SOUTH WEST ABALONE GROWERS ASSOCIATION

Abalone Feed Requirements

March 2008

Final Report for SEAFISH

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Authors Note

The views expressed in this report are those of the author and not necessarily representative of South West Abalone Growers Association. The information and data given is provided in good faith with the intention of helping other potential farmers. This report is intended as a guidance document to assist others in the preparation of their own site specific investigations.

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EXECUTIVE SUMMARY

Abalone naturally eat seaweed of which some less abundant species are preferred. Although some seaweeds are more nutritious than others it is generally accepted that a mixed diet of weeds is optimal. In the case of the European abalone or ormer delicate red and green weeds are preferred although some abundant weeds such as the kelp *Laminaria digitata* is commonly used as a bulk feed.

In culture situations where seaweed sources are considered it will be necessary to demonstrate that operations are sustainable to ensure no significant impact on the marine ecosystem. Furthermore, when abalone culture is proposed in Special Areas of Conservation (SAC's) a higher level of 'Appropriate Assessment' will be required. This report is a guidance document to help address some of these issues and present options for individual scheme consideration.

Feed options for abalone are influenced by local situations in terms of availability and seasonality. They are also influenced by the choice of culture technique with offshore systems generally better suited to seaweed use, whilst in onshore high rate recirculation systems artificial feeds may be more appropriate. In consequence, feed selection is site specific and therefore different between potential site options. This variation in local feed availability and selection is typified by case studies from SAC's in the Isles of Scilly (IOS) and Porthkerris within the area of the Fal estuary designation.

IOS has a large standing stock of seaweed that theoretically can be harvested at a sustainable level without significant impact on the SAC features. However, although a scientific case could be made for this approach the burden of proof is high and local support is vital.

Porthkerris has a wide range of feed options which could vary seasonally according to environmental limitations, availability and economics. In the summer some local beaches are subject to 'green tides' with nuisance mass deposits of *Ulva,* a species favoured by the ormer. In the autumn local beaches can also receive significant drift deposits which can either be directly used, or stored following suitable preservation. During the winter significant quantities of weed are removed off the Carrick Roads oyster fishery during oyster dredging operations. Over the late spring / early summer months seaweed availability (unless preserved) may be low during which artificial feed may be employed. In theory, artificial feed may seem the easiest option for culture throughout the year. However, artificial feeds do present some concerns and are not yet well suited for sea culture. Even within land culture settings it is likely that some seaweed will always have a place for use in early life stages and perhaps as a finishing pre-market diet.

Seaweed utilisation cannot be separated from its social context. Although historically the UK has a history of seaweed utilisation, this heritage has largely been lost in England. In communities where this tradition has been maintained, such as France, Ireland and Scotland, there is less fear of harvesting activities. In contrast, within the UK and the South West in particular such activities are likely to be viewed with suspicion at best, and hostility at worst. In consequence, proposed culture operations will need to address public fears and false perceptions in addition to the legitimate concerns raised by conservation agencies.

Potential operators should aim to work in consultation with Natural England to explore and monitor the levels of the different feed sources in the proposed operational area over a couple of seasons. This will provide valuable data to aid the decision making process in order to ensure a sustainable operation without undue environmental impact. Trial monitoring exercises could allow limited and logged removal of small seaweed quantities that could be utilised for demonstration projects and for the early years of culture when weed requirements are low. This approach is a pragmatic way forward that allows protection of the environment whilst not stifling industry development.

1. Scope of Document

South West Abalone Growers Association (SWAGA) promotes sustainable development of abalone culture in the South West of the UK. Abalone feed type and sourcing is a central consideration for any prospective aquaculture operation as it dictates the choice of technology, environmental limitations and cost of production. This report reviews information of abalone feed information in the context of the SW and an initial assessment of the available resources, potential impacts and areas worthy of future commercial or research consideration.

A number of nearshore culture sites have been considered throughout the SW with the main focus of offshore trials within Cornwall following the work by Cornwall Sea Fisheries (FitzGerald 2003). Although there are a number of potential culture sites under consideration, two prospective sites are currently being considered within Special Areas of Conservation (SAC). As part of the due diligence required for potential operators a study is required of the feed options and impact at both sites. SAC's are an ecosystem based conservation measure brought in following the EU Habitats Directive 1994. A proposed development scheme requires an 'Appropriate Assessment' to be carried out if it is considered to have a 'significant' impact on the features of interest. Natural England (formerly English Nature) is the responsible agency for considering these assessments. Wider legislative requirements for seaweed utilisation are considered within an accompanying report on "UK Abalone Culture - Legislative Issues." The legislation report incorporates licensing issues such as permissions for seaweed harvesting from the Crown Estate.

This document provides a general summary of the European abalone (or ormer) *Haliotis tuberculata* feed requirements followed by a site specific assessment related to potential impacts. It is intended that this document can be used as a discussion document with Natural England (NE) in order to help satisfy the needs of an appropriate assessment. Although all potential developments will have site specific features, this document can be used as a template adapted to individual needs thereby aiding members with future development plans.

2. Biological Overview of Ormer Feed Requirements

FitzGerald 1997 reviews the seaweed requirements of the European abalone in terms of its species preference and dietary performance. Seaweed is the natural diet for abalone. The following sub-sections present different aspects of seaweed nutrition whilst seaweed sourcing is considered in Section 3. It should be noted that although culture in Great Britain will focus on the needs of our indigenous ormer information relating to other abalone species will be used where relevant.

2.1 Seaweed Preferences

It is widely accepted that each species of abalone has its own preference to particular species of seaweed, although most abalone will eat other less favoured weed types if given no choice. Generally, *H. tuberculata* prefers red and green weeds while *H. discus hannai* and *H. rufescens* prefer the more common brown weeds.

There are a number of factors that influence weed preference. A brief summary provided below:

1) Phagostimulants. It is thought that the preference of wild abalone for certain macroalgae is a function of chemical attractants. Some work has been done to identify specific chemoattractive properties although Peck (1983) could find no specific evidence of chemosensing for the ormer.

2) Phagorepellants. Certain phenolic compounds, such as those frequently found in kelp, are frequently considered to act as a repellent to abalone and inhibit digestion.

3) Food Texture/Toughness. Abalone feed by means of a rasp-like radula whose effectiveness is strongly influenced by the form and toughness of the food. Generally, the red seaweed that are found deeper are more fragile than the brown weeds and are often soft and filamentous and are considered easier to ingest.

4) Abalone Age. Some studies show weed preferences change from juvenile to adult that have been attributed to changing nutritional needs. In the case of the ormer comparative studies by Culley and Peck (1981) showed no feeding preferences between old and young animals.

5) Energy Content. Culley and Peck (1981) conducted a series of tank weed preference trials for young and old ormers, comparing a number of weeds. The study showed a weed ranking of:

a) *Enteromorpha*
b) *Ulva* and *Palmaria*
c) *Laminaria* and *Chondrus*

Peck (1983) latter showed that the ranking correlated to the energy content of the weeds with the ormers aiming to optimise their food resources although other workers working on other species have shown no major relationship with the seaweed energy content.

6) Weed Freshness. It has been suggested that abalone prefer drift weed over attached growing weed.

In summary, it would appear that a number of features affect the weed preference of different species of abalone and may not always correlate necessarily with nutritional value.

2.2 Seaweed Nutrition

A good deal of work has been conducted on the macroalgae diet for the ormer with notable contributions from Peck and Culley (Portsmouth) and Mai, Mercer and Donlan (SRL Carna).

