costs associated with the labour required. The Whayman-Holdsworth sea star traps was also found to be ineffective in areas where sea stars were found in low densities and in areas where other food sources were abundantly present. Also, the suggested weekly deployment of traps was not easily maintained. Other studies using Whayman-Holdsworth sea star traps looked at their potential efficiency of preventing sea stars from entering a cleared area by placing traps 2½ m apart around a perimeter. The traps were found to be unsuccessful at stopping sea stars from migrating into the cleared area.

Barkhouse et al (2007) surmised that sea star traps may be efficient to use in small enclosed areas where there is a high abundance of sea stars and low alternate food sources available.

Possible application in Ōhiwa Harbour

Due to trapping requiring a lot of maintenance, emptying and re-baiting as such, it may not be as well suited to the Ōhiwa Harbour. It is deemed best for long term efforts in small enclosed areas. It will prove costly having to run for such a long period of time before proving effective. It is also largely unused due to it being unsuccessful in minimising sea star numbers. The processes outlined have all proved ineffective, so to adapt a failing method would ensure more money and research would need to go into ensuring the method and processes are used in a way that will be successful. The method would need to be improved before being able to be implemented. I do not recommend the use of trapping to control sea star populations in the Ōhiwa Harbour because of these reasons. The cost compared to the success rates concludes that other methods would be best suited for the purposes of the Ōhiwa Harbour.

Part 4: Other methods

There are several methods that were trialled but due to inefficiency or risk, are not in practise anymore. Some of these methods include cutting, biological controls and fencing. Within this section, other methods are included that can loosely be related to the problems within Ōhiwa Harbour.

Method

Lassig (1995) states one of the earliest methods of starfish control was cutting up starfish, however, this method has been disbanded as it became known that some starfish can regenerate, multiplying the problem.

Flimlin & Beal (1993) agrees that culturists should not cut starfish and throw pieces back into the water. Starfish have the ability to regenerate. Some starfish species can regenerate an entire organism from just one arm. The process is slow, requiring as much as one year.

Barkhouse et al (2007) fences are an exclusion method, which are primarily used to protect scallops from predation. Numerous studies have shown fences to be effective in controlling crabs but the effectiveness of fences against sea stars has not been fully explored. One study looked at the exclusion of both crabs and sea stars using a one metre high fence with a 45° overturned edge of 15 cm and embedded 20 cm into the substrate. Predators were removed bi-weekly by diving and were thus reduced by a factor of five to seven within the enclosed area. The Great Barrier Reef Marine Park Authority experimented with a steel wire mesh fence (one meter high) with a 60 cm overhang at the top to control crown-of-thorns sea stars. They found the fence to be an effective barrier for this species of sea stars, however, there were some drawbacks with the method concerning cost and up-keep of the fence. The cost of the fence is high with materials running at approximately $8.45 CAD/m. The fence is difficult to set up in rugged areas and there will be additional maintenance costs associated with damage to the fence due to rough sea conditions. Furthermore, fences did not stop juvenile sea stars from migrating or sea star larvae from settling into the protected area.

Lassig (1995) fencing was also a method mentioned, once an area is cleared of starfish the idea of erecting a barrier or fence to keep starfish from repopulating the area, has been researched. The best structure was found to be rigid steel wire mesh one metre in height with a 60 cm overhang. Unfortunately, Lassig (1995) found the creation of a fence to be difficult due to expenses, construction and maintenance as they are prone to damage. They are also aesthetically displeasing.

Kuris, Lafferty, Grygier (1996) considered (*Orchitophyra stellarum)* as a control agent of (*Asterias amurensis)* due to its substantial effect on their male gonads and feeding on the germ cells. It has also been repeatedly associated with low male sex ratios, mortality's of males, and reduced recruitment following years of infection levels.

Byrne, Cerra, Nishigaki, Hoshi (1997) similarly did experiments on the effects of *Orchitophyra stellarum* on Japanese sea star *Asterias amurensis*. Male infertility is a new phenomenon affecting populations of the Japanese sea star. The agent causing partial or total castration of the testes is identified to be *Orchitophyra stellarum*, a parasitic ciliate endemic to the north Atlantic. This ciliate disrupts the germinal layer and phagocytoses sperm.

Lamare, Channon, Cornelisen, Clarke (2008) tested archival tagging of sea stars. This study represents one of the first to utilise electronic tagging to study the ecology of a mobile invertebrate such as a sea star. The tagging was undertaken to test the viability of using electronic tags in research on the ecology of the sea stars in a New Zealand fiord.

Lamare et al (2008) started this experiment as sea stars are difficult to tag, so there is little information on activity of sea stars in their natural environment over extended periods of days to weeks. This experiment occurred at Espinosa Point, Doubtful Sound along the southwest coast of New Zealand. New Zealand sea star *C. muricata* was tagged with small archival electronic tags that recorded water temperate and depth every five minutes for up to two weeks. The effects of the tagging were tested in the laboratory and in the field, with tagging having no detectable influence on the species.

