Integrated Multi-Trophic Aquaculture systems incorporating abalone and seaweeds

A report for

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Foreword

Aquaculture in Australia is a relatively new and constantly evolving industry. Having worked primarily in the fields of abalone and oyster seed production for over 10 years, it became clear that 'looking outside the square' was a necessity for solving challenging problems and for assessing new opportunities. There was possibly no better way to look outside the square than to step out of the country through the opportunity afforded by an FRDC-sponsored Nuffield scholarship. Prompted by an interest in the culture of marine plants and the potential to re-commission a 50t capacity/annum abalone farm at Louth Bay, South Australia, this study investigated seaweed and abalone culture with a view to the integrated culture of the two.

As primary producers, marine plants are critical to the oceanic food chain. Despite the crucial role of seaweeds and micro-algae in driving oceanic productivity, as well as their prevalence in the sea environment, aquaculture in many 'western' countries is dominated by monocultures of aquatic animals.

Seaweed culture has significant potential for a range of applications, but has not 'taken off' in Australia, and there are a number of reasons for this. Culture challenges are diverse and for the application as a feed source for marine grazers, the high quality and availability of artificial diets has reduced the drive to cultivate seaweed for this purpose. Also, costs of production are generally considered to be high, especially for aerated tank culture which has largely been the focus of land-based research in Australia.

The high costs associated with the production of seaweed in aerated tank culture channelled the focus of this study toward alternative systems and methods. Studies on the production of seaweeds in large paddlewheel ponds in Israel and South Africa have shown the culture of seaweed (*Ulva* spp.) using this method to have significant potential as an addition to abalone farming operations. Furthermore, the integration of seaweed culture with existing (aquatic animal) aquaculture operations has successfully been achieved in land-based contained systems. A reduction in costs associated with the production of seaweeds can be achieved by utilizing nutrients and carbon dioxide (necessary for high density seaweed culture) from aquatic animal waste water.

A new acronym in the aquaculture world, IMTA (Integrated Multi-Trophic Aquaculture) refers to the culture of aquatic organisms which interact through water in shared or connected systems. IMTA systems incorporating marine plants and aquatic animals have the potential to decrease costs, improve efficiency and productivity for a number of species and systems. Integrated aquaculture systems aim to capitalise on the benefits offered by the interactions between organisms in a normal ecology, thus mirroring natural processes in aquatic ecosystems, especially in the way that one organisms waste is another's resource.

In regard to studying seaweed culture, it soon became apparent that identifying and evaluating the reasons for growing seaweed were just as important as the methods for seaweed production. The economics of growing seaweed independently and in IMTA systems are very complicated and depend on a range of factors, especially site conditions and species cultured.

The study of IMTA focused on several aspects. The fundamentals of IMTA systems were investigated as one tool for assessing the long-term potential of land-based IMTA systems. Recirculation of water is one aspect of 'true' IMTA systems. Most of the knowledge gained on recirculation aquaculture systems (RAS) has originated from fish culture using this method, with less research having been conducted on molluscs in RAS. As a result, a major focus of this study became RAS involving marine grazers, with a particular emphasis on the health of molluscs in these systems.

A range of aquaculture operations were visited and conferences attended on the study trip in the U.S., Mexico, England, Ireland, South Africa and New Zealand. Several aquaculture facilities visited in the U.S. and China on the group's Global Focus Program also yielded useful information.

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Abbreviations

IMTA	Integrated Multi-Trophic Aquaculture
RAS	Recirculating Aquaculture System
SAABDEV	South Australian Abalone Developments

Contents

Executive Summary

This study investigated a range of aspects of land-based seaweed culture, abalone production and Integrated Multi-Trophic Aquaculture ventures in order to assess the potential for isolated seaweed and integrated abalone/seaweed aquaculture in Australia. This research was considered worthwhile due to the significant potential for the economically viable production of seaweed as an on-site food supply for marine grazers in land-based aquaculture systems in Australia. As an aspect of IMTA, water recirculation and re-use in mollusc aquaculture systems were investigated with a view to assessing their potential compared to flow-through systems (the primary method for growing abalone in Australia). Recirculation is a significant aspect of most land-based contained IMTA systems which offers several advantages and/or opportunities over single pass flow-through aquaculture systems. These aspects are discussed with a view to seeking opportunities for abalone farming operations in Australia, including an abalone farm at Louth Bay on the Eyre Peninsula, South Australia which retains potential for re-commissioning.

Background

In Australia, abalone exports hover around $A200m/annum, with the bulk of production coming from the wild catch sector. Annual quotas limit the harvestable quantities of abalone from the wild and so, aquaculture presents the only suitable option for increasing abalone production in Australia.

Land-based abalone farming is undertaken primarily in the states of South Australia, Victoria and Tasmania. The industry has progressed rapidly in the last 20 years. Innovative farmers and researchers have developed efficient and productive systems and culture methods. However, most aquaculture businesses generate products for export where competition on price is an ongoing challenge. In fact, between 2000/01 and 2007/08, abalone average-unit prices fell by 40%. The reason for this was a combination of several factors, including the appreciation of the Australian dollar during this period (ABARE, 2008). The need for maximising efficiency and maintaining or improving quality is paramount to competing in a global market where large volumes of products are supplied from overseas countries which have lower production costs.

Seaweeds (or macro-algae) are the primary food source of wild abalone and a host of marine grazers with aquaculture potential. In Australia, most abalone farms almost entirely feed abalone with an artificial pellet diet whilst most overseas operations in countries such as China and South Africa supply abalone predominantly with seaweed collected at sea (cultured or wild). The production of seaweeds as an on-site food supply was considered as one way to improve efficiency by reducing feed costs and improving abalone health.

The production of seaweeds in land-based culture systems for the purpose of feeding abalone is gaining popularity in several countries, including South Africa, where seaweed production units are established and proving to be economically viable. Paddlewheel ponds are large rectangular raceway systems that are used to produce large quantities of the seaweed *Ulva* spp. The production of *Ulva* spp. using the paddlewheel production method has been shown to pay back the installation and running costs in the first year (Robertson-Andersson, 2006) resulting in a significant return on investment. Also, within the last 10 years there have been many inspirational models and reviews on IMTA systems (e.g. Neori et al., 2004). Overall, the objectives of this study were to investigate current research and systems with a view to utilizing this knowledge to identify opportunities in Australian conditions. The production of marine plants and integrated aquaculture systems could be the next major growth areas in the industry.

Key findings

- The green seaweed *Ulva* spp. are a suitable diet for Australian abalone (Boarder and Shpigel, 2001) that can be grown in waste water and supplemented with fertilizers to produce large quantities of feed. Paddlewheel ponds are the most efficient method for producing this seaweed species.
- Red seaweeds such as *Gracilaria* and *Grateloupia* spp. can be grown in aerated tank culture units to provide a mixed diet for abalone and to provide health benefits such as anti-bacterial activity against pathogens (Rebours, 2010)
- Recirculating aquaculture systems are much more complicated than flow-through systems, especially for molluscs. Water quality parameters such as pH and oxygen levels as well as temperature require very close monitoring. For example, pH levels below 7.6 can occur in recirculating systems due to a build-up of carbon dioxide and can cause shell erosion in abalone.
- Bacterial levels rise rapidly in recirculating aquaculture systems where artificial pellets are fed. The installation of UV sterilizer units to control bacterial levels is considered necessary due to the increase in *vibrio* levels associated with decaying feed and faeces.

