World Abalone Fisheries and Stock Enhancement

Where in the world are we at? Is it worth it?

A report for

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Executive Summary

This report gives an overview of the world's wild harvest abalone fisheries, how they are managed, and the findings of what stock enhancement has been occurring. The countries explored are Australia, New Zealand, Japan, USA and the Republic of South Africa. Hong Kong and The Peoples Republic of China was also visited to explore the market for abalone and customers' perceptions of hatchery spawned but wild raised abalone.

The world's wild abalone fisheries production is declining while abalone aquaculture production has been increasing. Australia's wild harvest abalone production remained relatively stable since the commercial dive fishery started in the 1950's until about 2010. Total allowable commercial catch (TACC), commonly called quotas, were implemented in all harvesting regions by the mid to late 1980's. Successful abalone recruitment is the key issue for a sustainable fishery. There was a low biomass post the implementation of quotas but now fishing pressure was controlled and reduced. A slow recovery occurred from a low spawning biomass until very good recruitments in the late 1990's, from 2002 to 2006 there was a large spawning biomass on the reefs, the largest it had been for 15 years; recovery was occurring.

Unfortunately, since 2010, despite the large spawning biomass and controlled fishing pressure, production has decreased at an alarming rate. What is happening to recruitment? Why are the abalone larvae not surviving? How can it be overcome? Something is happening when the abalone are in their early larval and settlement stage, at their most vulnerable stage. Can they be nursed through this stage in a hatchery, reseed them when they are stronger and enhance the reefs and commercial production? These questions were the motivation to visit the world's wild harvest abalone countries.

Abalone stock enhancement is in its infancy, except for Japan where 30 plus years of stock enhancement sees 30% of their total annual harvest consisting of seeded abalone that achieves a survival rate of 10-15% of what is released. All other countries have undertaken experiments, some for decades with varying results. Further research particularly around the ecology of release areas and large scale projects are needed to determine and improve success. This will be long-term investment requiring substantial money and resources. It is therefore crucial that there is confidence in government to provide protection to the reseeded abalone from any external factors which may interfere with the abalones' survival.

Not all locations will be conducive to successful stock enhancement and keeping the handling of the juvenile abalone to a minimum is important for survival. No release method stands out as the most successful. The ideal release size appears to be about 30 millimetres shell length. This size is the best because of genetic fitness. The juvenile abalone is strong enough to not succumb to the environmental factors inhibiting recruitment in the first place and is small enough not to be too domesticated from being raised in a hatchery.

Genetic diversity contributes to the genetic fitness and the brood stock parents consisting of tens of males and tens of females should be sourced from the area the juveniles are intended to be released to achieve the greatest survival. The parents should be replaced after each spawning season.

Stock enhancement, combined with resting areas, will be the best way to rebuild the biomass of abalone on the reefs and therefore commercial production. Utilising technology in a fully transparent commercial fishery will be the way to monitor and manage harvesting pressure to find optimum efficiency, quality and reef production.

To progress abalone stock enhancement the following recommendations are made:

- Form professional relationships with colleagues in the world's abalone countries to share knowledge about issues and challenges faced.
- Form a working group of expert skill sets to explore and steer a commercial stock enhancement project. Utilizing resources such as the 'Responsible Approach Update 2010' (Lorezen, K. et al 2010) and Lorenzen's 'Enhancefish' software.
- Work with the abalone aquaculture industry as they understand the early life cycle of abalone.
- Ensure governance arrangements are sufficient to provide the security necessary to undertake an investment in commercial stock enhancement.
- Undertake inclusive and transparent trials including all stakeholders in the process.

A recommendation from the market is to tell the story of successful stock enhancement whereby the sustainability of abalone stocks is being ensured.

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Foreword

Growing up on an island 30 kilometres off the coast of Elliston on the Eyre Peninsula of South Australia meant the ocean and fishing was surrounding me. My parents were from the land and bought Flinders Island to grow Merino wool. However, with fishers as their neighbours it was not long before my parents purchased an abalone licence.

We shifted to the 'mainland' when I was 10 years old so my brother, sister and I could attend a 'normal' school. My father continued pursuing seafood ventures, so I was exposed to many seafood species and businesses over the following decades. When I reflect back it may have been wise if he had stuck to farming which was what he knew best, because success at these businesses was rather varied. The adventure and lifestyle benefits of abalone diving captured my attention (when the swell is up you cannot work, but you can surf) and after completing my studies in 'the city' I returned to the coast of Eyre Peninsula to start my abalone diving career.

Over the past 20 years I experienced the recovery of the abalone fishery from over utilisation prior to quotas being introduced in 1985, resulting in an exceptionally good increase in the population of abalone in the late 1990's. This led to record harvests being enjoyed in the early 2000's. But, since the mid 2010's we have been presiding over the worst harvests since quotas were introduced and I needed to understand what could be done to address the situation.

Add to this the intrigue I'd always had for the world of abalone. How this underwater snail, a marine gastropod mollusc from the *Haliotidae* family harvested in the wild from the treacherous oceans of the Republic of South Africa, Oman, Japan, USA, New Zealand and Australia could be considered such a delicacy and one of the treasures of the sea by Japanese and Chinese consumers fascinated me.

Our experience of declining harvests is not unique. The countries mentioned above have all been there before us; their industries being older and more knowledgeable than ours. I wished to understand their story and learn what they have learned, to bring back the positive and successful aspects and apply them to our industry.

Acknowledgments

My utmost appreciation is extended to Nuffield Australia and Fisheries Research and Development Corporation (FRDC).

My brother Tobin (Figure 1), his wife Carissa and their three girls Meisha, Harper and Clea, my sister Shelley and her two children Chloe and Taris, my mother Pamela and old man Peter who have been holding the fort, listening to me with envy and wondering if I can actually spend any time in one spot?

My beautiful partner Pepita for whom our first real year in a 'relationship' has seen me spend as much time away as home and is also wondering if I can actually spend any time in one spot?

To Bill Ford and Dr Nicole Hancox for tending to local abalone industry issues in my absence.

My amazing hosts who went out of their way to look after me when I visited, some I had never met before and were very receptive to this guy who sent an email out of the blue introducing himself, what he was doing and that if he were to come and visit would they take the time to explain a little bit about their industry, what management underpins it and if any stock enhancement had been taking place?

- Dr Tom McCowen
- Assistant Professor Jun Hayakawa
- Jim Marshall
- Erick Peterson
- Professor Ken Leber
- Professor Kai Lorenzen
- Professor Peter Britz
- Alli Lea

And to all of my new friends who shared their story with me on my journey of discovery.

Abbreviations

AVG; Abalone Viral Ganglioneuritis

Co-op; Co-operative

CPUE; catch per unit of effort (kilograms per hour for harvesting abalone)

GVP; gross value of production

H.; Haliotis

MLL; minimum legal length

MM; millimetre

MPI; Ministry of Primary Industry

PauaMAC; Paua Management Advisory Committee

NSW; New South Wales

NZ; New Zealand

PI; performance indicator

PIC; Paua Industry Council

Prof.; Professor

QMA; quota management area

RSA; Republic of South Africa

SA; South Australia

TACC; total allowable commercial catch

TAS; Tasmania

t; tonnes

VIC; Victoria

USA; United States of America

WA; Western Australia

Objectives

While abalone populations and commercial harvesting occurs in only a handful of countries around the world, cohesion between these countries is limited. Facing similar issues of sustainability and all focusing on the South East Asian market, great potential exists to collaborate and grow the wild harvest industry back to heights once enjoyed.

Objectives of this study are therefore to;

- Gain an understanding of the world's major wild harvest abalone producing countries.
- Explore the fundamentals of fishery stock enhancement with a focus on abalone.
- Determine if and how successful abalone stock enhancement can occur.
- Consider the implications of abalone stock enhancement (including to the market).

Figure 1: Author (left) and his brother, Tobin, with green lip (H.laevigata) and black lip (H.rubra) abalone

Chapter 1: Introduction – Australia

People of European descent started Australia's commercial abalone fishery around the 1950's, following the introduction of underwater breathing apparatus. However, prior to this Chinese immigrating to Australia in search of mining riches are said to have started trading abalone as early as the mid 1800's. Even before the Chinese, unsurprisingly, Australia's indigenous population had been harvesting and consuming abalone. When the first Europeans tried abalone at the offering of Aboriginal people they quickly became known as 'mutton fish' due to them being a rather tasteless and tough lump of meat (Harrison, 1983, The Tasmanian Abalone Fishery).