Lamare et al (2008) sea stars were tagged with small archival temperate and pressure DST-milli™ electronic tags manufactured by Star-Oddi (Iceland). Tags were attached by piercing one arm 10 mm from the central disk with 0.7 mm stainless steel wire. The piercing was directed through the mid-line of the arm, with the wire protruding through the oral side doubled back between the arms. The tags have a small attachment hole that the wire was threaded through, and both ends of the wire twisted together and the excess wire removed. This left the tag firmly hatched to the aboral surface of the sea star arm.

Barkhouse et al (2007) conducted a review of existing control methods of sea stars. It was found that methods such as the suction dredge, the plough, heavy metals or broadcast lime application are no longer used due to their inefficiency or harmful effect on the environment.

Discussion

Byrne (1997) tested whether this parasite could be used as a biological control for the predatory sea star but the idea was not supported. Due to the parasite's lack of species specificity, there are cautions against its use. The apparently rapid spread of *Orchitophyra stellarum* in Japan and its ability to paralyse several asteroid species, indicates that the use of this parasite for biological control in Japan, or elsewhere, might result in the infestation of a range of endemic asteroids in the family Asteriidae with serious consequences for their population biology.

Lamare et al (2008) surmised that electronic archival tagging used in this study provide continuous, fine time-scale, quantitative information on sea star activity such as the vertical position, vertical direction and rates of movement at the individual level. The data collected shows the potential of electronic tagging as a powerful tool for understanding behavioural ecology of sea stars and other foraging benthic invertebrates beyond that possible from discrete observations.

The research done by Lamare et al, could prove useful when trying to adapt a method to the Ōhiwa Harbour. Many methods will require more research before being able to be successfully adapted to the harbour. Some of these include looking into the eleven armed starfish as no control programs have focused on this particular species. Considering it is the focus within Ōhiwa Harbour, research into how they will react to chemical control and how much can be safely removed before altering the ecosystem will need to be studied. Tagging may be a useful tool to undertake this further research.

Causes of sea star population increase

Yamaguchi (1986) theorised the reasoning's behind *Acanthaster* infestations in the Ryukyu Islands as having originated from the larvae transported by the warm Kuroshio Current. The Kuroshio is now known to have changed its path drastically in 1975 during the period of the infestations. The hypothesis of larval transport by the oceanic current was supported by a coincident shift in the sites of *Acanthaster* infestation in the extra tropical waters.

Lee (1951) believed that starfish outbreaks fluctuated in abundance from year to year, due to temporary relaxation of control efforts when few starfish are to be found. These then resulted in significant increase of starfish. Migrations from uncultivated areas not subject to control measures are also considered responsible for maintaining the starfish population.

Potential uses of sea stars

Lee (1951) summarised some investigations into uses of sea stars. Some found value of starfish meal as a feedstuff. It was found to be a valuable protein supplement in amounts up to six percent by weight of growing mashes for chicks. In addition, starfish meal satisfactorily supplied both protein and lime in laying mashes.

Raw starfish used as fertiliser supply about 1.3% available nitrogen and 3.5% of acid soluble calcium. The proximate, analysis of starfish does not indicate any other way in which starfish might be used.

Lee (1951) who studied the chemical composition of sea star concluded that fresh sea stars will yield one ton of meal per four tons of raw material. Sea star meal contains about one half the proteins of that of fishmeal but compares favourably to meal prepared from crab or lobster scrap and shrimp bran. The protein portion in sea stars contains some of the essential amino acids. Experiments provided evidence that sea star meal could be used satisfactorily as one of the protein concentrates in chick rations. However, the high calcium content of sea star meal, limits the amounts that can be fed to chicks.

Whakatane Beacon (2012) Te Upokorehe a hapū tied to the Ōhiwa Harbour, promoted eating the starfish as a solution. Control efforts in Maketū, New Zealand saw starfish collected, successfully used to fertilise kumara gardens.

Summary of findings

This table shows the projects reviewed in relation to mussel restoration efforts. There are merits to each method but further research is necessary within Ōhiwa Harbour to be able to correctly establish which will work best.

Table 1 *Mussel restoration projects*

Author/s	Year	Location	Method	Success	Advantages	Disadvantages	Comments
Abadia, K	2014	Okahu Bay, NZ	Translocation, dropped 40,000 mussels	Not specified	Easy method, mussels can be donated, cost effective.	Expensive if support and donations aren't forthcoming	Simple method that can be easily adapted for Ōhiwa Harbour
Bay of Plenty Regional Council	2015	Tauranga Harbour, NZ	Caging (oysters)	Not specified	Cheap cages can be bought, many structures to secure them on.		Oysters deployed to check oil and metal contamination in water
Carey, C, Jones, J, Butler, R, Hallerman, E	2015	Clinch River, Virginia, USA	Translocation (freshwater mussels)	Successful	Mussels only found at site of translocation.		Should focus on the release of larger individuals
Cope, W, Hove, M, Waller, D, Hornbach, D, Bartsch, M, Cunningham, L, Dunn, H, Kapuscinski, A	2002	St Croix River, USA	Relocation (freshwater mussels)	Successful	In situ refugia a viable tool.	Low recovery in Site B due to movement of mussels	Movement a problem
Dunn, H, Sietman, B, Kelner, D	1999	USA	Relocation (Unionids, freshwater mussels)	Partially		Mussel movement	
Gray, M, Kreeger, D	2014	Pennsylvania, USA	Caging (freshwater mussels)	Successful	Viable tool.		