- Seaweeds possess a range of anti-bacterial properties (Anggadiredja et al., 2010) which have the potential to improve gut flora and reduce the build-up of pathogenic bacteria. The use of seaweeds could actually improve the viability of water re-circulation/re-use by reducing bacterial levels within the system.
- Ozone is a highly-effective sterilizer that can be used effectively for treating top-up water in recirculating systems to prevent entry of diseases. Saltwater wells, which can be installed in some sites, provide a suitable quality of water for effective ozone treatment without any mechanical filtration (which is usually necessary for effective ozone treatment).
- Pumping costs are a significant expense for land-based abalone farms, normally accounting for over 80% of electricity costs for flow-through systems. Recirculation of water at low head heights, as opposed to pumping water from a lower point (below sea level), affords land-based aquaculture facilities the opportunity to save on pumping costs. Air lifts and propeller axial pumps can move high volumes of water at lower cost than centrifugal pumps.
- In regards to the fundamentals of IMTA systems, it is preferable to develop the culture of multiple species together. Simple logistical issues such as the layout of established facilities can prevent the addition of other culture systems, such as paddlewheel ponds to existing abalone farming operations.
- The integrated culture of abalone and seaweeds in land-based systems is complicated as the success of integrated systems relies on numerous factors. However, depending on design, seaweed culture and abalone raceway systems can be run independently.
- Abalone produce relatively low nutrient levels compared to fish culture (Neori, pers. comm., 2010). Additional nutrients need to be added to grow significant volumes of seaweed and to correct nutritional deficiencies likely in Australian seawater.
- Seaweeds in integrated abalone culture can improve water quality parameters (Yongjian et al., 2008) and can at-least form part of a water treatment system. The quantities of seaweed required for nutrient stripping, oxygen addition and carbon dioxide removal are much less than quantities required for bulk food production. Therefore, the potential for seaweeds to improve water quality parameters could be of equal or greater value than the potential of seaweed as a feed source.
- Management of seaweed cultures requires fundamental knowledge of seaweed biology. A number of management practices can ensure contamination by epiphytes are minimized, seaweed nutrition is adequate and other factors which affect growth or survival (such as photo-inhibition) are reduced.

Applications

- Overall, it is recommended that Australian abalone farms investigate paddlewheel ponds for production of *Ulva* spp. Farms which have suitable land could consider installing a trial paddlewheel system using waste water. The opportunity to recirculate water is then worth considering during parts of the year, primarily to reduce electricity costs and utilize waste nutrients.
- Recirculation could be investigated further as a method of allowing the sterilization of incoming water for mollusc culture systems, especially brood-stock and juvenile culture units. The spread of diseases is occurring at a fast rate, and is likely to have an increased effect on aquaculture productivity in the future. Systems for protecting genetic stocks are considered worthy of further investigation.
- On-site research is crucial to the development of seaweed culture systems and should be a foremost priority to any company developing seaweed culture.
- Information gathered from this study could help to recommission an on-site abalone farm at Louth Bay, South Australia. The use of heat/chill pumps to cool water for less than 14 days per year would prevent 'summer mortality' if abalone operations were re-commenced. In addition, the use of saltwater wells could provide cooler water from several meters below the surface. Furthermore, the selection and production of seaweeds with anti-bacterial properties could reduce vibrio levels in abalone and the culture system to improve survival during periods of stress.

Introduction

Aquaculture includes the culture of a wide range of organisms in freshwater and saltwater, from microscopic algae to large fish. Like many other primary industries, aquaculture operations in Australia must continually work toward being efficient to compete with cheaper overseas products, which are usually the result of lower labour costs and greater production volumes (economies of scale effect). Continuous improvement of methods and systems is critical to most aquaculture operations in Australia.

In recent years the sustainability of some aquaculture sectors has been brought into question. Fish meal is a component of most aquaculture feeds which are used as a diet for cultured finfish, prawns, abalone and other species. The use of fish meal to feed aquatic animals of higher market value has prompted the question of whether aquaculture is actually reducing pressure on wild stocks or just transferring one biomass into another. It is generally recognised that the world's oceans are being overfished and for a number of species, aquaculture is perhaps the only way of supplying increasing demand to take the pressure off the fishing of wild stocks. With global food security becoming an increasing concern, sustainable aquaculture will probably remain the most rapidly increasing food production system worldwide.

The culture of seaweed as an on-site feed source for marine grazers has the potential to decrease feed costs, improve abalone health and also offers other benefits which are discussed in this report. Many types of seaweed have the potential to be incorporated into artificial feeds for all aquatic animals including finfish (Pereira et al., 2010). Research has shown that seaweeds can be used as a partial replacement for fish meal, as well as a significant source of protein, carbohydrates, vitamins and trace elements.

Integrated Multi-Trophic Aquaculture (IMTA) has the potential to increase the sustainability of aquaculture across the globe. In the last 10 years there has been a shift toward viewing waste nutrients as a resource that can be recycled through plants in a range of aquaculture situations from land-based freshwater to open-ocean culture. The incorporation of plants and filter-feeding organisms can increase the viability of land-based recirculating aquaculture systems (RAS) which were investigated for their potential benefits to land-based mollusc culture in Australia.

1. Seaweed culture

1.1 Overview

Seaweeds are multi-cellular marine algae and are the fastest growing plants on earth. Like terrestrial plants, seaweeds utilize light, nutrients in inorganic form and carbon dioxide to perform photosynthesis. Although some seaweeds' have a root-like structure, this is used for attachment only. Seaweeds obtain their nutrients direct from the water through fronds.

Whilst the ocean contains billions of tons of seaweeds, wild harvest is not permitted in Australia with the exception of an introduced brown species (*Undaria* sp.). The industry in Australia is based on the collection of beach cast seaweeds, with notable companies such as seasol marketing product to agriculture and home gardeners. This is not the case in a number of countries across the globe. Acadian Seaplants in Nova Scotia harvests seaweed direct from the sea and has established a renewal resource program involving a team of scientists. The team carries out research to ensure that harvest is not damaging the biomass and that they are not impacting on the fisheries industry or the marine habitat (Nichols, pers. comm.). This is important as seaweeds are an integral part of marine ecosystems, providing food and shelter for a range of aquatic creatures.

Even if regulations change in Australia and it is possible to harvest seaweed from local sources, seaweed culture on land is likely to be the preferred method for obtaining seaweed biomass. This is for a number of reasons, including the fact that Australia's marine waters are generally oligotrophic (low in nutrients) and do not support large seaweed productivity, and that collection and transport would be a costly exercise compared to on-site production. In comparison, in Ireland, ocean upwelling brings nutrients to inshore waters, where large biomass of seaweeds is obvious along the coastline. Figure 1 highlights the productivity of the seaweed *Ascophyllum* sp.