Peck (1983) showed that the ranking of food preferences correlated to the energy content of the seaweed whereas Mercer and his co-workers conducted a series of comparative growth and dietary studies on the ormer looking at a range of dietary factors to yield a slightly different ranking for mono-specific diets:

1) *Palmaria palmata*
2) *Alaria esculenta, Ulva lactuca, Laminaria digitata*
3) *Laminaria saccarina, Chondrus crispus*

It is generally accepted that a mixed diet is better than a monospecific diet. Some workers have showed that the calorific value of abalone faeces was still high suggesting either incomplete digestion or inability to digest certain components. It is possible that if the grazing process of the abalone does not completely rupture the cellulose cell walls of the weed, digestion of the cell contents may be inhibited. Studies of microbial gut populations and microbial generation of cellulase suggested that gut fauna may be a feature in the feed assimilation in a similar fashion to that of some land herbivores.

In summary, a number of factors are important in the effectiveness of food assimilation that lead to differentiation in the growth rate according to algal species available. Although red and green seaweeds appear to give the best nutritional value and growth to the ormer, a mixed diet often provides the best growth.

2.3 Seaweed Feed Requirements

Mercer (1991) considered collection of large quantities of weed as one of the major problems in the cultivation of abalone. Consideration of feed requirements is therefore of vital importance to not only business success but also in order to assess potential environmental impact.

There are a variety of weed consumption values provided by a number of authors with disparity often apparent with differing seaweed source, abalone species and market size of abalone produced. LaTouche, Moylan and Twomey (1993) provide a quick look up table of weed requirements (*P. palmata*) for a farm producing 100,000 marketable abalone/year. Weed requirements clearly intensify through the culture period ranging from 2.1 tonnes/yr to 24.5 tonnes/yr between years 2 and 4. A constant level of abalone production (i.e 100,000 abalone/yr every year) would require a total of 37.1 tonnes of seaweed per year. Another weed consumption estimate by Fallu (1991) suggested a weed requirement of between 0.5-1 tonnes of weed per week for a 250,000 abalone/yr farm (or seaweed quantities of 10.4-20.8 tonnes/yr for a 100,000 abalone/yr farm).

Peck (1983) provides some of the most comprehensive data of theoretical requirements from tank based studies for a range of ormer sizes with results expressed in terms of both wet and dry weights. In summary, on a wet weight basis seaweed requirements range from 5%/day to 1%/day for animals ~10mm to 70mm respectively. For an abalone production unit in steady state 10t abalone production/yr would require 40-50t of seaweed/yr. This conversion rate compares favourably with terrestrial based herbivore farming such as cattle with conversion rates of >10:1 and a much greater environmental impact.

3. Seaweed Sources

This report has been summarised using information produced by South West Abalone Growers Association (SWAGA) website (FitzGerald 2005).

Seaweed collection or harvesting for a commercial abalone venture should be performed in concert with regulating authorities using agreed methods and in agreed areas. Requirements will often be site specific according to the sensitivity of the area in question. Section 6 and 7 provide a more detailed consideration of harvesting impact in relation to potential operations for case studies from the Isles of Scilly and Fal Estuary.

Seaweed can be obtained from natural sources in a number of ways:

-Collected as drift (washed up on the beach, or offshore)
-Harvested using divers
-Harvested by hand at low water (particularly at low water springs)
-Harvested remotely from the surface using specialist equipment (e.g. air lift pumps, trawling)
-Culture in land based or sea based culture systems

As natural sources tend to have marked patterns of seasonal availability this section also includes consideration of storage techniques.

3.1 Seaweed Drift Collection

Drift weed may accumulate either on the surface along beaches or at depth between rocky outcrops. The advantage of beach drift is clearly its ease of collection, which must be weighed up against potentially poor quality rotting weed and a possible extensive cleaning requirement for the removal of sand and pests. The advantage of submerged drift is that it is of higher quality being both cleaner and with a greater chance of being still alive. This must be offset against the difficulty in obtaining such weed.

The major problem with drift seaweed is its limited seasonal availability which would suggest it would be a poor sole source of feed. Much of the South African *H. midae* production is made using beach cast material which is abundant in the spring and autumn but limited in the summer. Francis et al (2007) compared growth rates of abalone subject to starvation periods against stock with an ongoing ration and surprisingly found that they grew as well as the control animals. Indeed because they ate less food their conversion rates were better than the well fed stock! In the UK attitudes towards the collection of beach cast seaweed is highly variable from district to district and indeed from beach to beach. Some areas actively remove seaweed as a nuisance in tourist areas, whilst on other beaches seaweed is viewed as a vital component of the beach ecology. Clearly the use of beach cast is unlikely to be a suitable sole source of feed although there may be a potential to obtain limited stocks on a site specific basis subject to local agreements.

3.2 Seaweed –Harvesting

3.2.1 Kelp Biomass

Werner and Kraan (2004) review literature biomass production rates for kelps from a number of countries. French studies for *L. digitata* indicate a standing stock of 2-10.5kg/m^2, Irish studies again for *L. digitata*, indicate slightly high levels at 3.4-15kg/m^2, whilst Norwegian studies on *L. hyperborea* recorded 5.8-19.05kg/m^2. In all cases the biomass levels had a minima in the early spring and maxima in mid-autumn.

Rothman (2006) considers the harvesting ecology of the South African kelp in relation to harvesting for abalone culture. The kelp *Ecklonia maxima* was shown to have biomass densities ranging from 10.5kg/m^2

to 21.3kg/m^2 with an average biomass of 14.4kg/m^2 of which 8.6kg/m^2 was frond biomass indicating that 62% of the kelp biomass was surface reaching. An average density of 10kg/m^2 was proposed as a guide biomass density for seaweed management.

Using examples of our own native kelp biomass levels at between 2-20kg/m^2 with the majority of values over 5kg/m^2 a conservative 5kg/m^2 is proposed as a management guide in UK assessments. The Isles of Scilly Case Study (Section 6) reviews the potential area of seabed harvesting needed for a possible culture operation on this basis.

3.2.2 Kelp Depth and Extent

In terms of the area of kelp present it would be of interest to firm up on the extent of the different species types with depth. Werner and Kraan (2004) provides an account of the differing banding of kelps with depth for the five main kelp species. Generally, in coastal water rich in particles the depth limit is 10-15m below MLW whereas in clearer water of the open Atlantic coast kelps can be found to 30-40m. Off Norway dense stands of *L. hyperborea* grow down to 30m at 5% of surface light levels. The low solids levels found in IOS waters would suggest that *L. hyperborea* (the main shelter species – Section 3.2.4, with the slowest re-growth period) may well extend beyond 18m depth. As this species is not the target species for harvesting then many concerns relating to re-growth and loss of habitat are reduced as this deepwater seaweed is not required and would be below the maximum harvest depth for the Scoubidou system anyway (~5m).

3.2.3 Seaweed Regeneration / Fallow Period

The length of the regeneration period is strongly influenced by what type of weed is extracted and what harvesting method is employed. Other site specific considerations may include the local light regime, temperature and availability of nutrients which will influence the rate of growth.

Abalone culture would primarily require *L. digitata* as a primary (but not exclusive) food source. *L. digitata* has a life cycle of 3-4 yrs and becomes fertile after 2 yrs, with 50% of blade coverage with reproductive sori by the third year and 80% coverage by the fourth year (Werner and Kraan (2004)). In Brittany around 60,000t of *L. digitata* is harvested primarily using the Scoubidou system from 60 licensed boats. Around 30% of the total biomass is removed annually yet despite this significant level of removal harvesting has taken place for a number of years. Werner and Kraan (2004) reviews the performance of the Scoubidou and importantly indicates that this technique not only leaves the smaller plants (<60cm in length~ younger than 2 yrs) on the seabed but that there was no obvious difference in recovery time following Scoubidou extraction than from manual cutting (see Section 3.2.5).