Author/s	Year	Location	Method	Success	Advantages	Disadvantages	Comments
Hua, D	2015	Clinch and Powell River, Virginia, USA	Caging (freshwater mussels)	Effective, successful	Determined site suitability.		Tool of value
Kreeger, D, Thomas, R	2014	Skippach Creek, Pennsylvania, USA	Translocation (freshwater mussels)	10% of mussels found a year later at sites			Two species of freshwater mussels were successfully reintroduced to Skippack Creek
Layzer, J, Scott, E	2006	French Broad River, Tennessee, USA	Translocation (freshwater mussels)	Good results		Extensive process with mussels placed in quarantine	
Luckenbach, M, Coen, L, Ross, P, Stephen, J	2005	Virginia, USA	Reef construction (oysters)	Successful	Able to be monitored easily.	More costly cause orderly and precise	
McLeod, I, Parsons, D, Morrison, M, Taylor. R, Le Port, A	2011	Firth of Thames, NZ	Caging (mussels)	Successful	Easy to replicate and adjust to better the method.	Costly, need monitoring and maintenance	Losing cages a problem, predation disregarded
Mussel Reef Restoration Trust	2015	Hauraki Gulf, NZ	Translocation (first drop) 7 t (mussels)	Successful	Easy to replicate, cost effective.		
New Zealand Herald	2014	Hauraki Gulf, NZ	Translocation (second drop) (mussels)	Successful	Mussels supplied, easy.	No order	
Schulte, M, Burke, R, Lipcius, R	2009	Chesapeake Bay, USA	Reef construction (oysters)	Successful	Oysters from other rivers.		Success due to high vertical relief reefs
Sheehan, R, Neves, R, Kitchel, H	1989	Virginia, USA	Translocation (freshwater mussels)	Good results	Relatively easy method.	Mussels unaccounted for	Mussel movement no problem

This table summarises the projects reviewed in relation sea star control efforts. Further research is required to select the most suitable method for Ōhiwa Harbour and it will need to work in conjunction with an appropriate mussel restoration method.

Table 2 *Sea star control projects*

Author/s	Year	Location	Method	Success	Advantages	Disadvantages	Cost	Comments
Andrews, Whayman, Edgar	1996	Ralphs Bay, Derwent Estuary, Australia	Trapping	97,972 sea stars caught in 51 days	Long term intensive programs	Require a lot of traps, a lot of material, expensive. Efficiency decreases over time.		Good method to control chronic sea star infestations
Australian Associated Press	2015	Great Barrier Reef (GBR), Australia	Robot/drone	Trial a success	Good advancement	Not applicable due to costs etc, maybe in the future.		
Barkhouse, Niles, Davidson	2007		Dredge, mopping, hand removal, brine, lime, trapping, fencing	Varied between methods	Mopping found most efficient for bottom culture. Brine doubled mussel yield	Hand removal not effective. Trapping impractical and costly. Fencing ineffective.	Mopping: $43,000. Brine: $4000. Lime: $600 - $20,000. Trapping: Cage: $65 each.	Some concerns of mopping effecting flora and fauna
Byrne, M, Cerra, A, Nishigaki, T, Hoshi, M	1997		Biological control	Unsuccessful		Unsafe, unsuitable.		Not well practised or researched
Calderwood, J, O'Connor, N, Roberts, D	2015	Belfast Lough, Northern Ireland, UK	Mopping	Varied successes	Mops more effective on beds with smaller mussels			Used film to monitor program
Galtsoff, P S, Loosanoff, V L	1939	Long Island Sound, NY, USA	All methods	N/A				A guide of methods

Author/s	Year	Location	Method	Success	Advantages	Disadvantages	Cost	Comments
Grand, A, Rivera-Posada, J, Pratchett, M S, Aguilar, C, Caballes, C F	2014	GBR, Australia	Chemical - injection	One chemical was more successful than the other	Single shot injection	Trial stage.		Would minimise costs and efforts required
Johnson, D B, Moran, P J, Driml, S	1990	Grub Reef, GBR, Australia	Chemical - injection	Unsuccessful	Starfish declined	Starfish still present, costly.	$111,600 - $35 per starfish.	
Kenchington, R A, Pearson, R	1981	GBR, Australia	Chemical control	25,850 starfish killed	Copper sulphate worked best			Locally intensive control program and widespread control unfeasible
Kuris, A M, Lafferty, K D, Grygier, M J	1996		Biological control	Partially	One agent had potential			
Lamare, M D, Channon, T, Cornelisen,C, Clarke, M	2008	New Zealand	Archival tagging	Successful				Good way to undertake research
Lassig, B	1995	GBR, Australia	All control methods	N/A	Injections - sodium bisulfate most efficient	Hand removal ineffective, fencing difficult and expensive.		This is a guide to handling starfish outbreaks
Lee, C	1951	Long Island Sound, NY, USA	Mopping, dredging, quicklime	N/A				Just explains each method
Loosanoff, V L, Engle, J B	1942	Long Island Sound, NY, USA	Chemical - lime	70% mortality, relatively successful	Cheap, and relatively harmless	Waste of resources, ineffective.		