Figure 1: Natural growth of *Ascophyllum* sp. near Galway, Ireland

1.2 Propagation

Seaweeds are rich in diversity, having evolved a range of characteristics in order to compete in the oceanic environment. They display a range of morphological features, most notably variations in colour and structure. Seaweeds are also diverse in the way in which they reproduce. Reproduction for some species is as simple as asexual reproduction involving the break-up of cells which are independently capable of becoming an adult plant. For other species, complicated lifecycles can involve an alternation of dimorphic generations and sexual reproduction involving male and female types.

Many types of seaweed can also be grown from vegetative fragments, in a similar way that cuttings are taken from terrestrial plants. The optimum method depends largely on the species in question, however, the production of spores is generally favoured even when vegetative propagation is possible, due to the large quantity of spores that can be produced into adult plants (Le Gall et al, 2004).

In Ireland at the Martin Ryan Institute, fertile fronds of *Palmaria palmata* are induced to spawn by simply desiccating the seaweed and then placing these fronds back into seawater. Once the seaweed has 'spawned', spores are collected and simply using a spray bottle can be set to ropes for sea deployment (Figure 2).

Figure 2: Sporelings of the red seaweed *Palmaria palmata*

Fortunately, most species of seaweeds that have been cultured for abalone feed have relatively simple lifecycles and can be reproduced using both spore and vegetative methods. Propagation is not considered a major impediment to seaweed aquaculture. Reproductive methods have been described by scientists for a range of species, even with very complex lifecycles.

1.3 Culture methods

In the ocean, most seaweeds are observed attached to a substrate such as rock, whilst some are epiphytic, growing on other seaweeds and seagrasses. Seaweeds can be cultured using a range of methods both on land and at sea. At-sea production usually involves rope or raft culture. Land-based seaweed production can involve a range of systems, including plastic-lined ponds and various tank designs. Conical-based tanks and paddlewheel raceway systems are two of the more popular designs. A key principle of most systems is to ensure that both water and seaweeds are in constant motion to maintain continuous exposure of seaweed to light, water for nutrient uptake and gas exchange, and to prevent settlement of organic matter or fouling organisms such as benthic micro-algae. The opinion of several scientists at the seaweed symposium in Mexico was that constant movement of water is very critical for some species, as metabolites build-up rapidly on the surface during periods of low or no water movement.

Many seaweeds are prone to fouling in contained environments. Fouling by micro-algae will occur on most species if a combination of low water movement and high nutrients occurs. At the Cape Town Aquarium, kelps are replaced on a regular basis, despite the installation of flushing devices to improve water movement, which is required to minimize particle deposition and epiphyte attachment (see figure 3). However, due to the high fish: plant ratio, seaweeds are unable to take-out the majority of nutrients, providing an ideal growing environment for benthic microalgae. Fortunately epiphytes can be managed in land-based culture systems using a range of methods. Selecting fast-growing seaweeds, maintaining high water movement and where chemical nutrients are used, pulse nutrient dosing can help minimize micro-algae growth. (Pulse nutrient dosing involves supplying nutrients every 2-3 days to the seaweeds, which have an ability to store nutrients).

Figure 3: Flushing devices and water movement systems at the Cape Town Aquarium

This study focused on two systems for the production of seaweeds, including aerated tank culture and large paddlewheel raceways/ponds. A method of production involving large, lined ponds was considered, but this method appears difficult to manage and evidence suggests that productivity is low per unit area compared with other systems. Deep aerated tanks can be used to grow a range of seaweeds, including many red species that are consumed by abalone. Paddlewheel ponds arguably present a minor breakthrough in the production of large quantities of 'fleshy' type seaweeds at low cost compared to other systems.

1.3.1 Tank culture

Aerated, deep tank systems utilize air to constantly move seaweeds to provide exposure to light and the uptake of nutrients and carbon dioxide. Figure 4 shows how red seaweeds are maintained in suspension in tank-based aerated systems.

At Abagold in South Africa, quantities of *Gracilaria* sp. are grown as part of a mixed diet for juvenile abalone (*Haliotis midae*). Species such as *Gracilaria* cannot be grown in paddlewheel ponds as string-like seaweeds clump in paddlewheel systems (Robertson-Andersson, pers. comm.). This method of growing seaweeds has potential for growing smaller volumes of feed for juveniles and to supplement the diet of adult abalone. However, mass production of seaweeds using this method has higher associated capital and running costs and is considered not to be an option for bulk food production for abalone culture in Australia. Acadian Seaplants in Nova Scotia produces red seaweed in tank systems for the Japanese food industry. The higher costs associated with tank-culture are helped by a premium received for the product.

Figure 4: Aerated/tumble culture of *Palmaria palmata*

1.3.2 Paddlewheel ponds

Paddlewheel ponds or raceways are large rectangular structures with a divider down the middle, usually lined with canvas or plastic. A paddlewheel moves water in one direction continuously within these systems. *Ulva* spp. are the most commonly grown seaweeds in paddlewheel ponds. Figure 5 shows an experimental culture unit at Abagold in South Africa.

Observation of aquatic organisms is crucial in aquaculture. In paddlewheel ponds, *Ulva* could be observed spinning in a circular motion up and down throughout the water column. This is an important feature of this system as the seaweed must be prevented from layering which prevents gas exchange and nutrient uptake. Also, many types of seaweed are negatively affected by photo-inhibition which is caused by exposure of marine plants to either sudden increases in light levels or simply exposure to high light intensity. Seaweeds possess a range of photo-protective compounds to provide protection from harmful UV rays; however, there is much variation between species (Hupel, 2010). Some species have adapted defensive mechanisms to higher light, but most species seem to perform poorly at maximum light intensity in the upper water column. Photo-inhibition is likely to be an issue when growing many seaweeds in Australian conditions where light intensities can exceed 120,000 lux. Ensuring adequate mixing will help and maintaining appropriate seaweed stocking levels can reduce the effects of photo-inhibition by the principle of ‘self-shading’. Figure 6 shows the even distribution of seaweed in a paddlewheel system which is mainly due to high water movement.

Figure 5: Paddlewheel culture of *Ulva*.

Figure 6: Close-up showing *Ulva* in suspension

1.4 Species selection

Australia has the greatest diversity of seaweeds in the world. With over 2,000 species known, there is a diversity in the properties and potential products that can be generated from these seaweeds. Chiovitti et al., (2001) points out that Australian seaweeds show a chemical diversity unmatched by species from around the world. Based on presentations at the 20th Seaweed Symposium in Ensenada, Mexico, it became clear that even within species there is a huge genetic diversity for a range of traits.

The species of seaweed selected for aquaculture needs to take into account a range of factors. In particular, the species selection needs to match the culture method, site conditions as well as the application. Furthermore, the potential for genetic improvement is substantial given the genetic diversity of seaweeds, the short generation times and the ability to place a high selection intensity on traits such as fast growth.

Ulva spp. have a tendency to spawn-out in culture conditions, possibly due to changes in water temperature or other factors. This is considered a significant problem in the production of *Ulva* for human consumption (Windberg, pers comm.). When *Ulva* spawns, white patches appear where cells are released from the main frond, resulting in a patchy, unhealthy looking appearance. Whilst some loss of cells is not a significant problem for the application as abalone feed, minimizing the tendency of the *Ulva* to spawn-out is preferable. The selection of *Ulva* strains can reduce the tendency of this species to spawn (Robertson-Andersson, pers. comm.).