In France re-cutting of *L. digitata* is permitted on a 3-4 yrs basis. Most areas off the Brittany coast are harvested without allowing a growing season for standing stock to recover. In the case of intensive harvesting of greater than 30% of the stock a proportion of smaller plants are removed. A 1-2yr fallow period has been proposed to improve the recovery of *L. digitata* beds and hence increase the reproductive output of the *L. digitata*. This would also allow better scope for Year 3 weed to shade out opportunistic *S. polyschides* growth.

Seaweed harvesting in Norway turned from *L. digitata* to *L. hyperborea* in the 1960's following extensive stock surveys along the coastline which showed that 10 million of the 15 million tonnes of standing stock were *L. hyperborea*. A cutting dredge was trialled in 1964 and has been subsequently developed for deployment from either specialist craft or fishing vessels. This dredge cuts the stipe 5-20cm above the holdfast although often entire plants are removed. Modern dredges with a capacity of 2t /haul can be operated between 2-20m depth on relatively level seabed surfaces. Annual production in Norway increased from 118,00 to 170,000t between 1973 and 1984 with current production at 140,000 to 180,000t/yr. This is calculated to be 15-20% biomass from each field in addition to 10-20% biomass loss from natural causes. A 4 yr fallow period was introduced in 1972 with associated demarcation of beds. Following scientific studies the harvesting cycle was extended to 5 yrs which still applies today despite a comprehensive review in 2000. Harvesting of *L Hyperborea* with a kelp trawler commenced in France from 1995 using a similar management methodology to that of Norway with a 5 yr fallow period and an annual production of 2,500t/yr (Werner and Kraan (2004)).

Norwegian studies have shown that seaweed regeneration is more rapid than complete fauna and flora recolonisation with the number of macrofauna remaining low in the first 3-4 yrs following trawling after which species number and diversity increased leading to the adopted 5yr fallow period. In some areas the total abundance of some epifauna remained reduced until 6 yrs after harvesting suggesting to the authors that kelp structure may vary with local environmental factors indicating the need for a local adjustment of harvest times.

In the UK, and particularly Scotland, there has been a long history of rockweed (*Ascophyllum* and *Fucus*) harvesting in addition to drift collection from beaches for fertiliser. The Scottish industry and management guidelines on fallow periods for *Ascophyllum* and *Chrondus* are provided in the Minch Project (1995). This study found almost complete recovery of the *Ascophyllum* and its associated ecosystem within 5-6 years. However, if *Ascophyllum* is cropped to approximately 20cm it should be harvestable again after 3 years. *Chondrus* can recover from severe harvesting (close cropping) after 18 months, although this is affected by the timing of the harvest.

More recently *Laminaria* harvesting has been undertaken in Scotland by the Orkney Seaweed Company who are consented to obtain 50t/yr which is harvested using a specially designed cutting grab (Milliken and Bridgewater, 2001). The companies web site (**www.orkneyseaweed.co.uk**) indicates that they harvest just 0.001% of the standing crop.

Seaweed harvesting was performed by Rocquaine Shellfish Ponds, an ormer farm on Guernsey, for over 20 yrs. Locally harvested seaweed was obtained initially by hand cutting, before use of a scoubidou system in the 1990's. Although abalone production was moderate, (generally <5t/yr), continual sustainable cropping of seaweed, as monitored by Guernsey Sea Fisheries, was undertaken from the same reef (R. Tostevin pers. comm.).

3.2.4 Seaweed Canopy as a Habitat

Seaweed provides a valuable habitat to shelter a range of vertebrate species. Kelp forests in particular have been recognised for their importance in the provision of a canopy.

The loss of habitat with the removal of seaweed should also be placed in the context of the natural variation both through storm loss and grazing. Werner and Kraan (2004) cites storm loss of seaweed of up to 50% biomass. In addition, Werner and Kraan (2004) reviews the impact of sea urchins which have caused some destructive grazing on kelp beds in the last 20 years. Sea urchins can create barren areas as new settlement is prevented by continuous grazing until coralline algae becomes the dominant flora.

Although it could be argued that seaweed harvesting is additional to these 'natural' losses the critical consideration for the Appropriate Assessment is whether the impact is 'significant'. The considerations provided in Points 3.2.1 and 3.2.2 suggest that the quantity of seaweed required would be small relative to the total standing stock and much less than the natural variation from year to year and therefore not significant.

3.2.5 Seaweed Holdfasts as a Habitat and the Choice of Harvesting Methods

Kelp holdfasts provide an important shelter to a large range and number of invertebrates and epiphytes. Werner and Kraan (2004) cites species diversity and abundance studies of the holdfasts for both *L. digitata* and *L. hyperborea*. Although both species have a range of both flora and fauna associated with the holdfast there is a stark difference between both diversity and abundance between the two species. The shallower *L. digitata* supported both fewer species and lower densities and the deeper *L. hyperborea* with 7:17 plant species and 16:55 animal species respectively. This observation is not surprising as *L. hyperborea* plants will tend to live longer (10-15yrs) and in deeper water are less likely to be exposed to high energy conditions. The significance of species disruption from *L. digitata* harvesting should therefore be viewed in relation to the quantity of biomass removed relative to that which is lost through storms in a season (~50% biomass).

The impact of the harvesting method on the seaweed population structure itself is outlined in Section 3.2.3. The environmental impact of mechanical *L. digitata* harvesting has been monitored frequently by French workers since the introduction of the Scoubidou. There is evidence that frequent harvesting in an area does shift the age distribution with proportionally less of the older larger plants and will reduce the overall reproductive output through loss of older plants. However, removal of the oldest weed can act to reduce the proportion of weed lost from a bed during a storm as the older plants are susceptible to lose significant amounts of material from the distal tips of the frond, and cannot cling on via their holdfast so well in the autumn. Furthermore, the growth rate of younger plants is enhanced when older shading plants are removed. In un-harvested areas growth of spring recruited weed over the summer is much slower than autumn recruited weed which receives more light once the older plants have either lost their tips or been stripped from the rocks by storms.

The impact of hand harvesting of fronds for abalone culture and the impact on regeneration times and reduced reproductive potential is considered by Rothman (2006) for the South African kelp *Ecklonia maxima*. This study showed that the removal to the stipe and the cutting of the fronds made no difference to the rate of stipe elongation and recruitment when compared against a control area. The reduction in fertile blades area was calculated as 0.93×10^{11} spores/m^2/yr for under-canopy plants as opposed to an untouched area with 2.46×10^{11} spores/m^2/yr. It was concluded that the 10% annual biomass harvesting (of fronds) would be unlikely to have a significant impact on the recruitment of gametophytes and ultimately the population structure and biomass of the sporophyte population.

3.3 Seaweed – Culture

The culture of algae is a major subject in its own right and as such it is beyond the scope of this report to review this discipline.

Seaweed culture appears to fall into one of two main areas:

-Culture for weed production (1)
-Culture for nutrient scrubbing (2)

3.3.1 Seaweed Culture Optimised For Production

Seaweed culture from tetraspores to produce germlings and the subsequent culture to harvest is a complex subject beyond the scope of this report. The success of developing seaweed culture in the SW will be strongly dependant on support from associated academic institutions. Nationally CMar in Northern Ireland and SAMs in Scotland undertake comprehensive seaweed work whilst both Portsmouth and Plymouth universities also have seaweed experts.