Today they are more generally referred to as abalone and are harvested from the southern waters of Australia from slightly north of Perth in Western Australia (WA), south along the coast through South Australia (SA), Victoria (VIC), around Tasmania (TAS) to north of Sydney in New South Wales (NSW). Four species are commercially harvested black lip, (*Haliotis rubra)*; green lip, (*H.laevigata)*; brown lip, (*H.cornicopora);* and roei, (*H.roei)*.

Each state has its own Fisheries Act and regulations that control the commercial, recreational and traditional harvest of abalone. The wild abalone population is a community resource and the State Government assumes ownership and management of it on their behalf. The Government's fisheries department in each state passes the cost of management back to the commercial sector by various ways. In VIC, TAS and WA Abalone licence/quota owners incur a resource rent based on 7.3%, 7% and 5.25% of gross value of production (GVP) respectively (Fox, McKibbon, Adams, 2018). NSW has a tiered system that ranges from 2-6%, increasing as more total allowable commercial catch (TACC) is allocated and the beach price received reaches certain thresholds (Smyth, 2018). SA is the only state that pays a fixed management cost that the fisheries department determines, regardless of gross value of production (GVP). For SA it has ranged from 8 to as high as 12% of GVP (BDO Econsearch, 2017).

Each state has a representative association that advocates and manages industry affairs on behalf of their licence holder/quota owner members. All state associations are members of the Abalone Council Australia Ltd who advocate and manage industry affairs, such as research priorities, at a national and international level.

Black lip is the predominant species and makes up 77% of Australia's 2018 TACC at 2,236 tonnes (t). Green lip makes up 19% at 478 t, roei 3 % at 79 t and brown lip 1 % at 27 t giving Australia's total TACC of about 2,889 t (Webster, 2018).

Diving using surface air supplied by a 'hookah' (motor driven air compressor) and a hose from a small vessel (5-10 meters) is the method used to harvest abalone in Australian waters. Divers must have a commercial abalone licence with an allocation of abalone quota for a designated zone to go fishing and collect abalone. A season generally runs for 12 months and

will start in late summer or early autumn to coincide with the abalone being at their best quality. They are in their worst condition when they are spawning and the few months after, which is during spring.

Black lip has a minimum legal length (MLL) that ranges from 110mm to 145mm. The majority of the bigger and better quality abalone is sold to the live market. Some will also be dried and the remainder canned. Black lip tends to grow best under and around cavernous rocks in shallower water that has a high swell activity. Black lip is mainly found in the eastern states in the cooler waters of the Southern Ocean.

Green lip generally grows larger than black lip and consequentially have a larger MLL at 145mm. They inhabit more open rocky bottom on deeper drop offs and edges aggregating in gutters where drift seaweed gathers. Green lip is found in WA and SA in an area of ocean called the Great Australian Bight. There is also a population around Flinders Island in the Bass Strait between VIC and TAS.

Roei are found in the shallow waters in the 'impact surf zone' of WA and western SA. They can tolerate warmer water temperatures and can grow up to 130mm in length. The MML in WA is 60mm and 75mm in SA and each has a small TACC allocated. WA is the only state with a recreational roei fishery that operates only a few weekends a year in a designated area on low tide when they are hand collected from exposed or slightly submerged reefs without diving.

Black lip and green lip are also taken by recreational divers with a daily bag limit of two per person per day in NSW to five per person per day in most other states. If fisheries inspectors or police find a person without a licence and in possession of more than 20 abalone that person is deemed to be trafficking and a hefty fine is received along with confiscation of all diving/fishing gear including boat and vehicle, plus a court will determine if time in jail is justified.

Illegal fishing or 'poaching' is an issue in Australia as there is considerable money that can be made. Opportunistic thieves and in the worst cases organised crime syndicates are caught from time to time. A small number of Australia's indigenous population have been caught and prosecuted for taking commercial quantities of abalone for sale under the pretences of traditional fishing. State and Federal Governments take poaching very seriously as it may compromise the sustainability of the resource if let get out of control.

Poaching, however, has not been the major threat to sustainability. Neither has overfishing, as each state and zone operates under strict harvest strategies which limit commercial fishing effort. Harvest strategies collect fishery performance data such as catch per unit of effort (CPUE), abalone size, and transect surveys are undertaken that monitor changes in abundance and fishery performance to make management adjustments to the TACC as necessary. Granted, adjustments need to be made quick enough and of an appropriate size

to negate the risk of overfishing and historically this has not been the case in every situation. Moves to electronic data reporting are helping allow more real time decisions to be made and minimise any risk of overfishing.

The biggest issues for the industry have been pests and disease and poor recruitment driven by environmental changes. In 2006, an outbreak of Abalone Viral Ganglioneuritis (AVG) devastated stocks in western and central VIC which closed the fishery for a number of years. Recovery is occurring and the fishery is back commercially harvesting but not to pre-AVG quotas.

A parasite called Perkinsus infects abalone and other mollusc in WA, SA and NSW. It flares up after warm water events caused by extra strong currents of warm water flowing further than their normal range or bodies of water being heated by the atmosphere for weeks before being dispersed by swell and wave action. This stresses the abalone allowing Perkinsus to thrive causing devastating mortalities and leaving survivors with unsightly lesions that renders them unfit for sale.

Another problem that has been arising from warm water events and shifting currents is kelp bed die offs, associated with a population explosion of sea urchins called *Centrostephanus rodgersii*. They devour the kelp before it can recover causing large kelp barrens meaning there is no food or shelter for the abalone. The NSW, eastern VIC and eastern TAS coasts are experiencing problems with *C.rodgersii.*

Other predators of abalone exist in all waters and consist of octopus, eleven armed sea star, rock lobster, wrasse and a whelk that bores a hole through the shell into the meat.

As can be seen from Figure 2, Australia's total TACC has been declining and since 2014 the situation has continued to worsen.

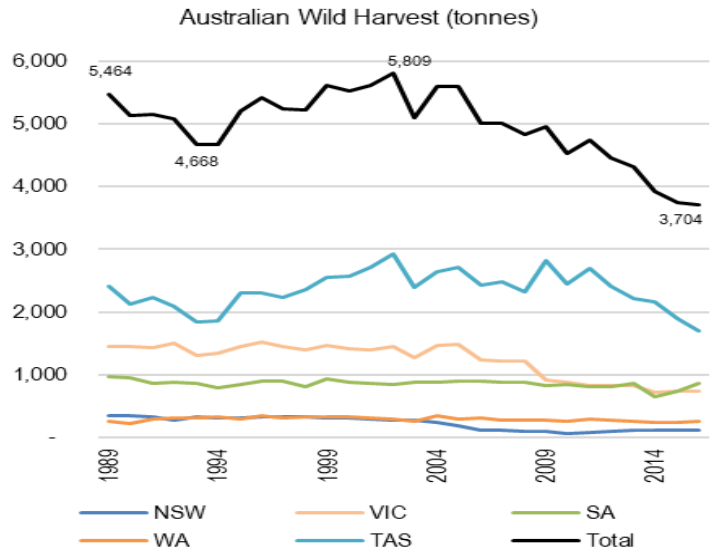

Figure 2: Wild Harvest Abalone Production. Source; Abalone Council Australia (2014)

Abalone aquaculture in Australia produced 757 tonnes in the 2015/16 financial year according to the Department for Agriculture Fisheries and Forestry, Australian fisheries and aquaculture statistics report 2016.

Abalone farms operate in all states except for NSW growing mainly green lip or a hybrid of black lip and green lip. All of the farms are utilising land grow out systems except for a farm in Augusta, WA, that has placed concrete structures on the sandy seafloor within a designated aquaculture lease area and is placing hatchery raised juveniles at about 18 months old (40 – 50mm) on them to grow out to about three years old (110 – 120mm) (Adams, 2017). The farm is in its infancy however, and commercial viability is uncertain. It is operating next to a productive wild harvest reef, is not incurring high electricity water pumping costs and is taking advantage of a supply of drift seaweeds and algae to feed the ranched abalone, all of which will improve their chances of being viable. A similar in-sea abalone farm at Elliston, SA, attempting to grow out juveniles on plastic troughs suspended in big nets under floating rings went bankrupt in 2016 after three different owners over a period of approximately two decades could not keep the business viable.

The WA ranching farm came about after research had been undertaken by the WA wild harvest abalone industry to test stock enhancement in the early 2000's. While the results showed promise, the industry decided against progressing to a commercial scale release after concerns around the potential for disease after the VIC outbreak of AVG (Hart, 2017).

Abalone aquaculture incurs very high production costs in Australia and the cost for juveniles is 2.5 cents per mm. Juveniles at 30mm would cost AUD 0.75 (Lindsay, 2017). This is one of the main reasons why abalone aquaculture has not progressed at the same rate in Australia as in other countries. Australian investors do enjoy tax minimisation incentives to conduct research and develop more efficient production systems, however this in itself does not provide a sufficient competitive advantage on the world scale.