Author/s	Year	Location	Method	Success	Advantages	Disadvantages	Cost	Comments
Paine, R T	1971	Anawhata, NZ	Hand removal	Partially	Mussel abundance increased by 40%	Species diversity and richness diminished.		All sea star were removed so couldn't regulate mussel numbers
Roe, I, Calderwood, K	2015	GBR, Australia	Chemical - vinegar	100% mortality rate	Cheap, readily available	Trial stages.		Could be an easy method for Ōhiwa Harbour
Whakatāne Beacon	2012	Maketū, New Zealand	Removal, injection, cutting	Successful		Some methods stopped when proved unsuccessful.	Interesting uses of starfish.	
Yamaguchi, M	1986	Ryukyu archipelago, Japan	Hand removal,	13m starfish removed	Bounty system, extra incentive	Reefs still devastated.	May be well over 500m yen for a period of 13 years.	

Appendices

Appendix 1 - Annotated Bibliography

Abadia, K. (2014). Waterways Cleaned with Mussel Power. East and Bays Courier: Auckland, New Zealand. *Retrieved from http://www.stuff.co.nz/auckland/local-news/east-bays-courier/10434404/Waterways-cleaned-with-mussel-power*

This is a newspaper article detailing the launch of the Ngāti Whatua Orakei Mussel Reef Restoration Project that occurred in Okahu Bay. This is one of the projects undertaken in New Zealand; it empowers the Māori, iwi of the area and encourages community participation. This is very relatable to the Ōhiwa Harbour, in which community and whānau, iwi and hapū participation is greatly encouraged.

Andrews, D., Whayman, G., Edgar, G. (1996). Assessment of Optimal Trapping Techniques to Control Densities of Northern Pacific Sea Stars on Marine Farm Leases. *Final Report to the Fisheries Research and Development Corporation.*

This report reviews the method of trapping and specifically the Whayman-Holdsworth trap. Although not a very common method used, the authors did note some attributes that could prove useful to other control programs. Many experiments were conducted in this study, investigating a variety of different things. It was found that divers are more efficient than traps during sporadic periods of sea star abundance. Traps were also unfounded to stop sea star migration.

Australian Associated Press (2015). Robotic Killer been Trialled to rid Great Barrier Reef of Crown-of-Thorns Starfish. Retrieved from *http://www.theguardian.com/environment/2015/sep/03/robotic-killer-being-trialled-to-rid-great-barrier-reef-of-crown-of-thorns-starfish*

This article details the latest efforts in trying to control outbreaks of the crown-of-thorn starfish on the Great Barrier Reef. With advancement in technology, this robot will be able to be sent out on the reef for up to eight hours at a time, delivering more than 200 lethal shots. Despite it not out-competing a human diver, it can sustain longer times in the sea and withstand any weather conditions.

Barkhouse, C. L., Niles, M., Davidson, L. A. (2007). A Literature Review of Sea Star Control Methods for Bottom and Off Bottom Shellfish Cultures. *Canadian Industry Report of Fisheries and Aquatic Sciences, 279, 39p.*

This literature review compiles information on sea star control methods that are in use today around the world. This includes methods to control sea star predation on a variety of molluscs, including mussels, oyster and scallops, for both bottom and off bottom cultures. A summary table is presented, which includes a description of each method, where it is used, cost and corresponding literature.

Bay of Plenty Regional Council (2015). Summer of Science for Tauranga Harbour. Retrieved from *https://www.boprc.govt.nz/news-centre/media-releases/media-releases-2015/december-2015/summer-of-science-for-tauranga-harbour/*

This article was a 2015 media release on the Bay of Plenty Regional Council website, detailing an Oyster Study initiated by the regional council science team in the Tauranga Harbour. This study is part of a five year sediment accumulation study project. The materials used are both easily accessible and cost efficient.

Brumbaugh, R., Beck, M., Coen, L., Craig, L., Hicks, P. (2006). A Practitioners' Guide to the Design and Monitoring of Shellfish Restoration Projects: An Ecosystem Services Approach. *The Nature Conservancy: Arlington, VA.*

This guide was created due to the increase of shellfish restoration projects in the USA. It clearly states the unique role shellfish play within their ecosystem. Lifecycle and how they work is detailed, as well as the systematic identification, design and monitoring template they endorse. Strategies for restoration are based on the stresses shellfish experience.