Monterey Abalone Company in California has been culturing the red abalone (*H. rufescens)* since 1992 utilising locally harvested giant kelp *(Macrocystis*) (www.montereyabalone.com). A number of claims and counter-claims have been made regarding the sustainability of this feed source and as such the company has developed a proactive collaborative research into rope culture with Mike Graham of Moss Landing Laboratories. FFI (2007) reports that Graham has worked with *Gracilaria pacifica* and *Gracilariopsis andersonii* which are suitable for vegetative propagation and have grown well on 10m rope lines placed offshore of Monterey Harbour. Growth trials at a variety of depths have established an optimum depth at ~3-3.5m which gives good growth (up to 17cm in 2 weeks) without excessive epiphytic growth. Research is ongoing with a second phase of research 2006-2008 which includes the optimization of production and linking production to the support of commercial abalone production. The company is activity marketing the apparent improved shell colouration resulting from the diet.

In common with California, Chile production of *H. rufescens* has a similar pattern of shifting food sources between wild harvested *Macrocystis* and cultured *Gracilaria*. Flores-Aguilar et al (2007), reports that the wild harvested kelp disappears in the winter forcing producers to use cultured *Gracilaria*. This stock is twice the price of the wild kelp and is claimed to yield a slower growth rate. Seaweed culture developments in Chile are reviewed in Buschmann *et al* (2005).

In recent years comprehensive studies have been performed in both France and in Northern Ireland looking into longline cultivation of *Palmaria palmata* in terms of both technical and economic aspects. The work by CMar at Portaferry has compared longline productivity and economics for both seedlings and tetraspore techniques and provided a comprehensive model for seaweed production. The work recently conducted at SAM's in Scotland takes this a stage further by growing *Palmaria* longlines alongside salmon pens to aid with nutrient scrubbing as considered further in the following section.

3.3.2 Seaweed Culture Optimised For Nutrient Scrubbing

The use of algae for the scrubbing of nutrients from fish farm effluent has received attention from a number of workers in different areas of the world. This system clearly has the benefit not only of removing potential pollutants from receiving waters but also of providing a ready supply of feed material for other species.

Pioneering research work at Woods Hole into integrated aquaculture systems based on human derived waste water was conducted by Rhyther et al. (1975) and LaPointe et al. (1976) using a combination of micro and macroalgae for nutrient scrubbing. Algae produced was fed to a variety of finfish, crustaceans and molluscs. Abalone inclusion into this multispecies system was also considered by Tenore (1976) with three species of abalone feeding on *Ulva* cultured within the system.

The use of macroalgae for nutrient stripping has also been considered with great progress by workers in Israel into nutrient stripping of waste water from sea bream ponds using *Ulva* (Cohen and Neori, 1991 and Neori, Cohen and Gordin, 1991). Research by this group in association with SRL Carna (Ireland) extended to polyculture with the ormer although performance in temperate climates was not considered as effective (J. Mercer, pers. comm.).

Work with *Ulva* and abalone is still ongoing as described in FFI (2007) for the abalone hatchery at Danger Point South Africa. The use of this ‘green filter’ is reputed to reduce water requirements and feed costs to the 200t/yr abalone production facility. The biofilter is claimed to provide water of sufficient quality to allow a reduction in top-up water or complete recirculation in the event of red tides in offshore waters. Surplus seaweed from the biofilter provides an output with an enhanced protein content (37-58% for *Ulva* and 35-45% for *Gracilaria*) suitable to feed to the abalone. The 1600m^2 of raceway tanks (x4 tanks) for the seaweed is sufficient to feed 40-50t of wet weight abalone and is reported to save the farm ~US$70K/yr. However, there is some uncertainty about the level of seaweed production as Bolton’s (2006) description of integrated aquaculture in South Africa describes x40 raceway ponds producing 960t of *Ulva* and *Gracilaria* in 2006. Dlaza (2006) reports on the growth performance of these weeds whilst his current PhD work now includes the culture of *Porphyra* for abalone and use as ‘nori’.

Briggs and Funge-Smith also considered the use of *Gracilaria* as a potential means of effluent scrubbing for shrimp ponds effluents (1993) although latter work demonstrated the difficulties of algal culture in heavily loaded effluent (1995). *Gracilaria* has also been used in an integrated salmon culture trials in Chile. In this case the nutrient scrubbing capacity has been associated with the production of a seaweed product with a higher agar content (Buschmann *et al*, 2005).

Nutrient stripping on a commercial scale for a salmon raceway farm in Oregon was undertaken using a red dulse seaweed (FFI, 1992). Operations were extended to incorporate clams and then abalone to mop up weed production. Levin who conducted the work in 1991 as part of an MSc claimed that the high nitrogen content of weeds produced exceptionally good growth in abalone. The inclusion of seaweed into any polyculture system may be an effective means of nutrient scrubbing while also providing a valuable food source to the ormer or as product in its own right. Work with Oregon University continued with Rosen, Langdon, and Evans, (2000) who studied the nutritional content of *Palmaria mollis* and also showed that growth under a variety of light, flow and nutrient regimes all provided different morphologies of weed. Evans and Langdon (2000) also reported the co-culture of *Palmaria* with the red abalone which aimed to balance the effluent scrubbing rates with the growth rates of the abalone produced. This interesting study also produced very good growth rates of between 3.5-4mm growth/month.

BIOFAQs (BIOFiltration and AQuaculture) was an EU project led by SAM's at Oban running from 2000 to 2003 that aimed to evaluate the effectiveness of 'biofilters' (biological filters) on reducing the environmental impact of intensive mariculture (www.sams.ac.uk/biofaqs). SAMs are currently working on seaweed mitigation of aquaculture nutrient input with a view to then feeding the enriched seaweed to herbivores such as urchins or abalone.

SEAPURA is another related EU project that aims to evaluate species diversification and improvement of aquatic production in seaweeds purifying effluents from integrated fish farms (www.seapura.com). This project ran from 2001 to 2004 and involved the Queens University (CMar) group with Lynn Browne that had performed the *Palmaria* longline work mentioned in the previous section. Other species included *Gracilaria* and *Ulva* whilst tasks included studies of nutrient uptake rates, the use of weed for finfish feed and husbandry techniques to improve process control. One such measure included the use of low level light to prevent the mass sporulation of *Ulva* (see other notes relating to *Ulva* below).

BIOPURALG is another similar European Interreg IIIC project running from 2004-2006 that aims to reduce the environmental impact of land based aquaculture through cultivation of seaweeds. The project is run by the MRI (University of Ireland, Galway) with partners in Norway (http://www.irishseaweed.com/New%20projects.htm).

3.3.3 Seaweed Culture Problems

The seaweed industry was worth 6 billion US$ in 2002 with a strong growth rate (reviewed in Buck and Buchholz (2004)). Although seaweed culture is widespread there are a couple of key problems that influence the potential for this source to be utilised for abalone culture:

-*Economics.* Fallu (1991) considers that the culture of seaweed would probably provide a better financial return if produced for human consumption rather than for abalone feed. Indeed the edible species of *Undaria* (for food 'wakame' in Japan), *Gracilaria* (for food and agar production) and *Porphyra* (for lava bread) all fetch good market prices.

-*Seasonality.* Conventional seeding of seaweed germlings in the early spring will only generate harvestable biomass in the later summer/autumn. This does not provide a continuous supply of feed material throughout the year. The use of optimised culture conditions (e.g. artificial lighting) within tank culture can help provide material out of season but may be challenging economically.

-*Storm Loss*. Under ideal culture conditions good growth rates can be obtained. Unfortunately, the best performance from longlines is obtained when biomass levels are high which is also when the risk of storm loss is the greatest. Buck and Buchholz (2004) considered seaweed culture in high energy Northern European waters using 'ring' structures to provide a more stable platform than conventional longlines. Although the technology was successful the potential income from seaweed production was 40 euros/ring whilst the capital cost was 100 euros/ring (assuming a 10year depreciation). Even accounting for price rises in seaweed this production cost does not include operational costs let along allowance for the loss of systems within the 10 year payback period.