World abalone production has increased rapidly since 2002 which has mainly been aquaculture production in the People's Republic of China, as can be seen in Figure 3.

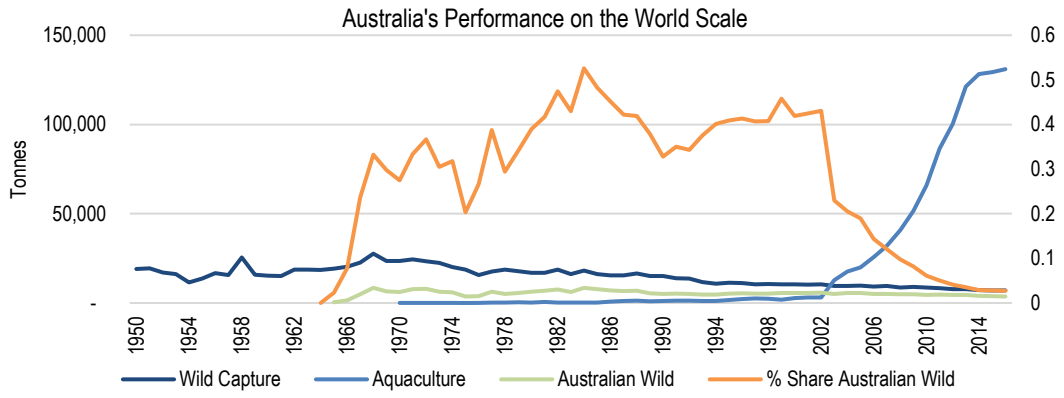

Figure 3: World Abalone Production. Source; Abalone Council Australia, 2014

Australia is no longer the major producer of abalone that it was and no longer enjoys 40% market share. The wild Australian abalone product is however very sought after as a premium abalone and as such a real potential to rebuild the wild biomass through stock enhancement exists. This report explores the world's wild harvest abalone fisheries and provides insights as to what stock enhancement has been taking place.

What is stock enhancement?

Marine stock enhancement is a set of management approaches involving the release of cultured organisms to enhance or restore fisheries. Such practices, including sea ranching, stock enhancement, and restocking, are widespread, of variable success, and often controversial. As explained by Professor Kai Lorenzen, Prof. Ken Leber and Prof. Lee Blankenship in their paper '*The Responsible Approach 2010*', which is arguably the premier paper written on stock enhancement by the most experienced scientists in the world on the subject. Visiting Prof. Lorenzen and Prof. Leber in Florida, USA, provided invaluable insight into stock enhancement and how it might be applied to abalone. Their explanations of the various forms that are referred to in this report are below.

Sea Ranching

Ranching systems operate for species that do not recruit naturally or for which natural recruitment is considered unimportant. Ranching systems are stocked and harvested to maximize somatic production (commercial fisheries) or the abundance of catchable-sized fish (recreational fisheries), often manipulating populations in ways that could not be achieved in naturally recruiting populations.

Stock enhancement

Stock enhancement involves the continued release of hatchery fish into a self-recruiting wild population, with the aim of sustaining and improving fisheries in the face of intensive exploitation and/or habitat degradation. Stock enhancements can increase overall abundance of catchable fish and fisheries yield, while allowing for higher exploitation rates than could be sustained by the natural stock alone.

Restocking

Restocking involves time-limited releases of hatchery fish, aimed at rebuilding depleted populations more quickly than would be achieved by natural recovery. In restocking, the release number must be substantial, relative to the abundance of the remaining wild stock, if rebuilding is to be significantly accelerated. Fishing intensity should be low in order to maximize the contribution of wild and released cultured fish to population growth.

Supplementation

Supplementation is the release of cultured fish into very small and declining populations, with the aim of reducing extinction risk and conserving genetic diversity.

Two components of stock enhancement that also need explanation, and became apparent when the author was talking with scientists and viewing experiments while diving, are genetic diversity and genetic fitness.

> **Genetic diversity** ensures that a large gene pool is maintained and that certain genetic traits from the brood stock parents do not dominate due to the brood stock pool being too small or too selective. Abalone spawn by releasing eggs and sperm into the water column where fertilisation takes place. To ensure enough genetically diverse parents are available, like in a natural situation where abalone will aggregate together at spawning time, it requires numerous abalone to be contributing to fertilisation with the strongest ultimately surviving through to mature adult abalone.
>
> **Genetic fitness** is an outcome of genetic diversity. Where good genetic diversity is achieved it can be said that genetic fitness will be higher. The first generation of juvenile abalone bred from brood stock sourced from the location at which the juveniles are to be released have the greatest chance of survival. Local adaptation in fish fingerlings has been observed in fresh water lakes (Lorenzen, 2017). In this instance fingerlings from brood stock in lake 'A', where released into lake 'B' 50 miles away, but did not survive or grow as well as fingerlings from brood stock that came from that lake 'B'. Their ability to survive in the slightly different conditions is compromised along with their ability to compete.

Prof. Lorenzen has developed a computer modelling program called '*EnhanceFish*' that is able to give an indication as to whether the fish species considered for enhancement is in fact a good species to try. Known information about the species including its growth rate, natural mortality and economic figures are entered to calculate whether it is likely to be a viable venture.

For the purpose of this report, which became evident with all interviewees, that stock enhancement is also referred to as reseeding. The terms were considered one and the same.

Chapter 2: World Wild Harvest Abalone Fisheries

New Zealand

Paua is the Maori and common name for abalone in New Zealand (NZ). Two species, black foot (*Haliotis iris)* and yellow foot (*H.australis)* (Figure 4) are both simply referred to as paua. Black foot is the only commercially harvested species although yellow foot has been harvested commercially in the past. Both species are harvested recreationally fishers and Maori as part of customary seafood gathering (McCowan, 2017).

Figure 4: Paua; black foot (H.iris) and yellow foot (H.australis).

Fisheries NZ a business unit of the Ministry of Primary Industries (MPI), is the Government department responsible for managing the paua fishery in NZ. The resource is owned by the crown on behalf of the community.

NZ's coast line and islands are divided into 11 paua fishing zones, called Quota Management Areas (QMA's). The zones, QMA's, are designated a PAU1, PAU2, PAU3 and so on. Each zone has an allowable catch that is divided amongst commercial, customary, recreational and also includes an allowance for mortality. This mortality allowance is an estimate of other sources of mortality such as illegal and unreported take, environmental factors and so on (Cooper, 2018).

The MLL of paua (for both recreational and commercial) is 125mm. Juvenile growth rates are similar across the country, however after reaching sexual maturity (normally around 70 to 80mm) they grow more quickly in the cooler waters of the south. This is thought to be due to limits on food availability as kelp growth slows in warmer northern waters leading to paua prioritising available energy into reproduction at the expense of growth. Consequentially the commercial industry self-imposes larger MLL's in the southern zones as they consider that the prevailing MLL doesn't protect spawning adults for long enough to contribute adequately to maintaining the population (McCowan, 2017).

The recreational MLL for paua is 125mm except for the Taranaki area, zone 2, in the south and east of the North Island where it is 85mm. The recreational MLL for yellow foot is 80mm. No recreational licence is needed to take paua, but a bag limit of ten per person of each species per day and an accumulation limit of two days catch means there is a possession limit of 20 paua or 2.5 kg of shucked meat is enforced. Dave Turner the Director of Fisheries with MPI did allude to the need for more responsibility to be taken by recreational paua fishers as there were frequent incidents of recreational fishers exceeding their bag and possession limits.

Paua is a shallow water species typically inhabiting the depth range from the intertidal zone down to ten meters and, as such, diving using breath hold technique and snorkel is the only means permitted. The only place permitted to use underwater breathing apparatus to harvest paua is zone PAU4, Chatham Islands, due to the risks to divers posed by Great White Sharks of which there are numerous and allegedly more aggressive than those found around the rest of NZ (Turner, 2017).

Paua are harvested from 8 of the 11 zones. Not all of the TACC of 914 tonne whole weight is harvested as some of the zones 'shelve' (withhold) percentages of their TACC as a conservative catch reduction measure so as not to over harvest or to speed up the rebuild of the fishery. The actual harvest in 2016/17 was 795 tonne (Cooper, 2017).

The commercial paua industry in NZ is represented by the Paua Industry Council Ltd (PIC) at a national level. PIC acts as an umbrella organisation providing advocacy and support to five regional level organisations called PauaMAC's. The PauaMAC's are generally incorporated associations, while PIC is a limited liability company. This means that PIC is able to enter into contracted research and fund large projects. All organisations are funded by way of compulsory levies on quota shares owned through the NZ Commodity Levies Act. There is an annual voting round which presents to quota owners a work plan and budget for the coming year to be approved and voted on. At the most recent vote on the levy funding arrangement 86% of the quota owners who voted, representing 94% of the TACC voted in favour paying the levy (Gibbs, 2017).