Whilst most overseas abalone species grow well on a range of brown species, most brown seaweeds are unpalatable to Australian abalone, possibly due to the abundance of red seaweeds in their habitat (Shepherd and Steinberg, 1992). Initially this project focused on red seaweeds due to the perception that Australian abalone prefer red seaweeds and that green seaweeds had poor food value. However, it is apparent in the literature that *Ulva* may have been considered of poor value in the past due to the low protein levels in this species when fed to abalone in these trials. There is a strong correlation between protein levels in seaweeds which can be influenced by nitrogen supply (Shpigel et al., 1999). Several trials including in Western Australia in the late 1990's showed the green seaweed *Ulva rigida* to be a suitable species for abalone culture. In one trial it was shown that there was equal growth between abalone (*H.roei*) fed *Ulva rigida* and artificial feed (Boarder and Shpigel, 1999). The combination of the fact that *Ulva* spp. fed to abalone results in suitable growth rates and that it can be grown in a low cost system, makes this species an ideal candidate for culture.

A number of trials around the world have shown that abalone fed mixed diets grow better than single species diets. The red seaweed *Gracilaria* spp. has good potential for culture as a supplementary food source for abalone. *Gracilaria* spp. tolerate higher temperatures than many other red seaweeds found in oceanic waters, making them a suitable culture species for outdoor production in southern Australian locations which can experience maximum temperatures over 40^0C. Another red seaweed, *Palmaria palmata* can contain over 30% protein and is grown in tumble culture tanks for feeding abalone. A large abalone farm in Hawaii, Big Island Abalone, reportedly produces the largest quantity of red seaweeds grown in land-based tank systems in the world. Whilst *Palmaria* sp. is an ideal abalone food, this species prefers cooler water and was observed on the study trip in cooler parts of the world, including Ireland and Oregon in the U.S. Fortunately, red seaweeds grow in a range of environments and tolerate a wide range of temperatures. *Gracilaria* (figure 7) is cultured in South Africa for abalone food and also in tropical locations for the production of agar.

Figure 7: *Gracilaria* culture in South Africa

1.5 Applications

Seaweeds have a range of applications across a range of industries. Initially this study was aimed broadly at investigating seaweed culture opportunities in Australia, with a focus on seaweed as a feed source for abalone. Direction partly changed when the 'Seaweed Cultivation Manual' (by Barry Lee) was released shortly after beginning the scholarship. A thorough review of opportunities for Australia in seaweed culture, this manual was possibly the first expansive review of seaweed culture opportunities by an Australian author. This report and subsequent publications by another Australian researcher, Pia Windberg are recommended reading for those interested in seaweed culture opportunities in Australia.

1.5.1 Seaweeds as a food source for marine grazers

Seaweeds are the natural diet of many marine grazers including abalone and sea urchins. One of the main reasons that seaweeds have not been cultured in Australia is due to the very large quantities required. Approximately 7g of live algae is required for 1g of abalone live weight gain. The weight of seaweed fed-out to abalone must be approximately 7 times the quantity of pellet for similar growth results due to the fact that seaweeds are approximately 90% water. Seaweed production systems for bulk feed must therefore be large, covering a significant surface area for light capture. Fortunately, seaweeds are the fastest growing plants on earth and some seaweeds can be harvested on 6 week rotations. One farm in South Africa produced 60% of their feed requirement from cultured *Ulva* and *Gracilaria* (Troell et al., 2006).

In terms of benefit to the aquaculture industry, the majority of Australia's abalone farms rely on commercially-produced artificial feed, costing around $3/kg. Seaweed production does not need to replace artificial diets, but can supplement the primary diet to provide a number of benefits. A decrease in tank cleaning in abalone systems could be possible, through intermittent feeding with seaweeds. Unlike uneaten pellets, seaweeds do not rapidly form mould or contribute significantly to bacterial levels in culture systems.

On abalone farms during periods of high stress, such as high water temperature, abalone feeding is normally reduced. One reason for this is that artificial diets have been shown to rapidly increase total bacteria and total *Vibrio* spp. counts. On the other hand, some seaweeds may in fact illicit the opposite effect. One experiment in the literature showed that the poly-culture of abalone with the red seaweed *Gracilaria textorii* maintained lower levels of total *Vibrio* spp., and also influenced the balance of the *Vibrio* composition (Pang et al., 2006). *Vibrio alginolyticus* was one of two secondary, moderately pathogenic microbes present in high numbers during outbreaks at SAABDEV. Pang et al., showed that *V. alginolyticus* was inhibited by *G. textorii*. The inhibition of pathogenic bacterial species by action in the gut through feeding and as this study showed, through the water column, could have profound benefits to a range of marine aquaculture businesses across the globe. The feeding of selected micro and macro-algae to marine organisms may rival the application of probiotics (pure strains of 'beneficial' bacteria) as a method of inhibiting pathogens for the purpose of reducing disease outbreaks in aquaculture hatcheries and grow-out operations.

Prawn farmers in Southeast Asia have faced major stock losses due to outbreaks of a bacterial pathogen. The use of 'green water technique' has successfully been used to reduce mortality caused by the pathogen, *Vibrio harveyi.* Green microalgae (*Chlorella sp.*) are grown in separate ponds and introduced into the prawn ponds. This algal species contains substances that have anti-bacterial effects against pathogenic species of *Vibrio.* Further studies have also shown that aged fish water (tilapia) will also reduce Vibrio levels (Eleonor, 2003). Since fish are vertebrates, they have the capacity for specific immune responses to pathogens. Both non-specific and specific immunity in the form of macrophages and bactericides in the mucous reduce concentrations of *Vibrio harveyi* in the water. This is further evidence for both the antibiotic properties of marine plants and an example of where one species can benefit another (which is part of the IMTA concept).

1.5.2 Seaweed for agriculture

Alan Critchley from Acadian Seaplants stated at the 20^{th} seaweed symposium that seaweed extracts modify plant and animal responses at a fundamental level. The brown alga *Ascophyllum* shown in figure 1 tolerates a wide temperature range from -30^0 C to $+30^0$ C and is used to improve plant resistance to temperature extremes and resistance to drought.

Seaweeds possess a range of chemicals which are used by them as deterrents to herbivores, protection from high light levels, growth promoters and others. Some of these 'natural' chemicals can be used as pesticide additives. Natural hormones have been proven for some time to increase root development and reduce the impacts of disease. While some of these organic chemicals can be synthesized, the added benefits such as provision of trace elements can warrant the use of this natural product. Seaweed additives have been shown to improve health and increase milk production in dairy cows through supplementing their diet and altering the gut flora. AgriSea in New Zealand makes a range of products for agriculture from seaweeds. Their products are particularly focused on improving animal nutrition. Sales have increased in recent years as dairy farmers in New Zealand have observed the benefits in providing a seaweed extract to dairy cows which have become sick due to nutritional deficiencies.