Conceptually seaweed culture in an effluent stream is elegant and may reduce costs through the dual role of the seaweed as a nutrient scrubber and feed source. However, even here there are a number of technical and economic issues that require consideration before these models can be applied to an operation in the UK. An outline of some issues is outlined below:

> *-Process control.* Prevention of seaweed fragmentation which can block pumps and screens leading to husbandry problems. Fragmentation can be due to sporulation, (avoided by culture of sterile stock with vegetative reproduction), and morphological adaptation to thin stringy varieties, (avoided by culture of separate parent stock in low nutrient conditions).
>
> *-Production rates.* The best examples of seaweed nutrient scrubbing are provided from countries with high insulation rates. Inconsistent performance could well be a problem in temperate climates outside of the summer season.
>
> *-Biosecurity issues.* There may also be some biosecurity concerns of using seaweed from an effluent biofilter which is then fed back to stock.
>
> *-Market issues.* Aside from the perception issues of growing stock in effluent there is evidence that the seaweed produced in this fashion needs to be applied with care (see Section 5.3).

In summary, there has now been a great deal of research and academic work much of which has only been completed in recent years and not yet fully reported. Over the next few years this work will hopefully filter down to practical applications by industry. Whilst the scope for this approach is promising there are a number of issues that will require investigation and an ongoing level of good expert support.

3.4 Seaweed – Storage

Seaweeds must be stored carefully in order to prevent degradation that may have an adverse effect on abalone culture. Fallu (1991) mentions potential inhibition of growth from toxins produced by fungal growth in poorly stored food. Furthermore, partially rotted seaweed may lead to water quality problems within the culture tanks or containers, particularly on the oxygen demand.

Seaweed can be stored in a number of ways:
-Fresh in the sea within net bags (Mercer, 1991)
-Dried. Once dry a seaweed may maintain its nutritional value for many months (Fallu, 1991).
-Frozen. Peck (1983) considered freezing of weed as potentially a better means of preservation than drying although it would be more expensive to store.

At this stage it is not clear what effect drying or freezing will have on the nutritional value and stability of seaweeds. BIM were due to undertaking work trialling a tobacco drier for seaweed as a means to storage although it has not been possible to obtain these results. Testing performed on behalf of AquaGold has shown that *Laminaria digitata* yielded a mass of gelatinous material when re-hydrated which readily washed out of the seaweed. The resultant liquor had a massive BOD of >32,000mg BOD/kg of seaweed (wet wt.) in 24hrs at 18°C. The use of this dried seaweed in culture conditions would generate significant oxygen sag that would create husbandry problems.

In terms of nutrition Naidoo et al (2006) working on *H. midae* found poor growth rates of 0.90mm/month using dried kelp. It is suggested that seaweed preservation techniques could have large implications for abalone culture in terms of both nutritional quality and husbandry which will require further testing before this source of seaweed can be utilised.

Owing to the concerns relating to the problems associated with successful storage of seaweed a further option is to process seaweed when in abundance and then use the material as a component within artificial feeds to try and optimise the mechanical and nutritional stability issues (see following Section 4).

4. Artificial Feed Sources

Artificial feed can be used for abalone and is the dominant food source for a number of land based operations particularly in Australia but also of increasing importance in New Zealand, South Africa and Chile. It is suggested that both seaweed and artificial dietary sources have their place and should be considered on a site specific basis.

FitzGerald 2005 reviewed the benefits and concerns relating to the use of artificial feeds along with a listing of some varieties available on the market which are considered in the following sections.

4.1 Artificial Diets - Benefits

-Enhanced Growth Rates: Many workers have claimed many advantages for artificial feeds of which enhanced growth rates (due to the increased protein and dry matter content) is foremost. High growth rates can be achieved where diets have been optimised to provide all nutritional requirements with the added advantage that feed quality remains constant throughout the year. In addition to the ability to tweak formulations for different species or different life stages it is also possible to change the physical presentation. In this way powders, crumbs, pellets and strips can be produced and targeted to specific life stages.

-Biosecurity: Seaweed can contain many pests and parasites which if they become established within a culture system can both reduce growth rates and impact on mortality. Seaweed can be soaked in freshwater for a short period in order to try and remove these threats but complete isolation cannot be maintained. Even low level infection can stress stock which in turn can make abalone more susceptible to other problems (e.g. short term poor water quality). For this reason an artificial diet can have major advantages to a biosecure facility particularly in high intensity systems.

-Sea Independent: Artificial diets may be more appropriate for certain farm settings particularly for land based facilities with limited access to the sea. Access may be restricted for conservation or logistical reasons. In the first case seaweed use may be prohibited whilst in the latter seaweed collection may be too labour intensive and therefore expensive. The fact that these diets may not be as water stable as seaweed may not be a problem in these settings where food can be applied little and often.

-Not Seasonally Dependant: Seaweed from drift, harvest and culture will have periods of reduced availability. Artificial diets can be stored for prolonged periods and can therefore provide a year round diet.

4.2 Artificial Diets - Concerns

There is an increasing recognition that there are a number of potential concerns that must be evaluated:

-Over Optimistic Growth Rates: Some workers using artificial diets have reported fantastic grow rates. However, Fleming et al 1996, makes the point that caution should be used with some of the experimental techniques particularly with short studies. A poorly balanced diet may give good results in the short term yet certain nutritional components may then become limiting and reduce growth rates if a longer study had been performed.

Capinpin, EC Jr; Corre, KG (1996) studied *Haliotis asinina* fed an artificial diet and macroalgae to find better weight and shell growth in the first 3 months with the artificial diet, but better long term growth with the seaweed. It was suggested that the reduced long term growth rate with the artificial diet was a result of the channeling of resources into early gonad development and the paper concluded that seaweed was the best way forward.

-Adverse Impact on Water Quality: Some papers describe diets that have poor water stability so that the diet, at best, has certain nutritional components which may leach out, and at worst, just fall apart. Clearly, if this happens not only is nutrition (and growth) reduced but water quality may also be impacted. This could be in the form of reduced dissolved oxygen levels, or by feeding other opportunistic 'problem' species. Either water quality problem could reduce growth rates or increase mortality. This threat is not always apparent from lab. scale experiments where abalone are held in very low stocking density and uneaten food is carefully removed every day – not exactly representative of a commercial set-up. In the Guzman and Viana 1998 study, good growth rates of 2.2mm/month was obtained with an ensilaged abalone viscera diet that had a poor water stability with a loss of 24% dry mass on average in a 12hr period. The same experiment with abalone in a higher commercial stocking density and feeding regime would no doubt have been somewhat different!

Bissett, A; Burke, C; Dunstan, GA; Maguire (1998) showed that artificial diets supported a significant level of microbial and protozoan growth after 2 days immersion which affected the physical form of the diet and gave rise to a degree of breakdown although they concluded that there was no great decrease in the overall nutritional content. However, this does show that artificial feed will support fouling organisms.

-Adverse Effect on Precocious Sexual Development:: Lopez and Tyler, 2000 at Southampton Oceanography Centre did some artificial diet work at elevated temperatures. As expected growth rates at high temperatures were higher. However there were some surprising results on the artificial diet with shell deformations and early sexual maturity. Very early gonad development started at 1.09cm shell length on average and just 11 months in age. This condition did not occur with a seaweed diet. Another study by Jackson et al, 2001, on the Australian abalone *H. asinina*, has also shown the same unexpected result with artificial diets producing early sexual development, whilst the seaweed control did not. This paper also raised the concern that longer studies on artificial diets may produce lower overall growth rates as resources are funneled into early sexual maturity. These workers also suggest a potential causative link with high lipid levels used in these diets, and early gonad development.