PIC and the PauaMAC's are using very innovative technology to capture their stock assessment performance indicators (PI's) and improve harvesting efficiency. Data loggers are used - the boat unit records catch information per diver and the diver unit nicknamed a 'turtle' is worn by the diver to track surface position using GPS/date/time and dive time/depth/water temperature. This information is then used to populate the online 'dashboard' system where harvesters can look up the CPUE and amount harvested for each fishing area. The 'dashboard' shows the amount of fishing that is happening so divers can better decide on the areas they want to fish to minimise effort waste covering the same bottom. This also can ensure CPUE does not drop due to divers unknowingly covering bottom that has already been worked. Dropping CPUE's is a trigger for reducing TACC's (Abraham and Terrill, 2017).

Julie Hills, Fisheries New Zealand principle scientist, conceded that the Government stock assessment data collection was not great and that the independent dive surveys were

expensive to undertake, and had not proved reliable in the past. She relied heavily on the industry collected data and the verbal opinions of the divers to guide the TACC process and that fisher instinct has been instrumental in managing such a large area of coastline that makes up the paua fishery.

Two paua hatcheries are operational in NZ, one in the South Island and one in the North Island. The South Island hatchery is located opposite the entrance of the Tory Channel and is owned and run by Mike and Antonia Radon. They have a small operation spawning and growing paua in which they then plant a nucleus to produce paua pearls. The pearls are not spherical like oyster pearls but half spheres, Mabe style, when cut from the shell. They exhibit the deep green and blue mother of pearl colours that paua are famously known for.

Mike and Antonia's hatchery has produced juveniles for reseeding and has the capacity to upscale should the need arise. They do not grow out the paua in a traditional aquaculture venture as it is not viable to do so. The same general consensus was reached from various discussions - that paua aquaculture struggles to be viable in NZ due to high production input costs, hence there are few aquaculture grow out businesses.

The North Island hatchery is located at Bream Bay. This is NZ's only commercial paua aquaculture facility and produces approximately 100 t of paua per year.

Stock enhancement has been taking place at an experimental level. Many trials have taken place in the north and the east of the South Island including in the Tory Channel. Dr Tom McCowan (Figure 5) is the Paua Industry Council's scientist and wrote his PhD on paua genetics and stock enhancement. He has managed the monitoring for most of the recent trials and is an expert in the field.

Figure 5: Author with Dr Tom McCowan in New Zealand

Dr McCowan believes there is potential for restocking to be successful where natural stocks have been severely depleted through natural environmental events such as the 2016 Kaikoura

earthquake or pollution and sedimentation events caused by industries such as forestry and dairy farming.

Dr McCowan is not totally convinced that stock enhancement is viable at a commercial scale as it is hard to tell with small scale experiments. Determining survival is difficult due to the cryptic nature of paua and marking them is time consuming, expensive and is likely to contribute to higher mortality because handling them as little as possible is the key in his opinion. Genetic marking is an option however this is expensive, so has only been applied at small scale. Genetic marking would also allow for larval dispersal trials to be undertaken. Larval dispersal has not been trialled in NZ due to the difficulties in determining settlement success.

To really tell if stock enhancement works Dr McCowan believes it needs to be done on a commercial scale with around NZD 1 million invested and commercial CPUE used as the PI. The current cost of paua seed is NZD 0.40 per 10mm paua making a 30mm cost NZD 1.20 or AU 1.12. Quota owners say such an investment would be too risky because there is no ownership of the resulting paua once they grow through, they are available to all. Given that other sectors are poorly policed plus there has been no Government intervention to stop pollution and sedimentation they are not confident of receiving a return on investment. There is a proposal to do a large scale restocking project in areas affected by the Kaikoura earthquake. This project would have Government investment and broad community support. It is likely to be the best opportunity to test success.

This area will also give Dr McCowan a chance to scientifically test the theory that rotation harvesting, along with restocking, aids the recovery of the biomass. Rotation harvesting is where some reefs are rested from any fishing pressure for a period of time to recover while other reefs are incurring the fishing pressure. Then the effort will be swapped. Dr McCowan has considered this may be a more viable alternative to boost stocks but has not had a chance to run trials. Experienced industry divers add that resting areas, so long as the 'ingredients' are right, meaning all fishing pressures (commercial, cultural and recreational) and habitat disturbance factors are stopped, will produce good results for rebuilding stocks.

Dr McCowan believes that predators such as the seven-armed sea star and other fish consume juveniles upon first release of a stock enhancement event. A release method that protected them would be needed to mitigate this. He had tried settling the juveniles on empty paua shells for dispersal but they did not achieve the densities on the shells they wanted.

Reyn Naylor a NIWA fisheries scientist has designed and built cement blocks that he is trialling as release modules (Figure 6). He confirmed the high rate of predation in the first 48 hours where the juveniles raised in a hatchery environment are not only unfamiliar with their new ocean environment but also naive to predators they have never been exposed to before. Mr Naylor anticipates that using degradable galvanised wire to cage the juvenile paua in the dispenser with a handful of food should protect them for long enough for them to become accustomed to their new environment. It is early days and he will continue the experiments.

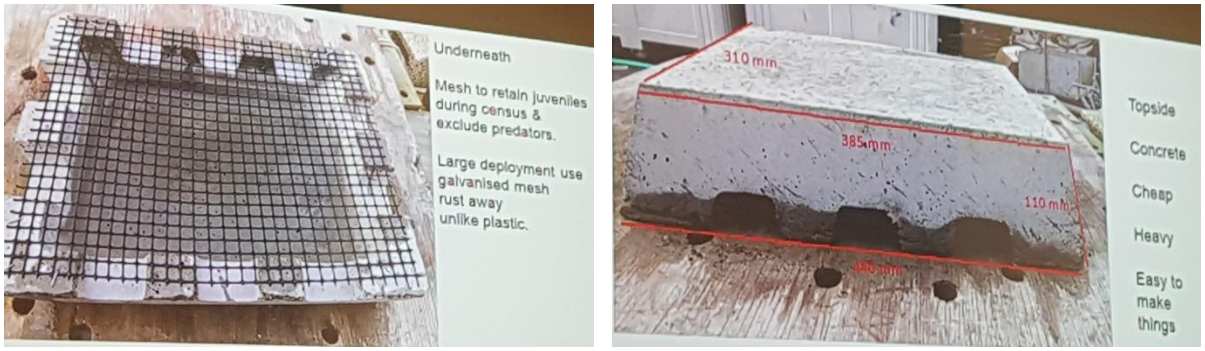

Figure 6: Release modules for juvenile paua. Source; Reyn Naylor, NIWA

Translocation of adult abalone from slow growth reefs to fast growing reefs is another method to build stocks where they have been depleted. The translocation trials carried out have shown great results with distinct visible fresh growth on the shells of the once stunted paua after they were placed in good growth areas, sometimes only hundreds of metres away. Paua appear to be a good species for translocation as once they emerge from cryptic habitat as small juveniles they live in the open and are easy to prise off their substrate without damaging the flesh of the foot. Tim McLeod, an industry diver, took part in trials which proved that translocating the 'teenagers' from stunted areas had the best results rather than translocating the biggest stunted paua they could find.

Mr McLeod is also not convinced stock enhancement is viable as juvenile paua easily become domesticated being raised in an artificial environment, even if only for a short time i.e. low genetic fitness therefore not knowing how to evade predators such as the seven-armed sea star.

Japan

Japan has a romantic history of abalone fishing dating back over a thousand years with tradition being that Ama 'sea woman' divers harvested awabi (*Haliotis discus discus* and *H.discus hannai*), the Japanese term for abalone. Women are said to have greater breath hold capacity to men and their distribution of body fat enabled them to brave the cold water better.

Assistant Prof Jun Hayakawa of the International Coastal Research Institute (University of Tokyo) based in Otsuchi, Iwate Prefecture, explained that awabi fishers utilise an intriguing fishing technique called 'hooking' (Figure 7). Fishers look for awabi through a viewing glass leaning over the side of a small vessel and use a pole with a hook on the end that can be up to ten meters long to prise the awabi from a rock. This type of fishing method is suitable due to the awabi being relatively exposed and mainly inhabiting the shallow water below ten meters. The species of awabi along this coastline is *H.discus hannai*, the cold water species. The water temperature fluctuates between 2 and 8 °C so diving would not be comfortable. Coincidentally, all diving is banned except for research diving. This is an enhanced way of controlling any poaching activity. The author was advised strongly against going for a snorkel to view the underwater habitat because he was likely to face arrest and questioning. The awabi resource in Japan is a community resource, however access, is tightly controlled by local fisheries Co-operatives (Co-ops).