Figure 8: AgriSea produces a range of products from *Ecklonia maxima*

2. Marine grazers in recirculating aquaculture systems (RAS)

2.1 Abalone culture- Australia and overseas

Abalone are a highly prized seafood throughout many parts of Asia, particularly Japan and China. In their natural environment, abalone predominantly consume marine plants including seaweed and benthic micro-algae. Methods for producing abalone vary both between and within countries. In China sea culture dominates abalone production. Cages, lantern nets and other structures contain the stock which are mainly fed seaweed grown locally on ropes. In countries such as the US, Mexico, South Africa and Europe, land-based aerated tank culture is the dominant production method, whilst in Australia, a shallow raceway tank design is most common. In NZ, one farm grows abalone in a tiered raceway system which recirculates water; however, globally most farms operate flow through systems. Figures 9 shows the shallow raceway system which dominates grow-out technique in

Australia and figure 10, the plate/aerated tank method which is prevalent in overseas land-based abalone culture systems.

Figure 9: Shallow raceway culture in Australia

Figure 10: Tank culture in Ireland

Australian abalone farming operations are viewed by some as the most efficient in the world, partly due to the low labour requirement associated with the shallow raceway systems. However, in Australia abalone farming has not been without its challenges. Site influences such as high water temperature, economic factors such as the low US dollar and more recently, the threat and outbreak of disease have challenged a number of operations.

2.2 Recirculating aquaculture systems

Water re-use involves the repeated use of water that has passed through one module such as a tank or raceway. Simply allowing water to flow from one system (via gravity) into another can be considered a water re-use system in comparison to flow-through in which water is discharged after a single pass.

In a recirculating aquaculture system a proportion of the water that has passed through a culture unit is returned to that same unit, usually by a pump. Unlike flow-through systems, recirculating aquaculture systems require water treatment to enable the water to be re-used. For basic water treatment, infrastructure or equipment are used that enable; oxygenation/carbon dioxide removal, solids removal, and biological filtration. Figure 11 shows some typical components of a water treatment system for abalone culture. These include a drum filter for removing solids, foam fractionators for removing dissolved organics, a biological filter to remove ammonia (background) and an ultraviolet light sterilizer (blue light) for disinfection.

Figure 11: Water treatment system for an abalone farm in southern Ireland

Flow-through systems have several distinct advantages over re-use and recirculating aquaculture systems. Provided the aquaculture facility is located in an oceanic site, water of consistent quality can generally be relied upon. So, why recirculate water when a continuous supply of high quality water can be pumped ashore into flow through systems?

The answer to the above question is relatively complex and depends on a number of factors. For Irish abalone farmers, recirculation is the only option for producing abalone as water temperatures are too cold for adequate growth and abalone need to be grown in greenhouses or closed structures with internal heating provided. In South Africa, the threat of harmful algal blooms has prompted several farms to consider recirculation in order to avoid drawing in toxic microalgae which have the potential to wipe-out entire stocks. It was reported at 'Aquaculture 2010' in San Diego that one abalone culture operation in Chile is considering recirculation as pumping water up a 15 metre cliff is an expensive option. The following sections look at several aspects of recirculating aquaculture systems involving marine grazers including; water quality management, temperature, health management and biosecurity. The ability and/or motivation to recirculate water for part or all of an abalone aquaculture operation depend on a number of factors which include risk management, system design and environmental parameters.

2.2.1 Water quality

Most abalone farms incorporate a brood-stock conditioning and spawning system, abalone nursery, juvenile system and grow-out. All sections must run smoothly and so risk aversion is a primary aim for many aquaculture operators. Water quality can turn quickly resulting in loss of stock. Poor water quality can reduce growth rates and increase the risk of bacterial diseases.

In natural conditions, abalone live in oceanic environments typically characterized by clean, cool, well oxygenated water of consistent salinity and pH. Land-based culture of abalone exposes them to conditions which they would not normally experience in their natural environment. Dissolved oxygen is normally the first parameter to become limiting in aquaculture systems, commonly reducing survival, health and growth. In flow-through systems, water is used once only in a vessel and then discharged. RAS systems generally require increased monitoring to ensure that parameters such as dissolved oxygen levels are maintained at optimum.

Oxygen uptake by abalone is affected by dissolved oxygen concentrations in the water and flow rate of water through the gills. Several trials carried-out on dissolved oxygen levels have been undertaken in tanks and have suggested abalone are very intolerant of low oxygen conditions. However, it is possible that oxygen uptake is greater in raceway systems than in tanks. Phil Heath from the Mahanga Bay facility (which is part of the National Institute of Water and Atmospheric research (NIWA)) in New Zealand is currently carrying-out trials on the effect of low oxygen levels on abalone in raceway systems. In aquaculture, it is important that site-based research is carried-out on a regular basis to monitor water quality parameters and their effects on growth and survival.

The pH tends to decrease in recirculating systems as a proportion of carbon dioxide from respiring organisms dissolves in water to form carbonic acid. A slight reduction in pH can be beneficial in some systems as at a pH of 8.3 (normal seawater), total ammonia (TAN) is toxic at very low concentrations. However, on the other hand, a pH of below 7.6 can cause shell wastage as calcium carbonate reacts readily with free hydrogen ions at this pH. The photographs in figures 12 and 13 were taken at a recirculating abalone farm in Ireland. The shell wastage is a clear sign of exposure to low pH. The abalone were obtained from another facility; calcium carbonate was used successfully to increase pH at this farm, however, the abalone take time to recover. For all species which incorporate calcium carbonate or aragonite in their shells, pH should be maintained above 7.8 at all times.

Figure 12: Abalone recirculation system

Figure 13: Close-up showing shell wastage caused by dissolution of calcium carbonate at low pH

2.2.2 Temperature

Heat/chill units use the principle of refrigeration to heat or cool water. John Seccombe has worked on a number of aquaculture operations in both New Zealand and Australia and considers that heat/chill pumps are the most efficient way of cooling water in enclosed aquaculture systems. In combination with a heat exchanger for exchanging 'top-up' water in recirculation systems and with adequate insulation, heating or cooling water could be a viable option for some closed operations. Increased cost of infrastructure and electricity can be offset to a certain extent by improved growth and survival. The ability to fully recirculate can enable ozone treatment, reducing the threat of disease entry in high risk locations. Heating and/or cooling water may be a viable option for juvenile systems which have a lower biomass and land footprint than grow-out systems.

Other methods for adjusting water temperature may have an application in Australia. OceaNZ operates a semi-recirculating system at a location on the northern most part of the north island of New Zealand. To reduce temperature in the warmer months, a cooling tower reduces incoming water by up to 3^0C. Australia has typically dry summers and low humidity, which makes evaporative cooling an effective way of reducing temperature in closed structures. Evaporative cooling could have an application in reducing temperatures in some abalone culture systems utilising recirculation.

2.2.3 Health management

By recirculating water, microbes can build-up to much higher levels than flow through conditions. There are a range of factors that influence the build-up of microbes in aquaculture systems. Organic loads particularly from faeces and uneaten food can cause significant increases in bacterial levels.

To control bacterial levels, OceaNZ has incorporated a UV sterilizer into the system which kills 99% of the bacteria in the entire flow before the water is re-pumped.