Teruel and Millamena,(2000) working on *Haliotis asinina* compounded a range of diets with total lipid levels varying from 2.2% to 10.7%. The study found that the best growth rates were obtained with a total lipid content of 4.69% Diet 2, (1.5% lipid from a 1:1 ratio of a tuna fish oil: soybean oil) and suggested that it may be used as a basal diet for abalone juveniles. Indeed a number of the artificial diets have ~5% total lipid.

However, the Fleming et al (1996) review, whilst showing that a number of abalone feeds did have a lipid content of ~5% also pointed out that abalone appeared to have a very high lipid absorption efficiency and that the best Japanese diets had a very low lipid content.

Britz, PJ; Hecht, T; Knauer (1998) studied gut enzyme activity and surprisingly found low lipase enzyme secretion rates when fed on Abfeed artificial diet, leading them to suggest that lipid extraction was low in *H. midae*. A feeding frequency of once per day was also recommended!!!!

Dunstan, GA; Baillie, HJ; Barrett, SM; Volkman (1996) compared the fatty acid and sterol content of *Haliotis laevigata* and *H. rubra* abalone reared on artificial diet compared to those of wild caught animals and found that the captive animals exhibited enhanced levels of both fatty acids and sterols in the foot.

-Shell Deformation: Lopez and Tyler, 2000, also showed a high rate of shell deformation (87%) after just 4 months on a commercial diet. This clearly suggests a nutritional deficiency in some area which could have a marked negative impact on the possible commercial value of such a shellfish product.

-Environmental Impact: There is little information on the utilisation rate of abalone feeds and the potential for seabed enrichment by uneaten feed. Flores-Aguilar et al (2007), describes the current status of abalone culture in Chile which is primarily based on sea culture using seaweed. Although some land based farms in the north use artificial feeds offshore farms are reported not to use these feeds as they then are classed as 'intensive' farms and therefore need to be separated from neighbouring concessions by at least 2.8km. The high incidence of salmon farms in the area therefore limits the availability of suitable locations where these feeds can be used. It is uncertain to what degree similar measures may be employed in the UK.

4.3 Artificial Diets - Sources

A review of some of the commercially available diets is provided below: It should be noted that this list is not yet exhaustive as feedback has not been received from certain manufacturers and some feeds are no longer produced. No information has been received back from Redmills (Ireland), NOSAN (Japan), Silver Cup and Zeigler (US).

'Adam and Amos' Adam and Amos feed (Australian) comes in variety of grades and forms (crumb, pellets, sheets). The web site includes a paper showing French comparative trials conducted in 2000 against *Palmaria*. Adam and Amos has a good website showing their product range (www.adamamos.com). The site also provides a number of papers exhibiting the growth performance of their products.

A recent study by Dlaza (2006) included a growth comparison of a number of artificial feeds and seaweed combinations. Three Adam and Amos feeds were included that yielded growth rates of around 1.5mm/month. This performance was enhanced when the artificial feed was fed in conjunction with seaweed to provide a growth of 2mm/month.

'Abfeed' – was developed by Rhodes University and a company called Sea Plant Products with FFI articles appearing as long ago as July and October 1997. Peter Britz (Rhodes uni.) claimed lower juvenile mortality at 2-5% (as opposed to 4-8% on diatoms). Juveniles as small as 3mm were fed on pellets. Britz reported growth rates in *H. midae* of ~2.4mm/month - superior to natural weed diet which was attributed to the higher protein content and with a good conversion ratio of 1.3:1 (article does not say if this is a dry weight ratio). Dlazas (2006) comparative growth trials produced similar results the high growth obtained by the Abfeed diet (growth rate at 1.9mm/month). Dlaza indicated that the artificial feeds based on animal protein such as Abfeed were superior to those based on plant protein as it was more readily absorbed by the abalone. This contrasted with Naidoo et al (2006) who also worked on the same species yet obtained a lower growth of 1.5mm/month from the Abfeed diet and better growth (2mm/month) on a mixed weed diet. However, it should be noted that the mixed weed diet of kelp, *Ulva* and *Gracilaria* with the latter two species were cultured in farm effluent (see Section 3.3.2).

Abfeed is claimed to have good water stability, as it becomes 'rubbery' with a seaweed consistency after absorbing seawater. This claim appears to be supported by the Boarder and Shpigel paper which stated that Abfeed was more stable after 2 days than Adam and Amos and Haliogro diets. Water stability is again reported as a central feature in FFI(2007c) where it is claimed that Abfeed needs to remain stable to allow consumption for up to 3 days after feeding. However, another paper by Guzman and Viana 1998 studying *H fulgens*, suggested that the Abfeed tough rubbery structure reduced feeding rates relative to other softer artificial feeds giving a reduced growth rate which averaged just 1.5mm/month.

Abfeed is reported to be under trial in Chile via a sister company Aquafarm within a number of land based farms (FFI 2007cii). Researchers are looking at developing a 'feeding plate' to carry the food and to improve cost efficiency. This report also includes information from Marifeed the Abfeed manufacturers who state that Abfeed include finely chopped kelp to attract abalone.

'Haliogro' – made by a NZ company called E N Hutchenson. Company technical data stated that this product was ~30% protein with a blend of protein sources of which 50% was plant based in origin. Growth rates were reputed to be good and 40% better than 'another commercially available abalone feed' and over 400% more growth than the seaweed *Gracilaria*. However, considering the NZ background of the company it is probable that the species tested was not *H. tuberculata*. Comparative growth data with this diet on *H. roei* is available in a Boarder and Shpigel paper which ranked Haliogro behind that of Adam and Amos and Abfeed diets. This study also suggested that the product was less water stable than Abfeed at test temperatures. There is uncertainty of the current availability of this product.

'FeedX' is a seaweed based diet described in studies by Dlaza (2006) with comparisons against Adam and Amos and Abfeed for *H. midae*. Growth rates were not good at 0.85mm/month which is comparable to the dried kelp growth rate of 0.90mm/month quoted by Naidoo et al (2006). Dlaza (2006) included analytical results for Adam and Amos, Abfeed and the seaweed based FeedX artificial diets. The animal protein diets contained comparable levels of carbohydrate, fat, ash and protein. In contrast the FeedX diet contained significantly more ash and fibre but less carbohydrate and protein (19%). Fat levels were also significantly lower at 0.7% as compared with the fishmeal based diets with 2-4% to 3.3% fat. Dlaza claimed that animal proteins were less readily absorbed than animal based proteins. Although FeedX is described as being available in South Africa no other reference to this feed could be obtained.

'Makura' is a casein based diet that was produced by a NZ company called Promak. This diet was widely discussed in papers and seemed to produce good growth rates. Makura was launched in 1993 after 6 years of development. Articles in FFI appeared as early as April 1994 which claimed average growth rates for several species at 2-3.5mm/month and a food conversion ratio of 2:1 (makura:abalone weight). Water stability is also claimed to be good with a recommended feeding interval of 4 days at 18C. The product came as 50g strips, smaller squares or a fine powder considered suitable for 3mm juveniles.

NZ work on *H. iris* showed better growth on this diet than for fresh weed. There is uncertainty of the current availability of this product.

'Eyre Peninsula Aquafeeds' based in Australia has developed a feed. In Coote et al (2000) a study is described that aimed to produce a feed with the same essential protein profile to that of the analysis of the abalone flesh. Growth trials at a range of concentrations indicated a protein digestibility of between 56%-72%. However, their paper describes work performed on the greenlip abalone, (*Haliotis laevigata*) with data from just 2 months of trials.