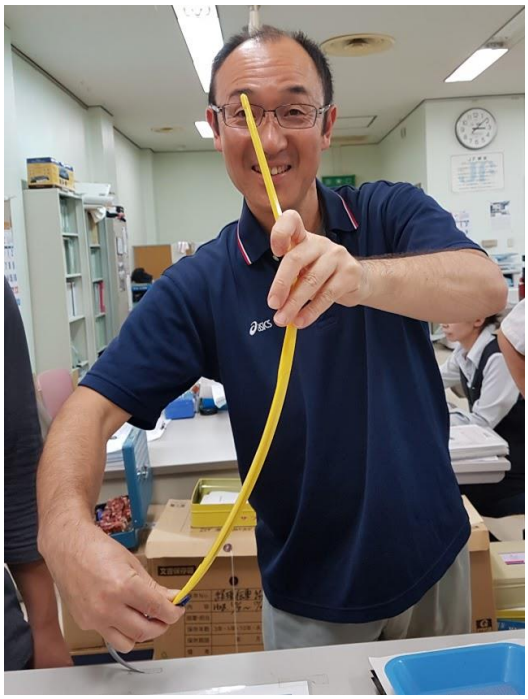

Figure 7: Mr Abe demonstrating 'hooking', (right); awabi hooks

Takahiko Abe, General Manager of the Otsuchi Fisheries Co-op, one of 27 fisheries Co-ops in Iwate, which controls all fisheries in their spatially defined Otsuchi Bay area, explained how the awabi fishery is managed. There are 180 fishers that are issued annual permits by the Co-op to harvest awabi. The fishers must be paid up members of the Co-op and must pay extra for the awabi permit. The money raised is used to purchase juvenile awabi to re-seed.

The harvesting season is during late autumn and early winter and is very short, being four mornings in November for 3.5 hours (6:30–10am) and three mornings in December for three hours (7-10am). The mornings to harvest are determined by the Co-op who monitor the weather and make an announcement the evening before over the town's loud speakers. This harvesting season is chosen due to it being well after spawning season when the texture of the abalone is considered the best by the market; there is the least kelp; and the water is clearest to help see and hook the awabi (Figure 8). The awabi are landed whole and the MLL is 90mm.

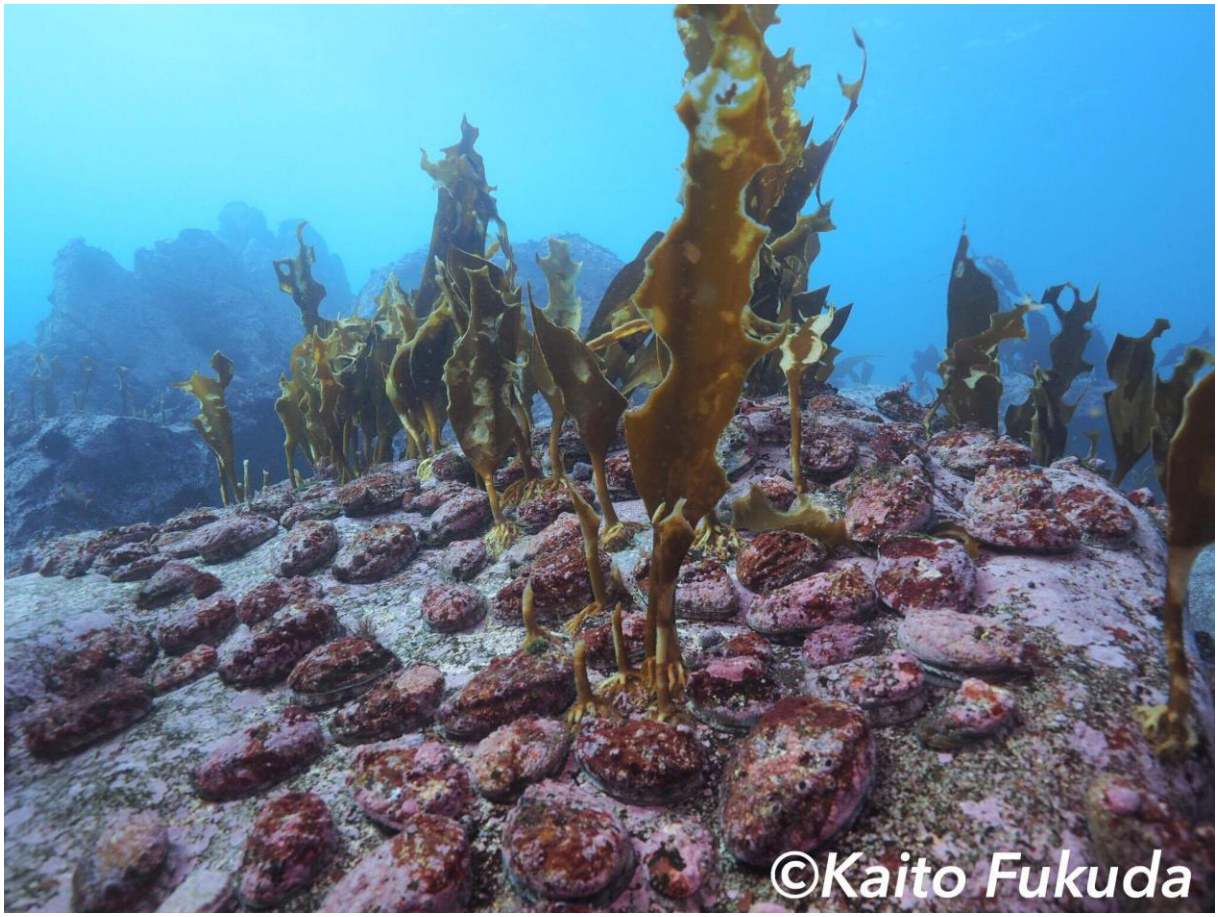

Figure 8: Exposed awabi (H.discus hanni) Source; Kaito Fukuda

The fishery operates in an Olympic-style where there is no individual permit catch limit but there is a total catch limit and fishing will cease when that is reached. The total catch limit is set by the Co-op board using information of the previous season's catch per day and per hour, plus information from university funded dive surveys that measures abundance by a timed swim, along with the size composition of the awabi on the transect. Before the season the Co-op will have some awabi harvested to check that they have spawned and that they do not detect radiation.

Mr Abe insists that 'fishers following the rules' is critically important to ensuring sustainability. The Co-op has sanctions for violations by its member permit holders and their membership is cancelled if they incur four breaches. There is a proposal before the Co-op to reduce that to two violations. As the right to fish (aquaculture and wild harvest) is controlled by the Co-op, loss of membership means the offender has no income. Checks at sea of the fishers and general policing of the coastline are provided at no direct cost to the Co-op or fishers by the coast guard and police.

Dr Saido of the Iwate Fisheries Technology Centre elaborated further that supply of juvenile awabi, while part funded by the Co-op through permit fees, is mainly funded by the prefecture Government. He also reinforced that the fishers do not pay for Government management, compliance or stock assessment and that the income tax for primary producers such as fishers is less than other industries.

Awabi stock enhancement first started in the 1980's and since then it has been determined that the ideal size for release is around 30mm, when the juvenile abalone are 12 months old. The cost to produce juveniles is 2.1 yen per 1mm, therefore, a 30mm awabi would cost 63 yen or AUD 0.75 (Saido, 2017).

The method for release Dr Saido mentioned was using a transparent bowl where the awabi stick to the inside. When it is placed upside down on a rock, juveniles crawl onto the rock to seek cover as they dislike having their foot exposed to the light. Release time was from spring to summer as this was when the algae diet they need is most prevalent and the octopus are not in the shallow water. Other predators that are present all year round include crabs and sea stars. The juveniles naturally settle on pebble sized rocks in about seven meters of water after being in larvae stage for around seven days. Then as they grow, they move shallower with them being in about five to six meters of water at one to two years old. At harvestable size of over 90mm they are in two to four meters of water.

Assistant Prof. Hayakawa described failed natural recruitment in past years when the cold water current was too strong and came too close to the coast for too long. This dropped the water temperature to 2-3 °C which the juveniles cannot survive in. In the 2016/17 winter the cold water current was not strong at all and the water temperature stayed at 7-8 °C, which caused some of the kelp beds to die, removing food and protection. The ideal water temperature is 6-7 °C.

The Omoe Fisheries Hatchery was established in 1981 by the National Federation of Fisheries Co-ops. It is managed by Mr Kousaka, who echoed Dr Saido's advice, that the ideal size for release is 30mm. The brood stock is collected in September/October and their diet controlled to develop the gonad for spawning in May. The juveniles are then reared in the hatchery tanks for 12 months ready for release the following May/June (Kousaka, 2017).