Skjermo and Vadstein (1998) describe the benefits in microbially matured water for marine larvae. ‘A diverse bacterial flora established by non-opportunists is believed to inhibit proliferation of opportunistic pathogenic bacteria in the water and the larvae’. In the US at the Aquaculture 2010 conference, Attramadal (et al., 2010), described that higher organic loads are not necessarily to blame for mortality outbreaks. Recirculation was considered as a microbial control strategy in the intensive culture of marine fish larvae. In fact, research in Norway has shown that sudden increases in organic loads can be much worse than maintaining a stable low to moderate organic nutrient load within a system. This is because most pathogenic marine bacteria are opportunistic and fast-growing. A relatively ‘clean’ system can suffer greater stock losses when a sudden organic load occurs, because of the absence of a stabilized population of bacteria.

OceaNZ grow abalone in a tiered raceway system such that water from the first raceway cascades into the second and then into the third. Reports are that abalone grow slightly faster in the second raceway. This has also been observed on Kangaroo Island Abalone farm. Reasons for this are unknown; however, one possibility is that there is some benefit in this ‘conditioned’ water, possibly that moderate bacterial levels help with digestion of feed. Maintaining a low to moderate organic load may actually improve survival.

Recirculation systems have benefits that are lesser known. Biological filters used primarily for removing ammonia from aquaculture systems can have a secondary benefit by maintaining a stable population of bacteria in a system. Taylors Shellfish in Washington State (U.S.) in conjunction with Professor Chris Langdon from the Hatfield Marine Science Centre (in Oregon) were carrying-out trials on stabilizing bacterial populations by using biofilter media to support a bacterial population (figure 14). This is not the standard use for a biofilter but shows that components of recirculating systems may have advantages. It is known by many marine hatchery operators that sterilized water can reduce mollusc larvae survival, possibly due to an absence of bacteria which are beneficial for the purposes of digesting food and competing with pathogens.

Figure 14: Biofilter for stabilizing bacteria in a marine system

Figure 15: Seaweed investigated for anti-microbial properties

The use of seaweeds in abalone culture could improve the ability to recirculate or re-use water without the need for UV sterilization, as seaweeds can not only reduce bacterial levels, but certain seaweeds can be selected to target known pathogens, identified through pathology testing. Cheng et al. (2004) showed that high water temperature causes a reduction in phagocytic activity (one of abalones' limited non-specific immune defences), leading to susceptibility to *Vibrio* and other bacterial infections. A well known specialist in health management in marine hatcheries, Ralph Elston (at 'Aquaculture 2010') described vibriosis as a recurrent problem in marine hatcheries, and stated that so far there is "no magic fix for vibriosis". In the absence of a suite of treatment options in the event of a bacterial outbreak, the combination of feeding seaweed to aquatic animals and maintaining a stable and diverse population of bacteria can help to reduce the proliferation of pathogenic bacteria which can gain a foothold in stressed animals. Figure 15 shows that a small experimental unit can be suitable for various studies.

According to Hart (2002), a (marine larvae) gut filled with vibrios' can cause symptoms that appear to be nutritional deficiencies. In the same way, a healthy, balanced gut is likely to play a significant role in the optimal gut health and digestion of food. The variation in bacterial flora in aquaculture systems could be part of the reason for commonly unexplained differences in growth between culture units.

2.2.4 Biosecurity

Sterilization of source water is one way in which pathogens can be prevented from entering an aquaculture facility. Globally, aquatic diseases are spreading at an alarming rate. Abalone stocks across the US were devastated and have been slow to recover from a deadly bacterial disease known as withering syndrome. More recently in Australia, the ganglioneuritis virus has caused losses of abalone stocks both on several abalone farms and also to wild populations. Mortality of over 80% of salmon in Chile has decimated this industry. At the Screebe fish hatchery visited in Ireland all fish are vaccinated before sending to sea, however, losses from viral infections still add up to 20%.

Ozone is a powerful oxidizing agent that is used in aquaculture to sterilize water. The potential to use ozone to prevent the entry of pathogens could be considered by some abalone aquaculture operations in Australia, especially in situations where pathogens are present locally. The Whiskey Creek Oyster Hatchery in Oregon used ozone to successfully remove an oyster pathogen *Vibrio tubiashii* from the water. Ozone is also capable of removing the toxin produced by this bacteria.

Ultraviolet light is probably the most common form of disinfectant used in aquaculture applications. Generally, it is used to reduce bacterial levels in RAS, rather than to prevent the entry of pathogens. UV sterilization is cheaper than ozonation; however there are several issues with its use as a sterilizer. UV only penetrates short distances and so shading of bacteria by particles can reduce its effectiveness. Many viruses and some bacteria require a very high dose of UV, and photo-reactivation, where bacteria repair DNA damage on exposure to light can occur (Liltved and Landfald, 1993).

Ozonation is expensive, but in some cases, costs could be offset by a reduction in stock cover insurance premiums. At some sites, saltwater wells can be used as a source of water for ozonation. A lower ozone rate is suitable for very clean water. Figure 16 shows a prawn farm in China. This farm draws 20 litres per second from an underground well. On the day we visited, the sea appeared a coffee colour (figure 17), whilst incoming water was completely clear.

Figure 16: Prawn farm in China using well water

Figure 17: Prawn farm- ocean at site

2.2.5 Water movement options for RAS

Abagold produces up to 350t of abalone per annum and is the largest abalone farm outside of China, employing 250 workers. Power is their primary running cost due to the need to pump over 2,000 litres per second to adequately supply its flow through operation. In contrast to pumping water direct from the ocean, recirculation of water on site provides the opportunity for a greater number of water distribution options. The slab tank raceway systems predominantly utilized for abalone culture in Australia are situated at ground level. Recirculation systems can be designed to minimize both pumping heights and frictional head losses as water does not need to be pumped long distances from sea level. At low head heights, axial flow propeller pumps are particularly suited to reticulating water at a lower electricity cost. These pumps (figure 18) were observed in both New Zealand and England where they are used to move high volumes of water between aquaculture ponds. Also, through the displacement of water via air, air lift systems are known to be a cheaper way of pumping water at low head heights compared to centrifugal pumps and have the added benefit of providing aeration. Connemara Abalone in Ireland uses a South African grow-out system to produce abalone for the European market. All water is recirculated via airlifts (figure 19). No pumping is required apart from drawing top-up water from the sea.

Figure 18: Axial flow propeller pump

Figure 19: Abalone grow-out airlift system

2.3 SA Abalone Developments- potential for recommissioning?

South Australian Abalone Developments (SAABDEV) located at Louth bay on the Eyre Peninsula was once a flow-through abalone farm which produced over 25 tonnes of abalone per annum. However, it was decommissioned predominantly due to 'summer mortality' rates at around 30% per annum. High water temperature beyond greenlip abalones' (*Haliotis laevigata*) normal range reduced immunity in farmed stock, leading to susceptibility to bacterial infection. Vibriosis was confirmed as the most likely cause of stress-induced mortality in abalone at SAABDEV by the following indicators; a) the effectiveness of antibiotics in controlled on-site experiments, b) the high variation in mortality rates between raceways and c) pathology testing. Data collected and analyzed on site showed that primarily, mortality was only caused by spikes over 23-24^{0}C. Extended periods at 22^0 C did not cause significant mortality, although stock losses would occur for several weeks following thermal spikes. The implications of this were that cooling of water need only occur for less than 10 days per year to potentially prevent 80% of stock losses. Before these data were collected, cooling was considered to be necessary for the entire mortality period of up to 2.5 months. The economic viability of cooling water by a few degrees for 10 days appears far more promising than 10 weeks.