Byrne, M., Cerra, A., Nishigaki, T., Hoshi, M. (1997). Infestation of the Japanese Sea Star Asterias amurensis by the Ciliate Orchitophyra Stel-larum: A caution against the use of this ciliate for biological control. Tokyo, Japan: *Department of Life Science.*

This article looks at biological control as a method to controlling sea star populations after an agent that affected male fertility in Japanese sea star *Asterias amurensis* was found. Despite this, biological control was deemed unsafe and unsuitable and has been cautioned against. This method is not well practised or researched.

Calderwood, J., O'Connor, N., Roberts, D. (2015). Efficiency of Starfish Mopping in Reducing Predation on Cultivated Benthic Mussels (Mytilus edulis Linnaeus). *Aquaculture, 452*, 88-96.

This article looks at starfish mops, a modified dredge used to remove starfish from mussel cultivation beds, used in several fisheries today. This study tested the effectiveness of starfish mopping to reduce starfish numbers on mussel beds. This strategy, by reducing abundance of a major predator, could assist in reducing losses in the mussel cultivation industry. Although mops appear to remove starfish from mussel beds, there is uncertainty as to their exact effectiveness and there is scope to enhance efficiency of this predator removal technique. If we utilised this method for the Ōhiwa Harbour, we could adapt it so it is more effective to the given situation.

Carey, C., Jones, J., Butler, R, Hallerman, E. (2015). Restoring the Endangered Oyster Mussel (Epioblasma capsaeformis) to the Upper Clinch River, Virginia: *An Evaluation of Population Restoration Techniques. Restoration Ecology, 23(4), 447-454.*

This report details the study of reintroducing freshwater mussel *Epioblasma capsaeformis* in the upper Clinch River, using four release techniques and comparing them. It details each method including the study area with maps, along with predictions on post release survival rates. The sampling design is included and data analysis and results are discussed. The evaluations that constitute whether successful reintroduction has occurred, include settlement of introduced species, post-release survival of individuals and natural recruitment. This research is a good indication of differing techniques to try and reintroduce declining species and the successfulness of each method. Limitations are that it doesn't state in detail, how each method was undertaken, only detailing the post release monitoring techniques utilised.

Clayton, J. (2013) Mussel Restoration in West Virginia Streams. *West Virginia Wildlife Magazine, 13(1), 8-15.*

This is a brief article that details the freshwater mussel situation within Virginia Streams, relocation is acknowledged as the leading method to restore mussel populations. In Ōhiwa Harbour there are mussels present, protection from predators is the main problem. This method can still be adapted for different purposes.

Cope, W., Hove, M., Waller, D., Hornbach, D., Bartsch, M., Cunningham, L., Dunn, H., Kapuscinski, A (2002). Evaluation of Relocation of Unionid Mussels to In Situ Refugia. *Journal of Molluscan Studies, 69(1), 27-34.*

This report catalogues one study done to ascertain how successful the method of relocating unionid mussels, to in situ refugia within the St Croix River of Minnesota and Wisconsin, USA. When established correctly, in situ refugia may be a viable tool for preserving unionid mussels. This method has promise for Ōhiwa Harbour, particularly if suitable sites are found.

Dunn, H., Sietman, B., Kelner, D. (1999). Evaluation of Recent Unionid (Bivalvia) Relocations and Suggestions for Future Relocations and Reintroductions. *First Freshwater Conservation Society Symposium, 169-183.*

This report evaluates seven relocation projects of freshwater mussels. Methods, site selection and results are discussed and compared between each project with recommendations also noted. Relocation is a frequently used method in freshwater mussel restoration but it can also be adapted to the Ōhiwa Harbour.

Flimlin, G., Beal, B. (1993). Major Predators of Cultured Shellfish. USA: *North-eastern Regional Aquaculture Centre.*

This short bulletin lists predators to shellfish including starfish, crustaceans, gastropods, worms, and vertebrate predators, briefly describing some control methods.

Galtsoff, P.S., Loosanoff, V.L. (1939). Natural History and Method of Controlling the Starfish (Asterias forbesi, Desor). *Washington D C: United States Government Printing Office.*

This is similar to Loosanoff's other work; it is a detailed report of the starfish, its characteristics, habitat as well as distribution in several areas found through extensive surveys. It lists mechanical methods of control and also experiments on chemical controls.

Grand, A., Rivera-Posada, J., Pratchett, M. S., Aguilar, C., Caballes, C. F. (2014). Bile salts and the single-shot lethal injection for killing crown-of-thorns sea stars (Acanthaster planci). *Ocean and Coastal Management, 102(A), 383-390.*

This report details the advancement in chemical control achieved in Australia. Bile salts have recently replaced sodium bisulfate as the chemical used to inject, and thereby quickly and efficiently kill, individual sea stars. This study reports on results of experimental studies conducted prior operationalising bile salts for widespread use on Australia's Great Barrier Reef, both to optimise doses of bile salts and further examine potential side effects of administering low doses of bile salts into individual sea stars, when found at high concentrations.