Mr Kousaka believes the best release method is using divers to hand place them. This, however is time consuming and costly, and is a far cry the other extreme, where some Co-ops fishers are said to just tip them over the side of the boat onto reefs, that they believe look like having good substrate from the viewing glass.

Mr Kousaka and his colleges had tried the larval method of release in 2016 and confirmed settlement and survival at two weeks, but beyond that, there was no survival. They have no plans to continue with this method.

The brood stock is replaced every season, and come from the area the stock enhancement is to take place, although there are no hard and fast rules around this, and from time to time, they will come from a neighbouring area. They do use 40 to 50 females and 20 to 30 males to maintain genetic diversity.

Mr Abe, Dr Saido and Mr Kousaka all agree that of the total awabi harvest, 30% is from reseeding. Survival ranges between 10 and 15% of what is released. The seeded awabi are easily identifiable because their shell is bright green from hatchery growth and then dark

green from growth in the wild. Up to 9 million seeds a year can be released by the 27 Co-ops in the Iwate prefecture. Iwate in 2014 contributed 304 t to Japan's total annual wild Awabi production of 1,363 t.

Stock enhancement of awabi is considered very important to the fishery as it provides a buffer for their harvest. Mr Abe, Dr Saido and Mr Kousaka all believe that the reseeded awabi contribute to natural spawning but they do not know by how much, although they are attempting to find out. Continuing to stock enhance for over 35 years implies that it works, though whether it is financially viable without government support is questionable. There were not any private awabi aquaculture grow out ventures as it was considered not viable due to high input costs. What has been achieved and was general consensus is that having an understanding of the ecology of the area is crucial to achieving success.

Fishers in Japan have a long history of strong cultural connection to their craft. Seafood takes priority in the Japanese diet and as such there is much respect shown to fishers. This includes by government in appreciation for the service they provide to the community. Fishers have influence over other industries and therefore were able to minimize land runoff from industries such as forestry that can ruin habitat and reduce abalone recruitment. It is recognised that if you care for the land then the adjacent ocean will be healthy and productive. It remains to be seen however if the immense effort put into the building of break walls and barricades along this coastline after the devastating Great Eastern Earthquake and Tsunami of March 11, 2011 changes the natural process for the better or worse. Prof. Masayuki Komatsu believes it will be for the worse and that a major restructure and rethink of how Japan's fisheries are managed is needed if they are to adapt and prosper in the future as they have in the past.

California, USA

Abalone, otherwise known as the Californian red *(Haliotis rufescens)* is the species that makes up the recreational fishery in California. The commercial fishery was shut in 1997 after disease and overfishing depleted the stocks. There were other species commercially harvested such as the black *(H.cracherodii)* which was devastated by the withering foot syndrome in the mid 1980's, green *(H.fulgens)*, pink *(H.corrugatta)* and white *(H.sorenseni)*. Dr Laura Rogers-Bennett, an abalone scientist at University of California, Davis, Bodega Bay Marine Laboratory explained that after withering syndrome devastated the black abalone stocks, commercial divers shifted their focus to other species, with no quotas to limit annual take, divers were able to maintain a relatively high CPUE. Once one species was depleted they shifted to the next, and before long with no other species to turn to, CPUE plummeted, hence the closure of the fishery.

Some divers shifted to sea urchin, harvesting them for their roe. Over the years while diving for urchins they watched the abalone stocks rebuild, in particular the red abalone, and despite their repeated attempts to have the commercial fishery reopened, using survey data to support their proposal, the fishery remains closed. Jim Marshall, an ex-abalone diver, now urchin diver insists it remains closed for political reasons and that the recreational lobby is

very strong. He believes it is wrong and that everyone in the community should have access to abalone, not just a select group of recreational divers. As in many other countries the resource is there for the whole population and if they cannot, or choose not to dive they should still have the option of being able to purchase and enjoy abalone that has been harvested by a commercial diver on their behalf.

In 2016 there was a 450 t recreational fishery with approximately 30,000 divers registering to get their 12 tags which must be attached to each red abalone they take for the season. The breath hold technique is the only permitted method to dive for abalone. There was talk of reviewing the 450 t recreational take and potentially reducing the catch limit due to warm water events having detrimental effects on the stocks. One such event in 2011 triggered an algal bloom which suffocated some abalone. Another algal bloom two to three years ago destroyed many of the kelp forests which provide food and protection for the abalone. Since then, small non-commercial sea urchins have exploded in numbers and are not allowing the kelp to grow back. The lack of kelp cover has meant divers have found it easier to see the red abalone giving a false pretence that stocks are abundant. Subsequently the abalone from the deeper water, normally out of reach of recreational divers have been moving shallower in search of food, replenishing the ones that are easily taken, like a conveyor belt. The prediction is it will all come to an abrupt end when there is no more abalone to replace those being taken.

Researchers found the lack of food has contributed to the condition of the abalone deteriorating and studies of gonad samples have confirmed poor reproduction capability. The abalone being more exposed due to the lack of kelp means predators like sea otter, octopus, whelks and others have easy pickings. The 20-arm sea star, that was also a predator, died out in an unusual disease event in 2013 (Kawana, Catton, Rogers-Bennett, 2017).

California has a few abalone aquaculture hatcheries and grow-out farms growing the red *(H.rufescens)* species and Mr Marshall believes, after talking with his associates who work on them, that their viability is questionable. Also, that their ability to expand is inhibited by environmental restrictions, so achieving economies of scale is difficult. Potential for new farms to establish is therefore non-existent.

Dr Rodgers-Bennett sourced juvenile red abalone from the farms when undertaking previous restocking experiments, where the 20 to 50mm size range was the most financially viable. A 30mm juvenile red abalone cost US 1.00 to produce.

Genetic work done on the red abalone has not identified spatial structure along the Californian coast. They do however apply a north and south rule for reseeding from Point Conception, a very prominent geographical land mark dividing north and south California. This means any juvenile abalone to be restocked north of Point Conception must be of brood stock from north of Point Conception and vice versa.

The success of these experiments has ranged from confirmed failure to undetermined and subsequently no ongoing stock enhancement is undertaken. Thomas Ebert's thesis *'An*

Innovative Method for Seeding Abalone and Results of Laboratory and Field Trials (1986)' identified a history of stock enhancement experiments through the 1970's along the California coast with nearly all resulting in an undetermined outcome. Ebert was testing a dispenser as a method of release due to all previous methods, (such as hand placing and using 'mother shells' like abalone and scallop shells), proving to be labour intensive and not producing satisfactory results. He found that while his dispensers handled large numbers efficiently, they became attractants for predators of abalone.

A method used in the past for releasing red abalone, as explained by Shelby Kawana, research assistant at Bodega Bay Marine Laboratory, was by using short lengths of PVC pipe that had a manganese release mechanism that would dissolve at 18 hours to allow the abalone to acclimatise and release at dusk. A video was set up to record one of the events and it captured an opportunistic octopus feasting on the newly released abalone when the door opened.

Restocking is planned for the white abalone as it is listed as endangered (https://www.fisheries.noaa.gov/species/white-abalone) and Dr Rogers-Bennett believes the Bodega Bay laboratory tanks hold the majority population of white abalone in California (Figure 9). Recently, some new white abalone had been found in the wild and collected to add to the breeding program which was considered a good thing as there had not been any new brood stock for many years. The approval process to access the white abalone from the wild was said to be exceptionally onerous.

Figure 9: (left); Endangered white abalone (H.sorenseni) brood stock, (right); juvenile white abalone held at the Bodega Bay Marine Laboratory

In light of what has been learnt about genetic fitness one cannot help but wonder if the survival of any released white abalone may not be overly successful, particularly if they are older domesticated abalone? Dr Rogers-Bennett and her team are however hopeful. They have also been focusing on finding and counting abalone larvae as a way of predicting recruitment, which, she believes in some way may be the direction for future stock enhancement success.

Baja California, Mexico

The fishery for Mexican abalone, or abulon as it is locally known, occurs on the Pacific or western side of the Baja Peninsula. Eric Peterson, Director of Aquaculture with the Baja California Government gave a snapshot of the industry, which is a dive fishery permitting surface supply air from 'hookah' equipment. The commercially harvested abulon consist mainly of green (*Haliotis fulgens)* (MLL 150mm) and pink (*H.corrugata)* (140mm), however black (*H.cracherodii)* (120mm), white (*H.sorenseni)* (140mm) and red (*H.rufescens)* (165mm) also grow along the coastline. The fishing season runs from December to June coinciding with winter and spring. The total tonnage landed in 2014 was 360 t.