Considering that such a short period of temperature reduction is required to prevent mortality outbreaks, the ability to recirculate water with minimal RAS infrastructure is a viable option. The combination of heat/chill pumps and insulation would be the main investments needed to maintain a low temperature. As the site is located on sand, bore water is available at full strength salinity. The bore water reaches a maximum temperature of around 21.5^{0}C in summer compared to an average maximum of 26^{0}C at sea (adjacent to the farm). A suitable volume of water could be obtained from a relatively large seawater well on site to assist with temperature control. Figures 20 and 21 show raceway design of the abalone grow-out system at the farm.

Figure 20: SAABDEV raceway system (1)

Figure 21: SAABDEV raceway system (2)

Urchins present another opportunity for SAABDEV. Urchin roe receives a high price on the Japanese market at around $1200/kg (wholesale). Wild harvest of urchins is not considered economical due to the inconsistency in roe (gonad). However, it has been recognized that roe enhancement can be achieved by feeding on land and at sea. Access to food is considered to be one reason linked to the inconsistency in roe harvest. In New Zealand, at Mahanga Bay Aquaculture facility, research is being conducted on several species including seaweeds, abalone, sea cucumbers and urchins. Feeding experiments involving the local sea urchin (known as kina) have shown an increase in roe yield from 3 to 10% body weight over a 10 week period. Greater than 10% roe is considered crucial to make urchin culture economically viable. Seaweeds (the natural diet of sea urchins) could be an important part of increasing roe. Also, recirculation of water can influence or control water temperature, thus further improving roe percentages. John Chamberlain runs a recirculating sea urchin hatchery and nursery in Ireland. The combination of recirculation and a greenhouse maintains temperature about 3-4C above the adjacent sea water.

3. IMTA systems

3.1 Fundamentals of IMTA

IMTA production is not a new concept. For centuries, pond poly-cultures have supplied a food source for rural communities throughout China and many other Asian countries. Figures 22 and 23 show poly-culture ponds in the Philippines and China. In these particular systems, chickens or geese are fed, with their waste providing nutrients for microalgae, which in turn provide a feed source for herbivorous and/or omnivorous fish. Products from these systems can include; poultry, plants (e.g. lotus), fish and freshwater crustaceans.

Figure 22: Poly-culture in the Philippines

Figure 23: Poly-culture in China

One of the fundamental concepts of integrated multi-trophic aquaculture is that animals and plants in the system must provide a benefit to the system and/or have significant economic value. The value of species in a system can be due to; improving water quality, reducing feed costs and/or direct sale. However, the benefits of integrated systems are not confined to economics. The environmental benefits of utilizing waste nutrients can help to prevent or reduce eutrophication of marine and freshwater bodies.

The localized eutrophication of the ocean is a continuing global problem. In the Gulf of Mexico a 25 mile anoxic zone has developed due to human impacts in the Mississippi delta. Whilst aquaculture is generally not a major contributor to large-scale eutrophication, the culture of aquatic animals can contribute to nutrient loads, which can be a problem especially in sensitive areas.

In the Mississippi delta, the pond catfish industry produces nutrients that are predominantly discharged into the Mississippi river. This practice certainly begs the question: Why can't the nutrient-rich water be used on cropping land? Discussions with researchers at Mississippi State University confirmed that crops grown on this nutrient rich water have increased yields. One of the issues is that ponds are clustered and with some farms covering 800 acres, there is a large distance required to pump water to cropping land. Turning monoculture systems into integrated systems can be difficult and it is clear that it is much better if plant and animal culture systems evolve together. During the global focus program it was realised that the majority of research and development over the past 30 years has focused primarily on independent monoculture systems, not on integrated farming systems or aspects such as waste utilization. This is one reason why integrated and waste-recapture systems have not progressed rapidly.

3.2 Abalone and seaweeds in IMTA

3.2.1 Current status

'True' IMTA culture involves interaction between plants and animals. Therefore, single pass systems in which water flows through abalone systems and then through seaweed systems prior to discharge are technically not considered IMTA systems. However, there is certainly no need to adhere to a concept. Unlike freshwater aquaponics, there are currently no known 'fully' recirculating (greater than 90% water re-use) integrated multi-trophic aquaculture systems incorporating abalone and seaweeds.

In South Africa, most abalone farms run seaweed culture units either independent to abalone culture or using wastewater prior to discharge. However, one IMTA abalone farm is running at 50% recirculation through a seaweed culture unit (Bolton et al., 2006).

3.2.2 Seaweeds for improving water quality

One of the main benefits of integrating animals and plants is the improvement in water quality by the plant component. Many seaweeds prefer nitrogen in ammonium form and all produce oxygen and remove carbon dioxide through the process of photosynthesis. With the exception of solids removal, these are the main functions of water treatment in a recirculating aquaculture system. Unfortunately, the contribution of seaweeds to improved water quality mainly occurs during light hours, as these functions which include oxygen production, carbon dioxide and ammonia uptake are predominantly correlated to photosynthesis. In a RAS, each kg of *Ulva* produces enough oxygen daily for 2 kg of fish stock (Neori et al., 2004). Based on a lower metabolic rate, 100 kg of *Ulva* could maintain enough oxygen for 500 kg of abalone. Therefore, to improve water quality parameters such as oxygen levels, a relatively low quantity of seaweed is required as a ratio to the abalone component.

3.2.3 Nutrient management

Nutrient concentrations from abalone farming systems are low owing to the high flow rates and lower metabolism of abalone compared to fish. Economic models in Israel have shown that fish/abalone/seaweed culture can be the most viable IMTA systems (Neori, pers. comm.), but this is highly dependent on the value and market of the fish component. Fortunately, nutrients can be added to seaweed culture units infrequently by pulse dosing. At Abagold ammonium phosphate and ammonium sulphate are the main fertilizers used. Every 2nd day, incoming water to the paddlewheel ponds is turned off for several hours after nutrients are added. Nutrient management is crucial to optimal production in seaweed culture systems. Research by Scheunhoff et al. (2003) showed that protein levels of 34% dry weight were achieved in a RAS fish system. Protein levels over 40% are apparently achievable according to researchers at the Seaweed symposium in Ensenada.

As mentioned previously, Australia’s coastal waters are generally oligotrophic (low in nutrients) and so little background nutrient is present. Trace elements such as iron are known to be limited in southern Australia and along with the major nutrients, nitrogen and phosphorous, may need to be added to seaweed culture units receiving abalone waste water to provide optimal seaweed nutrition. Trials by Demetropoulos and Langdon (2004) showed that a range of inorganic nutrients and trace elements could be added to seawater which is then added to abalone culture vessels without any impact on abalone growth. Similarly, based on research in freshwater aquaponics, addition of inorganic nutrients has not had adverse impacts on fish, with the exception of relatively high levels of potassium on striped bass (Rackocy, pers. comm.). Perhaps with the exception of ammonia as a fertilizer, water from seaweed culture units can be returned to abalone culture systems without concern over negative impacts from nutrient or trace element toxicity.