Gray, M., Kreeger, D. (2014). Monitoring Fitness of Caged Mussels (Elliptio Complanata) to Assess and Prioritise Streams for Restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems, 24(2), 218-230.*

This study describes the use of caged mussels as bio indicators to test prospective restoration sites, for their ability to support mussel fitness prior to beginning actual restoration. Mussels (*Elliptio complanata*) from a healthy population were caged and deployed to candidate streams. Their survivorship, condition, and proximate biochemical composition (protein, carbohydrate, lipid) was then monitored for one year. Streams that supported mussel fitness as well as or better than their source stream, were considered to be suitable for restoration. The methods, results and discussion of the research project are included.

Harris P., Babcock M., Carls M., Brodersen C., Rice S. (1998). Restoration of Oiled Mussel Beds in Prince William Sound, Alaska. *In Exxon Valdez Oil Spill Restoration Project Final Report Mussel Bed Restoration and Monitoring (pp 85-109).* National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Auke Bay Laboratory: Juneau, Alaska.

This chapter details the restoration of mussel beds contaminated by oil in Prince William Sound, Alaska in 1989. Five years after the spill, nine mussel beds significantly contaminated, were cleaned in an effort to reduce hydrocarbon concentrations in mussels and sediments. Methods, site selection, sampling and data analysis is discussed.

Hua, D. (2015). An Assessment of Site Suitability for Restoring Laboratory-Reared Juvenile Mussels to Historic River Reaches in Virginia and Tennessee. In propagation and monitoring of freshwater mussels released into the Clinch and Powell Rivers, Virginia and Tennessee (pp. 72-120). *Unpublished dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA, United States.*

This study discussed the use of caging to release rainbow mussel and wavy-rayed Lampmussel at three sites in the Clinch and Powell rivers. An overview of freshwater mussels in North America and specifically historical and current mussel and fish assemblages in Clinch and Powell rivers is discussed. Methods, material results and discussion are also included.

Johnson D. B., Moran P. J., Driml S (1990). Evaluation of a Crown-of-Thorns Starfish (Acanthaster Planci) Control Program at Grub Reef (Central Great Barrier Reef). *Coral Reefs, 9(3), 167-171.*

This report evaluates the effectiveness of a starfish control program initiated in Grub Reef. This study utilised the method of injections and includes the materials and methods used, results and discussion. The study itself proved unsuccessful due to the large number of starfish remaining, despite numbers significantly declining. The effectiveness of injections is dependent on the formula and the way in which it is administered and would need to be considered due to the target species differing from the sea star in the Ōhiwa Harbour.

Joint Standing Committee on Conservation/Standing Committee on Fisheries and Aquaculture National Taskforce on the Prevention and Management of Marine Pest Incursions. (E.d.). (1999). *National Control Plan for the Introduced Marine Pest Northern Pacific Sea star (Asterias anumernis).*

This document is a long term sustainability plan for the Great Barrier Reef. It provides an overarching strategy for management of the Great Barrier Reef. It coordinates actions and guides adaptive management until 2050. The plan responds to the challenges facing the reef and presents actions to protect its values, health and resilience, while allowing ecologically sustainable development and use.

Kenchington, R A, Pearson, R (1981). Crown of Thorns Starfish on the Great Barrier Reef: *A situation report. Proceedings of the Fourth Coral Reef Symposium, Manila, Volume 2.*

A very brief situation report detailing old control programs undertaken. It also mentions efforts in other reef systems and concludes that 130 starfish per hours is the best hoped to achieve.

Kreeger, D., Thomas, R. (2014). The Re-introduction of Freshwater Mussels to the Mainstream Skippack Creek. *Final report to Lower Salford Township, PA. ANSDU Report No: 14-01. 20 pp.*

The aim of this pilot study was to ascertain the need for mussel restoration in Skippack Creek and to determine whether mussels can actually survive and grow if restoration is expanded. The Skippack Creek was defined with maps outlining the watershed, tributaries and the creek itself. A map of the study sites was included with methods used in this study and what each pertained detailed. Discussion on the results as well as factors that may have influenced the results was described.

Kuris, A. M., Lafferty, K. D., Grygier, M. J. (1996). Detection and Preliminary Evaluation of Natural Enemies Biological Control of the Northern Pacific Sea Star, Asteria amurensis. Australia: *Centre for Research in Introduced Marine Pests.*

This report looks at the potential of two agents as a biological control method for starfish infestations. The potential for one such agent *S.gibberum* was believed to be less so than the other agent *O.stellarum.* Further studies were noted to be required for both.

Lamare, M. D., Channon, T., Cornelisen, C., Clarke, M. (2008). Archival Electronic Tagging of a Predatory Sea Star – Testing a New Technique to Study Movement at the Individual Level. *Journal of Experimental Marine Biology and Ecology, 373, 1-10.*

This report details a new technique to quantifying the activity of sea stars at an individual level, which is important in further understanding how they structure marine communities. Archival electronic tagging was undertaken to test the viability of using electronic tags in research on the ecology of the sea stars in a New Zealand fiord, where their vertical distribution is influenced by the presence of low-salinity layers. The effects of the tagging were tested in the laboratory and in the field, with tagging having no detectable influence on in vitro survival, feeding rate, and righting time, or on their in situ movement and depth distribution. Tagging of sea stars in their natural environment provides information on depth distributions, vertical migrations and the influence of the physical environment on their behaviour. This study proved successful and may become necessary when undergoing research in Ōhiwa Harbour to understand the appropriate amount of sea stars that can be safely removed.