'Halo' is a new feed introduced by the international feed company Skrettings. The product data sheet indicates that this feed is based on a combination of fish and plant protein sources. Growth curves to market size are not available for the ormer and as such some growth trials would be required before this feed could be relied upon to produce effective growth throughout the culture period. Skrettings claim that this product is the first to be produced by an advanced extrusion process and should outperform other products. As yet there is little growth performance information reported although a number of operators are trialling samples.

New Feeds. There may be scope for the development of a locally sourced artificial feed (see Section 4.4).

Although not strictly artificial feeds other non-seaweed feed options also include the use of terrestrial crops for fodder. Although lettuce has long been anecdotally suggested as an alternative food source for abalone, FFI (2007ci) states that testing is underway in Chile to explore these options on a commercial basis (see Figure below). Although the analogy of cattle grazing on beet crops instead of grass could be applied, it is uncertain at this stage how viable this approach will be for abalone. Aside from nutritional issues feed presentation may difficult as many terrestrial crops float making food capture problematic!

Evaluation of fresh vegetable feeds to red abalone (FFI 2007ci)

5. Feed Selection

5.1 Site Specific Considerations

In an ideal setting the best food sources giving the best growth would be utilised – however, this is not always possible. In practice selection of feed sources is likely to be site specific and seasonally dependant. For example, some sites may have sheltered deep water conditions suitable for seaweed culture, others may have recreational beaches where seaweed drift collection is acceptable, others may have a suitable seabed profile that allows large areas of seaweed standing crop that may be suitable for limited harvesting. Section 3 explores these options in more depth.

FitzGerald (2003) reports on 18 month sea trials conducted by Cornwall Sea Fisheries from 2001 to 2002 where a series of offshore demonstration trial moorings were deployed around the coast of Cornwall and IOS to look at growth and mortality. This included deployments of moorings with juvenile ormers in both the IOS and Carrick Roads SAC's with the agreement of NE.

Growth performance in these trials was good despite using only locally available weeds which in some cases were non-optimal foods. In the case of the Carrick Roads site an abundance of red weed (*Gracilaria*), considered a nuisance species on the oyster beds, was effectively used. Due to operational constraints the Mother Iveys site (off Padstow) was frequently fed only *Fucus*, the brown rockweed, a non-favoured species, yet growth rates were ultimately the same as for the IOS site where the optimal *Palmaria palmata / Ulva lactica* diet were provided. These trials showed that non-optimal species could be used and that in some cases food choice was perhaps not the limiting factor on the ultimate growth rate.

5.2 Legislative Considerations

Seaweed abundance and proximity are not the only considerations in feed selection. Increasingly environmental limitations will dictate what level of seaweed resource can be utilised from where. These legislative considerations vary on a site specific basis as demonstrated in the Case Studies outlined in Section 6 and 7. A wider consideration of legislative considerations will be provided in a separate dedicated report.

It is vital to assess the environmental impact of any potential harvesting technique upon seaweed regeneration and the associated species sheltering within the canopy and the holdfasts. A good review of SAC implications for seaweed harvesting operations may be found in Kelly et al. (2001) "*Impact assessment of hand and mechanical harvesting of Ascophyllum nodosum on regeneration and biodiversity."* Although this report deals primarily with intertidal rock weed many of the issues relating to Appropriate Assessment are also relevant to a sub-littoral seaweed harvesting operation. However, it should be noted that whilst existing 'traditional' harvesting is considered acceptable, a new development is unlikely to be measured by the same standards. This 'virgin' status would probably also apply in the South West of the UK following the demise in recent years of traditional seaweed drift removal and harvesting.

5.3 Market Considerations

Ultimately, abalone production is driven by market needs. In consequence, the influence of feed selection on product quality may be a vital factor. It should be recognised at this point that there are a number of potential markets and product presentations which will vary in their aesthetic, taste and textural requirements.

Shell Aesthetics

A major aesthetic consideration related to feed source is shell colour. Dietary influence on colour has also been reported for artificial feeds such as the NZ Mukura feed (see Section 4.3) which is reputed to give the paua shells a blue tinge. In Ireland the *H. tuberculata* is reputed to be largely green in colour relating to its specific weed diet. This is in contrast to the red shells found for the same species grown wild off the Channel Islands. In California the use of cultured seaweed species is also reported to give a better red shell colour relative to the wild kelp (FFI 2007a).

In addition to the aesthetic considerations for food products 'on the shell' it should also be recognised that shell products (jewellery and blister pearls) will place a high reliance on shell thickness and colour.

The aesthetic shell appearance can also be influenced by diet when certain nutrients may be limiting. A key example of this are cases where some artificial feeds have been shown to influence shell development along the respirator holes (see Section 4.2). However, the main influences on shell integrity are often due to husbandry issues such as infestations (e.g. *Polydora* and *Cilonia*) which can honeycomb shells with holes or 'shiny shell' where culture in poorly buffered waters can lead to dissolution of the outer calcite shell layer.

Flesh Taste

Market investigations have shown that certain markets (such as fresh' products for the Japanese market) are strongly driven by taste considerations. In consequence, it will be necessary to have taste testing of abalone produced from a variety of feed sources.

Deborah Robertson-Andersson has undertaken extensive work on *H. midae* in South Africa for her pHD which includes work on the influence of diet upon taste (as reported in Smitt et al (2007)). *Ulva* and *Gracilaria* (the two key species cultured in effluent scrubbing) were found to have high levels of DMSP (dimethylsulfoniopropionate) which is transferred to the abalone. Wild abalone fed on kelp were not subject to this bioaccumulation. Unfortunately, if such contaminated stock is processed by canning the DMSP is converted to DMS (dimethylsulfide) which is noxious and ruins the taste quality of the product. "The taste of the abalone lies in the different types of seaweed that the shellfish feed on. If it feeds on *Ulva* and *Glacilaria* exclusively, the abalone tend to develop an "off" taste and sulphur-like smell after the canning process, which makes the abalone quite unpalatable to some." (University of Cape Town Newsletter, Volume 25-16, August 2006). Robertson-Andersson has explored methodologies to maintain feeding with the high growth weeds and then subject stock to a depuration period prior to harvesting.

The use of finishing diets and the application of an appropriate feed regime is an area that will require significant market research. It may be possible to produce abalone on one feed (e.g. artificial feed) and then undertake finishing on another diet (e.g. seaweed) in order to provide the optimum taste quality.

Perception

It is hard to know at this stage how an indigenous market for an 'organic' product reared on seaweed will form in the Europe. The use of weed cultured in effluent waters (see Section 3.3.3) could also be problematic.

6. Isles of Scilly SAC – St Martins Case Study

The whole of the Isles of Scilly (IOS) archipelago falls within an SAC with eelgrass beds and shallow water sub-tidal sand flats identified as the key protected features (Ref. EN 2000i).

A prospective ormer operator approached SWAGA for support in establishing a culture operation within the IOS site on the island of St Martins. This potential scheme undertook a high level of negotiations with local parties, responsible agencies and national bodies. One of the core difficulties with this site relate to its SAC status and the protection of its unique features. A number of concerns were raised to Natural England by a local inhabitant in relation to the impact of the potential abalone culture operation proposed on the marine ecosystem and in particular to the seaweed stocks as the prospective operator was hoping to utilise the abundant kelp resources. These concerns have been considered in conjunction with the key protected features of the SAC in the following sub-sections. Much of the information provided has been based on Section 3.2 which was drawn of the various reviews conducted in France and Ireland looking at European experiences (Arzel (1984), Werner & Kraan (2004), Kelly (2005))

6.1 Kelp Biomass.

Section 3 reviews kelp biomass levels at between 2-20kg/m^2 with the majority of values over 5kg/m^2. Assuming a conservative 5kg/m^2 biomass production rate 1t of kelp could be obtained from 200m^2. Opposition to the proposed scheme stated 1t kelp could be obtained from 24,000m^2 with annual requirement of 8,760,000m^2/yr. If this were the case it would equate to a standing stock of ~42g/m^2 which is around x100 lower than the lower limits measured in other areas.