It was alleged by Benito Altamara, general manager of aquaculture business Abulones Cultivados, that in the 1890's the Emperor of Japan was issued with the first permit to harvest abulon and Mexicans were taught how to harvest and dry them to ship back to Japan. The first recorded harvest figures start in 1941 at approximately 1,000 t for a few years then building to a peak of 6,000 t ten years later, harvest then stabilised at around 3,000 t for 30 years and then from the early 1980's drops down to current levels. Quotas were introduced in 1997.

The Federal Government body SAGARPA (The Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food), is responsible for research of fisheries and setting quotas, and the state government bodies such as SEPESCA (Secretariat of Fisheries and Aquaculture) in Baja California, are responsible for the day to day running of fisheries and aquaculture.

The coastline and industry is divided up into 16 Co-operatives, each of which posses a licence to harvest abulon on the Pacific side of the peninsula. The Co-ops also have licences to harvest other species such as rock lobster, sea urchin and mussels. The community members are partners of the Co-ops. The Co-ops are the main industry of the coastal communities and they have been delegated local area management of the fishery including policing to stop poaching, which is a problem. If the resource is not protected and fishing becomes unsustainable then there is not much else for the community to rely on for income.

Government financial support is provided to the Co-ops for purchasing infrastructure like processing equipment, boats and outboards along with fuel subsidies. Stock assessment is carried out by the Federal Government fisheries management agency at no cost to the Co-ops who use the information to set quotas (Gonzalez, 2017).

Jose Gonzalez explained that a condition of the licences to harvest abalone held by the Co-ops state there is an obligation to carry out restocking. There is however a lack of regulation and little guidance as to how to undertake that restocking. This is currently being addressed with the development of a restocking plan. Restocking has been taking place since 2012/13 and six of the Co-op's have hatcheries. The hatcheries are government subsidised and help employment when the fishing season is closed. They only produce juvenile abulon to restock and do not on grow as it is not considered viable to do so at the places they are located. The methods of restocking have ranged from larval release up to 40mm, with no indication of a preferred method or size. There has not been a way of determining success of restocking to

date. Noe Garcia Cruz of Abulon Cultivados, indicated the cost to produce a juvenile to 30mm is USD .75 or AUD 1.01.

Aquaculture of abulon is not big in Baja California with 20 tonnes being produced annually from two farms. One farm is growing hybrids of a red and green, using barrel grow out in the open ocean and claim they are getting great growth rates with tolerance to temperature fluctuation. They are permitted to grow out in the ocean as there are no natural abulon stocks in the adjacent area.

Figure 10: Author meeting with Eric Peterson and Tania Nassar of SEPESCA and Jose Gonzalez of SAGARPA, 2017

Republic of South Africa

Perlemoen, genus *Haliotis midae* is the commercial abalone species of the Republic of South Africa (RSA), named after the mother of pearl of the shell. The commercial and recreational fishery has been closed since 2008 as poaching is rife and it is thought there could be up to a 2,000 tonne illegal fishery (when considering statistics of imports into Hong Kong). This is astounding as it is the size of the legal fishery when it was operating ten years ago. There are major social problems and unemployment issues in the RSA, for which there does not seem to be a solution in the foreseeable future, this is very unfortunate as the fishery is at real risk of collapse (Britz, 2017).

There is still demand for perlemoen and this provides opportunity for aquaculture. Perlemoen has a reputation for being ideal for drying which also makes it far easier to smuggle out of the country as it is one tenth of its wet weight and non-perishable. It is however starting to lose its premium reputation in the market as the association with poached product and inferior drying techniques (i.e. potentially non-safe food) are of concern to consumers (Lui, Sui, & Joubert, 2017).

The wild perlemoen resource, like every other country visited, is a community resource. However, due to extensive poaching that the RSA Government cannot contain, an aquaculture

lease has been granted to Wild Coast Abalone to trial stock enhancement along a small stretch of coastline near Port Elizabeth. Richard Clarke of Wild Coast Abalone explained that the lease is a ten-year experiment with a 25 year right beyond that for production should the experiment prove successful. The first reseeding as part of the project started in 2013 (the farm started in 2000), as a way of using excess stock produced on the farm. The lease conditions stipulate that Wild Coast Abalone will only be able to recover the perlemoen that they have introduced, not any that have originated locally. They can tell which ones are reseeded due to a fluorescent die introduced to the diet that leaves a distinctive band of green colour in the shell.

Wild Coast Abalone employ a security team that patrol the coast line to protect the area from poachers. This is critical to the success of the project, as otherwise the investment and work would be ruined by poaching. Thinking this would be expensive? The cost of producing the juvenile perlemoen is relatively low on a global standard. The cost of labour is 16.5 rand (AUD 1.85) an hour (agricultural minimum wage), although Wild Coast Abalone pays more. Electricity, which happens to be their 2nd highest cost, is the second lowest price in the world. It costs 4 rand (AUD 0.45) to produce a 25-30mm juvenile (Clarke, 2017).

A very fortunate opportunity (Figure 11) occurred while in RSA to observe a reseeding event and talk with Andrew Witte who is helping Prof. Britz with the research project and will use the results to write his PhD. A batch of 30-40mm juveniles were packed in foam boxes at 16 °C as per normal live transport and trucked to the release site. Keeping a constant temperature is important and any fluctuations over 5 °C have caused mortalities. Keeping handling to a minimum was also believed to be very important in avoiding mortalities (Witte, 2017). One could not help but wonder if the very bumpy road from the Wild Coast Abalone farm to the main highway down to Port Elizabeth would stress the perlemoen. While abalone are conditioned to turbulence happening around them in the ocean, they are always fixed to a solid structure that does not move unlike travelling in a truck.

Figure 11: Author with Prof. Peter Britz, and (right); divers ready to undertake reseeding.

On arrival at the boat ramp the juveniles (Figure 12) were in soak bags which were then taken out to sea and suspended from an anchored buoy to adjust to the ocean water. Once again they were subjected to movement as the swell was not at all flat. The bags were then collected by divers and the juveniles dispersed by handful into cracks and ledges at around six metres of depth. The juveniles seemed to take well and appeared to be full of life upon release. The shallower habitat at around two metres is preferred for release but there was no way that could be accessed with the large swell. The best growth rates are achieved at that shallower depth (Britz, Witte, 2017)

The deeper habitat did not appear to be good habitat for juveniles and when searched only two perlemoen of about 120mm were found and none smaller. It was very different in the shallows and when snorkelling in 0.5-2 metres of water, 16-18 per m^2 of perlemoen of all sizes were observed (Britz, 2017). The area had been reseeded however there was very few introduced perlemoen identified, with the majority being the result of natural recruitment. Based on the principle that the genetic fitness of the naturally recruiting perlemoen would be superior to the reseeded, it would not be unreasonable to suggest that they were displacing those that had been reseeded. Due to the area now being kept free of poachers, natural recovery had been enabled.

Figure 12: (left); Bags of juvenile perlemoen (H.midae), (right); juvenile perlemoen

Other than poachers the perlemoen have to contend with natural predators that include octopus, rays and some fish. Strangely, there are no sea-star (Witte, 2017).

Some believe that the deeper habitat has been severely depleted by poachers using scuba diving apparatus and the poachers are now moving into the shallows on snorkel but they are naturally restricted by swell which is the only thing protecting the perlemoen resource from total overexploitation. It was also noted that the restocking event that had just occurred was likely to have been watched keenly and the location noted by poachers.

Hong Kong, People's Republic of China

The People's Republic of China is the world's market place for abalone. While consumption does occur in other countries the market focus is on China, as this is where the highest demand, and therefore price is achieved. Travelling to Hong Kong to talk with importers of abalone was a crucial part of the research, not only to gauge the current market, but also ask their perceptions of restocked abalone and its acceptance in the market.

Hong Kong, prior to 1997, was a British colony however it has been reclaimed by China now. Much of the abalone trade over the decades, has been, and still is conducted through Hong Kong. Exporters would prefer to sell their abalone to importers in Hong Kong as abalone trading in mainland China is a complex business. China is a complex place to do business in general but when you are dealing with a luxury product that is highly perishable one must be very careful. Strong business relationships must be formed so trust and respect underpins the transactions. It is true that building the relationship is the most important thing to establish when doing business in China. Being very savvy, or even ruthless, is not an unusual way to describe the Chinese trading prowess.

The wild harvest abalone from around the world achieves a premium to farmed abalone, in most cases a considerable premium, due to a number of reasons, including but not limited to, size, taste and scarcity (Figure 13). The world supply of wild abalone has dropped but the supply of farmed abalone has risen considerably with China itself being the main producer.