3.2.4 Challenges

The ocean acts as a temperature buffer, whilst significant heat gain or loss occurs when water is maintained in open culture systems on land. Seaweeds require high light levels for growth and light adds heat. This can actually be an advantage in locations where water temperatures are low. In South Africa, water temperatures remain low through summer due to cool Atlantic currents. Aeration and water storage on land raises water temperatures and increases growth rates of the abalone. However, in the warm temperate conditions of Australia, the combination of water temperatures near abalones' upper limit and maximum daytime temperatures of up to 45^{0}C, it's clear that it is not possible to run an outdoor integrated abalone/seaweed system during these times.

3.2.5 Economics

In IMTA systems, the economics need to consider all products from the system. Each product must have a value that makes inclusion economically sensible. The economics of IMTA systems involving abalone and seaweeds are very complicated. It was difficult to obtain information on this important aspect for a number of reasons, including that there are few integrated abalone/seaweed land-based systems operating around the world, as the concept of land-based IMTA systems incorporating abalone and seaweeds is relatively new.

One farm in South Africa produces 4mt *Ulva*/day in 32 8m * 30 m paddle ponds (Bolton et al, 2006). This is equivalent to approximately 571 kg dry weight/day which is equal to over $A500,000/year in artificial feed. Paddlewheels have 3kW motors, based on this, if the paddlewheels were run all year, electricity costs would be well under $A100,000. As the system runs on abalone discharge water, no pumping is required. That leaves labour and nutrients as the remaining primary costs. Although Australia has higher labour costs, methods for the mechanical distribution of seaweed from culture units to abalone raceways could be developed, potentially preventing the need for hand harvest.

There are a number of factors that influence the financial viability of installing paddlewheel ponds to run separately, using waste water only or as part of an integrated system. Tierry Chopin at the 20th seaweed symposium in Ensenada made the point that there is an opportunity for a premium price for aquaculture products produced in land and sea-based integrated systems. Sustainably produced products are likely to receive a similar premium as 'organic' products in some markets.

3.2.6 Implications for Australian abalone farms

The Fizantakraal fish farm in South Africa grows trout in a semi-recirculating system (Figure 24). This system includes both recirculation and water cascading. Water is recirculated within individual raceway systems using airlifts. A simple system using a gate controls how much water is exchanged and is dependent on ammonia concentration as no biofilter is used in the system. This type of model is one that could be used to integrate abalone and seaweed culture. Abalone waste water directed to paddlewheel ponds or other seaweed culture units could be returned (using low cost pumping methods) only when parameters were suitable. For example, during daytime when seaweeds produce oxygen, some of this water could be directed back to the abalone, resulting in a reduction in pumping costs and increase in oxygen levels to the abalone culture system. Also, elevated carbon dioxide levels in abalone water can benefit seaweed culture units. Seaweeds at-least have potential to form part of a water treatment system and it is clear there are many potential ways in which integrated abalone/seaweed culture can prove viable.

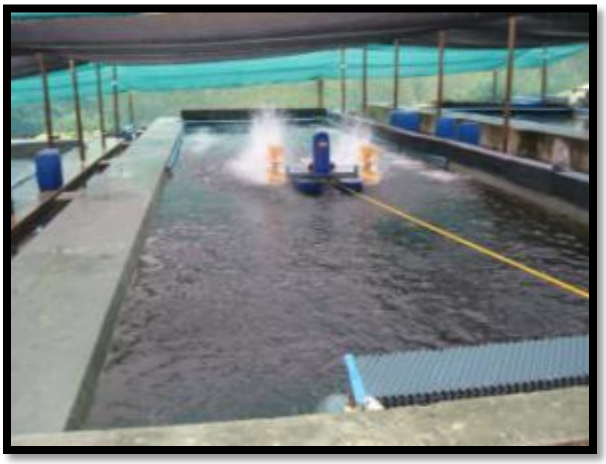

Figure 24: Semi-recirculating trout farm in South Africa

Conclusion

In summary, the study of RAS involving molluscs and the integrated culture of abalone and seaweeds highlights the diversity and complexity of challenges associated with aquatic culture of animals and plants. However, the production of seaweed as an on-site food supply, the option of reducing power costs by semi-recirculating using low energy pumps at low head heights and using seaweeds as part of a water treatment system, can help to improve efficiency for some operations. Although Australian seafood usually receives a premium in overseas markets, competition on price will be an ongoing issue for primary producers in Australia. The production of marine plants in land-based integrated and stand alone systems is likely to expand due to increasing research in this area, combined with pressures on aquaculture producers to reduce costs, utilize waste resources and improve aquatic animal health.

Aquaculture and the wild fisheries sector provide jobs right across regional Australia. In Ireland where the economy is in trouble due to the global financial crisis, a number of workers previously employed in the building industry are out cutting seaweed for export. This ability to move from one industry to another is crucial in a rapidly changing, globalised economy. The expansion of aquaculture in Australia can occur in a country with clean waters and a reputation for exporting high quality seafood. Marine plants and integrated systems can play a role in this expansion.

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Plain English Compendium Summary

Project Title:	Integrated Multi-Trophic Aquaculture Systems incorporating abalone and seaweeds
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Objectives	To investigate a range of aspects of integrated aquaculture systems incorporating abalone and seaweeds, primarily to assess the potential for seaweed production as an on-site food source for abalone.
Background	Australian abalone farms feed stock an artificial pellet, unlike most overseas operations which predominantly either collect or grow large quantities from the sea. The opportunity to produce seaweed as an on-site feed source was the basis for this study along with an interest in recommissioning an abalone grow-out facility at Louth Bay, South Australia.
Research	A range of aquaculture facilities were visited and conferences attended in the U.S., Mexico, Ireland, England, South Africa and New Zealand. The research focused on several aspects, including seaweed culture, recirculation systems incorporating abalone and sea urchins, and integrated aquaculture systems.
Outcomes	Seaweed culture has significant potential to provide an on-site feed source for abalone. The production of *Ulva* spp. in paddlewheel ponds can yield large quantities of a feed that is suitable for abalone culture. Integrated culture of abalone and seaweed culture can take advantage of the beneficial interactions between animals and plants, particularly, the uptake of nutrients via seaweeds. Recirculation of water may be an option for some farms for a range of purposes, including the ability to reduce pumping costs by opportunities afforded by lower pumping head heights
Implications	Abalone farms could consider installing paddlewheel ponds between abalone culture units and a discharge point. Waste water can be directed to these seaweed culture units to utilize waste and prevent the need to pump water for separately for the paddlewheel ponds. A range of issues discussed in this report may assist some abalone farmers interested in seaweed culture, recirculating aquaculture systems and integrated systems involving molluscs in Australian conditions. Depending on several factors, the potential to recommission a 50t capacity on site abalone farm by recirculating and cooling water during periods of high incoming water temperature appears promising.