Lassig, B. (1995). Controlling Crown of Thorns Starfish. Australia: Great Barrier Reef Marine Park Authority.

A guide into crown of thorn outbreaks outlining when controls are deemed necessary, success of controls, the cost, labour and organisation, assessing survey techniques, searching for starfish, permits, reporting results, first aid and other such necessities. This article is an informative report which offers helpful tips and is a guide for any control program. Although it is specific to the Great Barrier Reef and the species crown-of-thorns, I recommend this should be read before starting any program within the Ōhiwa Harbour.

Layzer, J., Scott, E. (2006). Restoration and Colonisation of Freshwater Mussels and Fish in a Southeastern United States Tailwater. *River Research and Applications, 22*(4), 475-491.

This report details the translocation of fresh mussel species and the occurrence of fish species in the Tennessee River which declined after the creation of the Douglas Dam. This resulted in the initiation of minimum flows and consistent reaeration improving conditions for the species. The study areas and maps are included, historical fish and mussel fauna is presented, yet poorly known. The methods and results are discussed and very detailed but this report is based on work carried out in the late 1990's and early 2000's, in another country and regarding different mussel species, so would need to be adapted accordingly for the Ōhiwa Harbour.

Lee, C. (1951). Technological Studies of the Starfish. *Washington D.C.: United States Department of the Interior, Fish and Wildlife Service.*

This article focuses on the five-rayed starfish *Asterias forbesi* within Long Island. This fishery leaflet details starfish controls, the chemical composition of starfish, value of Starfish Meal, thiaminase in starfish, starfish as fertiliser and economic considerations in the utilisation of starfish. There is extensive research within this report with relevant and prudent information available.

Loosanoff, V. L., Engle, J. B. (1942). Use of Lime in Controlling Starfish*. Washington, D C: United States Department of the Interior, Fish and Wildlife Service.*

This book details the new method of using lime and distributing it along the seafloor to kill starfish. This report is very thorough detailing the experiments and all the research undertaken. Because this method is relatively new within this report, it isn't as applicable to this day. There are advancements, and in some cases lime isn't used at all today.

Luckenbach, M., Coen, L., Ross, P., Stephen, J. (2005). Oyster Reef Habitat Restoration: Relationships Between Oyster Abundance and Community Development Based on Two Studies in Virginia and South Caroline. *Journal of Coastal Research, SI (40), 64-78.*

This study discusses findings relating to the value of alternative restoration metrics and associated success criteria for oyster restoration, using data from two very different systems and approaches: one conducted in Virginia's lower Chesapeake Bay (Rappahannock River), based on data from a two-year program utilising constructed reefs. The other study is a long-term study in South Carolina focusing on intertidal reefs. For each system, newly created reef structures were compared. Methods of site selection and reef construction for both are included, as well as data analysis, results and discussion. Again, focusing on oysters but the method is still applicable in New Zealand. This method is easily adaptable for Ōhiwa Harbour, although I recommend the more orderly approach in reef construction to enable more accurate monitoring.

McLeod, I. M. (2009). Green-lipped Mussels, Perna Canaliculus, in Soft-sediment Systems in Northeastern New Zealand. *Unpublished master's thesis, University of Auckland, Auckland, New Zealand.*

This study aimed to describe the formerly abundant but now severely reduced reefs of the green-lipped mussel, *Perna canaliculus*, on soft sediments. It describes human impacts on the marine environment in regards to mussel bed declines. It defines the characteristics of soft sediment mussel reefs in north-eastern New Zealand as well as small mobile invertebrates and fish associated. It then goes on to label factors preventing mussel reef recovery.

McLeod, I., Parsons, D., Morrison, M., Taylor, R., Le Port, A. (2011). Factors Affecting the Recovery of Soft-sediment Mussel Reefs in the Firth of Thames, New Zealand. *Marine and Freshwater Research.*

This study was designed and carried out primarily to test the hypothesis that mussel reefs in the Firth of Thames had not recovered from overfishing and increased sedimentation, due to the muddy sediments that replaced the reefs being unsuitable habitat for adult mussels. This incorporated the mussel restoration method of caging green lipped mussel (*Perna canaliculus*). The conditions of the area are included, the materials and methods used are described with the results discussed. Other factors possibly contributing to the mussel's inability to repopulate are included but require further research.

Mussel Reef Restoration Trust. (2015). Revive our Gulf Timeline. *Retrieved from http://reviveourgulf.org.nz/timeline.html*

The Revive our Gulf website is sponsored by the Mussel Reef Restoration Trust and catalogues their achievements and their progress. It also entails their vision, team and their inception. This website is a great interface for others to get involved and educated. Some issues around the community being unaware of the situation in Ōhiwa Harbour could benefit from a website detailing the efforts and would be a platform to ask for aid and resources.