The general consensus of the importers was that farmed abalone has somewhat flooded the market which brought the price down and consumers no longer believe it is a luxury product. To this end it is important to test if the reputation of restocked abalone that started life in an aquaculture facility then matured in the natural ocean environment would be tarnished in any way and not achieve the price of a luxury wild abalone.

Surprisingly, of the six importers that were interviewed, none thought it would compromise its luxury wild status (Lui, Law, Tse, Tsang, Cheng and Sui, 2017). In fact, two believed that if the story of stock enhancement was shared by explaining that the whole process was to enhance sustainability then it would be an added positive. They did stop short of saying a premium could be sought for reseeded wild abalone as through experience the price is always too high.

There are already a number of seafood products sold by these importers that have been stock enhanced, particularly from Japan such as scallops, eel and salmon and they believed there has been no adverse effect on price or demand.

It was explained that so long as the majority of an abalone's life had been spent in the wild environment feeding on natural food and it had not been genetically modified, had antibiotics or growth hormones or any other chemicals used in its early life then it would be accepted. Safe food grown in a clean environment is very important to consumers in China.

Figure 13: Dining on Eyrewoolf Enterprises large size, wild abalone in Hong Kong, People's Republic of China

Conclusion

Abalone stock enhancement is utilised at varying levels in the world's wild harvest abalone fisheries, from over 30 years of continuous commercial reseeding in Japan with measured success to smaller scientific projects in NZ, South Africa and Australia. In light of continued climatic variations resulting in warm water events that cause abalone stocks to decline and inhibit natural recruitment, restocking and stock enhancement will have a place in maintaining productive abalone reefs.

There is no conclusive method of how to undertake abalone stock enhancement and new information is being sought and learned. All of the *Haliotidae* species have their own peculiarities in behaviour and habitat, so finding a solution of one size fitting all is unlikely. Sharing knowledge and lessons learned however will allow more focused research to take place for the particular species and location.

Utilising the steps in the *Responsible Approach 2010 update* (Lorenzen, K. *et al* 2010) is a sound way to progress stock enhancement. While most of the work and communication would be between the industry and government, engaging with and keeping the local community aware of what was happening in the waters adjacent to their home is very important.

It would be advantageous to understand the ecology of the release area to achieve greater positive results. Understanding the ecology could be started with a survey of abalone divers and fishers that have been working in the area for decades. Then more focused research could take place. Relevant factors to explore include avoiding interactions with predators through seasonal variability, reseeding when the desirable food source is available for juveniles and selection of the optimal habitat and weather conditions.

Stock enhancement is not likely to be viable in all locations. Using stock enhancement in combination with rotation harvesting is likely to yield the best results.

Maintaining genetic diversity of the abalone resource was a common theme and all agree that it is best to take brood stock parents from the area where the stock enhancement is to take place. The 'area' did however range in large spatial variation from hundreds of meters to hundreds of kilometres. Determining what would be appropriate for the species you intend to reseed is the logical approach. This can be determined by identifying the spatial genetic structure of the population. For example Australia's black lip populations have a very discrete genetic population structure that ranges between tens to hundreds of meters, whereas green lip genetic populations range over tens of kilometres.

The best method of release was not conclusive and much more work needs to be done in this area. Whatever the method, the factors that need to be balanced are the cost of the juvenile abalone and the deployment method's effect on survival. The general rule underpinning both of these was to maintain the least handling as possible because handling increases the risk of mortality.

The size of the juveniles used for enhancement is likely to be a major contributing factor for success. Before undertaking this study the author's assumption was that bigger would be better. The thought was that the bigger abalone would be stronger and therefore survival would be better with the cost of the abalone being the main restricting factor. The realisation now is that bigger abalone will have become domesticated and therefore not genetically fit for their new environment. They would be prone to predation and may struggle to adapt to and compete for shelter and natural food.

A mid range size of approximately 30mm appears to balance the trade off between being strong enough to withstand the reseeding operation and not being too domesticated to survive and adapt to the new environment. The cost to rear to this size is not too excessive when compared against long term survival. Handling and releasing at this size is also more practical than smaller or larger individuals.

General consensus is that to measure the success of abalone stock enhancement a commercial scale ongoing effort would need to be made. This would allow performance indicators such as CPUE and Catch Per Unit of Area to be monitored and compared with current industry rates of harvest. More comprehensive surveys can be undertaken but survival and recovery of all of the reseeded abalone is not likely to be known and unachievable.

Under every fishery management jurisdiction visited, ownership of the reseeded juveniles did not remain with those that have released them. If the area was not designated under a spatial lease agreement to those who released them, then incentive to do so is not likely to be high. However, in Australia businesses undertaking stock enhancement would have access entitlements; licences, and the majority share of the allocated TACC, enabling them to harvest what they had seeded. However, to make a commercial scale investment, assurance from government in the form of regulation or policy that stock enhancement was the priority use for the area now and in the future over all other uses must prevail.

It is abundantly apparent that abalone stocks around the world are in decline, with the issues and challenges causing this decline being universal. Environmental changes due to warm water events are wreaking havoc on a sedentary species that cannot escape. Fishing pressure remaining too high only exacerbates the problem after mortality events due to warm water, disease, invasive pests and habitat changes. Commercial fishing pressure generally reacts more quickly to changes but recreational and poaching pressure in most cases is uncontrolled. This along with land based pollution negates any chance for recovery.

Abalone aquaculture is not immune from the environmental impacts of water temperature, disease and invasive pests. These issues can also wreak havoc on a farm that cannot move. The farm however has the ability to selective breed to overcome these challenges and produce abalone that are resistant or tolerant to these issues. Adapt to the new norm of climate variation or cease to exist is the only option.

Allowing the commercial wild harvest sector to utilise what the aquaculture sector are already doing can create the ability to restock or enhance the wild populations. It is likely to be the only way the resource can return to optimum utilisation in the face of environmental change. Ministers, their departments and industry must work together and it must not be the burden of the commercial sector alone. Declining wild stocks is not a deliberate or intentional objective of the commercial wild harvest sector. All of the experience we have in managing these fisheries has been found wanting due to climate variation and a new way of thinking is required to adapt.

World Seed Cost Comparison

Juvenile abalone seed production cost comparison at 30mm in $AUD.

Australia	75 cents
New Zealand	112 cents
Japan	75 cents – government subsidised
South Africa	45 cents – farm excess
Mexico	101 cents – government subsidised
USA	133 cents
People's Republic of China	42 cents (Weiwei You, 2018)

Recommendations

- Form professional relationships with colleagues in the world's abalone countries to share knowledge about issues and challenges faced.
- Form a working group of expert skill sets to explore and steer a commercial stock enhancement project. Utilizing resources such as 'Responsible Approach Update 2010' (Lorezen, K. et al 2010) and Lorenzen's 'Enhancefish' software.
- Work with the abalone aquaculture industry as they understand the early life cycle of abalone.
- Ensure governance arrangements are sufficient to provide the security necessary to undertake an investment in commercial stock enhancement.
- Undertake an inclusive and transparent trial including all stakeholders in the process.
- Tell the good story of stock enhanced abalone whereby sustainability of abalone stocks is being ensured.

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Plain English Compendium Summary

Project Title:	World Abalone Fisheries and Stock Enhancement
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Objectives	While abalone populations and commercial harvesting occurs in only a handful of countries around the world, cohesion between these countries is limited. Facing similar issues of sustainability and all focusing on the South East Asian market, great potential exists to collaborate and grow the wild harvest industry back to heights once enjoyed. Objectives of this study are therefore to; • Gain an understanding of the world's major wild harvest abalone producing countries. • Explore the fundamentals of fishery stock enhancement with a focus on abalone. • Determine if and how successful abalone stock enhancement can occur. • Consider the implications of abalone stock enhancement (including to the market)
Background	World abalone fisheries are declining while abalone aquaculture production is increasing. How are these wild harvest stocks being managed and is anything being done to reverse this decline? How is abalone aquaculture being used to enhance wild stocks?
Research	Meeting with abalone resource managers, scientists, fishers, aquaculture and marketers in New Zealand, Hong Kong, Japan, California, Florida, Baja California, South Africa and Australia.
Outcomes	Abalone stock enhancement is in its infancy except for Japan however all countries are or have undertaken stock enhancement trials. Stock enhancement can work in select locations and will be necessary as a skill to learn to help stocks recover in the likely event of environmental marine heatwave mortality events.
Implications	Allowing the commercial wild harvest sector to utilise what the aquaculture sector are already doing can create the ability to restock or enhance the wild populations. It is likely to be the only way the resource can return to optimum utilisation in the face of environmental change. Ministers, their departments and industry must work together, and it must not be the burden of the commercial sector alone.
Publications	International Abalone Society, 2018 Nuffield Australia National Conference, 2018