New Zealand Herald. (2014). Mussel 'Magic Carpet' for Hauraki Gulf. *Retrieved from http://www.nzherald.co.nz/element-magazine/news/article.cfm?c_id=1503340&objectid=11324593*

This article details the second drop of mussels in the Hauraki Gulf as a part of the efforts of the Mussel Reef Restoration Trust. This project is a great way of minimising costs, utilising resources and is a successful next phase of the project. This sets an exemplary example of how restoration could occur in the Ōhiwa Harbour.

Nordqvist, S. (2014). Iwi Enlist Mussels to Clean up Auckland's Polluted Waters. *Retrieved from http://www.3news.co.nz/environmentsci/iwi-enlist-mussels-to-clean-up-aucklands-polluted-waters-2014082414#axzz3x9ikH3jA*

This article also talks of the Okahu Mussel Reef Restoration Project and the start of their efforts within the Okahu Bay. It tells of how they carry out the projects in the hopes that the mussels will clean the popular stretch of water. The mussels have been destroyed by dredging and pollution but the local iwi hope they can be repopulated.

Paine, R. T. (1971). A Short-term Experimental Investigation of Resource Partitioning in a New Zealand Intertidal Habitat. *Ecology, 52(6), 1096-1106.*

This article was looked at due to the consequences of removing a single species. It is important when considering methods, the implications of each. If removal is chosen it is now known that sea stars are keystone species and will alter the current ecosystem. Considering the sea stars in Ōhiwa Harbour will not be able to be eradicated, instead removed to a suitable number that will maintain the current ecosystem. This will require further research, as this knowledge is not known.

Paul-Burke, K. (2015). An Investigation into Marine Management of Taonga Species in Aotearoa New Zealand: A Case Study of Kutai, Perna Canaliculus, Green-Lipped Mussels in Ōhiwa Harbour. *Unpublished doctoral thesis, Te Whare Wananga o Awanuiarangi, Whakatane, New Zealand.*

This thesis investigates marine management of taonga (treasured) species in Aotearoa, New Zealand with focus on the mussel, *Perna canaliculus,* green-lipped mussel populations in the Ōhiwa Harbour. This thesis provides relevant information to the topic matter and the location, particularly Chapter Four – Mussels, Sea stars and Soft Shore Systems. Good thesis for background information and baseline data.

Paul-Burke, K. and Burke, J. (2013). An Investigation into the Current State of Sea Star (Coscinasterias muricata) and Kūtai (Perna canaliculus) Populations in the Western Side of Ōhiwa Harbour 2013. *Report Number OH-004. Whakatāne, New Zealand: Bay of Plenty Regional Iwi Fisheries Forum, Bay of Plenty Regional Council, Ministry of Primary Industries (Fisheries).*

This report details the state of sea star and mussels in Ōhiwa Harbour and is a continuation of survey's conducted in 2007 and 2009.

Roe, I., Calderwood, K. (2015). Household Vinegar Advances the Fight Against Crown of Thorns Starfish Threat on Great Barrier Reef. *Retrieved from* *http://www.abc.net.au/news/2015-09-23/household-vinegar-advances-fight-against-crown-thorns-starfish/6797776*

This article details research into vinegar as a new chemical that can be used to control crown-of-thorn starfish. This method is deemed cheap, easily available and safe for everything other than the starfish themselves. The next phase is undertaking large scale field testing.

Schulte, M., Burke, R., Lipcius, R. (2009). Unprecedented Restoration of a Native Oyster Metapopulation. *Department of Fisheries Science, Virginia Institute of Marine Science, The College of William and Mary: Gloucester Point, VA.*

This study explains the great successes achieved in oyster restoration in Great Wicomico River. The success is attributed to deciding on construction of high relief reefs, the first of its kind in the region. This report is simplistic only briefly entailing methods, results and discussion. Although another region and species, the method of reef construction is still viable as an option in New Zealand.

Sheehan, R., Neves, R., Kitchel, H. (1989). Fate of Freshwater Mussels Transplanted to Formerly Polluted Reaches of the Clinch and North Folk Holston Rivers, Virginia. *Journal of Freshwater Ecology, 5(2), 139-147.*

A study of adult freshwater mussels translocated due to water pollution in rivers in Virginia. This study was completed to test whether the area was habitable for freshwater mussels, although the fate of the mussels was largely unknown. Due to the year it was completed, technology and advances have been made to more accurately monitor and undertake such projects.

Whakatane Beacon (2012). Starfish Massacre on Cards. *Retrieved from* *http://www.kawerauonline.co.nz/news/starfish-massacre-on-cards.html*

This newspaper article details possible plans for Ōhiwa Harbour as well as efforts in Maketū.

Yamaguchi, M. (1986). *Acanthaster planci.* Infestations of Reefs and Coral Assemblages in Japan: A Retrospective Analysis of Control Efforts. *Coral Reefs, 5*(1), 23-30.

This study details the *Acanthaster planci* infestations in Japan. Intensive controls efforts undertaken were hand collection and disposal on land. It includes background information, results and discussion and also explores theories as to why the outbreaks occur in the region.