In addition to the area of harvested weed required scheme opponents also considered that abalone would only eat the frond giving rise to a large quantity of waste material. In fact although the ormer tends to start grazing on the thin tips of the fronds it does eat the complete plant if held in containment. Observations of abalone farming in Guernsey showed that stock was fed weed which was dropped and loosely chopped into the sea cage. When the cage was removed a couple of weeks later all traces of the weed had gone with no wastage.

As a conservative assessment for the weed stocks just down to 10m along the north coast of St Martins there is around 1,300,000m^2 of area. A table of the weed production and high production scenario for an abalone venture with an annual weed requirement of ~400t/yr is provided below.

	Low productivity 2kg/m^2	Medium productivity 5kg/m^2	High productivity 10kg/m^2
Kelp production to 10m depth	2,600t/yr	6,500t/yr	13,000t/yr
Potential % used by Abalone (if no other stocks used or harvested from elsewhere)	15%	6%	3%
Fallow period (between cutting)	6.5yrs	16.25yrs	32.5yrs

The above table shows that even at the lowest likely biomass production the 15% seaweed requirement is half the annual rate of that annually harvested in Brittany (30%/yr) with twice the fallow period. At more realistic biomass production rates this impact is further reduced. At the 5kg/m^2 production rate the biomass requirement is ~x5 lower than the equivalent French harvesting rate. If seaweed harvesting were then spread over an area wider than just the north coast of St Martins then the impact would be accordingly lower.

6.2 Seaweed Regeneration / Fallow Period.

The length of the regeneration period is strongly influenced by what type of weed is extracted and what harvesting method is employed. Other site specific considerations may include the local light regime, temperature and availability of nutrients which will influence the rate of growth. Section 3 reviews seaweed management from other countries. Scheme opponents criticised IOS plans to re-cut seaweed from area after a 4-6yrs fallow period stating that preliminary studies in Norway indicated full biological recovery still had not occurred after 10 yrs. In fact in Norwegian harvesting has a fallow period of 5 yrs which has been scientifically monitored to allow recovery of associated fauna and sustainable production (Werner and Kraan (2004)). Furthermore, the Norwegian experience is based on the harvest of the slow growing *L. hyperborea,* whereas the French experience is based on the harvesting of *L. digitata* (the target species sought) which has a much quicker regeneration time and hence even shorter fallow period.

The assessment in 6.1 indicates a fallow regeneration period of over 16 yrs based on a conservative assessment of weed biomass. The use of 6% biomass/yr is less than that of France and Norway and the conservative 10% management level used in South Africa which was demonstrated to have no significant impact on seaweed recruitment (Rothman 2006).

6.3 Seaweed Canopy as a Habitat

Seaweed provides a valuable habitat to shelter a range of vertebrate species. Kelp forests in particular have been recognised for their importance in the provision of a canopy. Scheme opposition stated that seaweed harvesting would remove the seaweed canopy resulting in loss of shelter for thousands of young fish and for the seal population.

In view of the biomass production rates considered in Section 6.1 complete removal of seaweed from areas would not be undertaken. In practice weed would be gathered from patches allowing surrounding untouched areas to recolonise harvested areas. The use of Scoubidou (see next point 6.4.) as practiced in France allows removal at a single point (unlike a trawl as used in Norway) and is best suited for irregular rocky bottoms with boulders as found in IOS. This harvesting method therefore produces a patch-work of harvested spots amongst the seaweed canopy allowing recolonisation of weed (see Point 6.2.) and epifauna (see Point 6.4.). Section 3 considers the potential impact of harvesting in the context of other natural destructive losses.

6.4 Seaweed Holdfast as a Habitat and Harvesting Method.

Kelp holdfasts provide an important shelter to a large range and number of invertebrates and epiphytes. Scheme opposition expressed concern about the use of the Scoubidou system in terms of its impact upon associated species that might be lost as the holdfast is removed. Section 3 reviews the habitat value of different seaweed species types and the potential impact of mechanical harvesting. The significance of species disruption from *L. digitata* harvesting should also be viewed in relation to the quantity of biomass removed (<15% see Section 6.1) relative to that which is lost through storms in a season (~50% biomass).

6.5 Seaweed Drift Collection

The potential for beach seaweed collection for the proposed IOS scheme was not considered a primary food source. Scheme opponents considered the beach collection of seaweed to provide a small quantity of material that would need cleaning and labour intensive hand sorting of this infrequent food source which was needed as an important resource for the beach ecosystem.

Although seaweed cleaning systems and mechanical collection systems are available it is true that such a source would be influent and unlikely to supply the majority of culture requirements for a large operation. However, as a seasonally abundant supply, a proportion of the beach cast material could possibly be utilised at certain times. It is understood that extensive storm deposits periodically occur throughout IOS with substantial seaweed accumulation on certain beaches according to the wind direction. St Marys recently experienced a problem following a storm which gave rise to a large amount of seaweed on Town beach. Initially the weed was not removed for ecological reasons. However, when it started to rot and was infested by seaweed flies there was a significant public outcry. The council then had to remove the half rotten weed for expensive disposal (J. Dallimore pers. comm.). In these cases utilisation of beach cast for feed would reduce wild harvesting requirements whilst performing a public service!

In reiteration of points made elsewhere throughout this report the use of different seaweed sources needs to be assessed and agreed on a site by site basis according to the availability of local stock available.

7. Fal and Helford SAC – Porthkerris Case Study

Porthkerris is situated to the south of the Helford estuary and adjacent to the Manacles Reef. Although the site fell outside of the original Candidate SAC area, which was limited at Nare Point (Ref. Davis 1997) the final Carrick Road/Helford estuary SAC area was extended and is now demarked by a line from Zone Point to Manacles Point (English Nature 2000 ii). A number of key protected features have been identified including maerl beds, eelgrass beds, native oyster beds, rocky reefs and mud flats.

The Porthkerris site has received a comprehensive level of negotiations with local parties, responsible agencies and national bodies as the site has hosted a trial abalone hatchery for a number of years. The Late Mr John Anselmi was successfully awarded FIFG funding to develop the site for land based abalone culture with consents and agreements in place from both the Environment Agency and Natural England.

7.1 Seaweed Harvesting

The Porthkerris site hosts Porthkerris Divers which support extensive diving operations over the reef area of the Manacles and beyond. This sea based infrastructure is well suited to allow limited harvesting of seaweed from offshore areas. The extent of the rocky reef area extends beyond the SAC area although it is proposed that any harvesting operation is conducted in agreement with NE (see Section 5).

Seaweed harvesting could also be considered as a by-product of the oyster dredging operations that occur over the October-March flat oyster dredging operations in Carrick Roads. Weed build-up in the dredge is a common problem at the start and end of the season when weed coverage of the oyster beds make dredging difficult.

Red Weed (Gracilaria spp.) from Carrick Roads Oyster Dredging

The plate above shows a sample of the delicate red weed which appears to be a *Graciliaria* type species which forms in dense accumulations throughout the area. At the moment this material is disposed and has no market value. This was one of the original considerations for the culture of abalone within Carrack Roads by a SWAGA member who participated in the 2001-2002 CSF trials in the area. This red weed was used for abalone feeding and provided satisfactory growth and could be considered as a feed in the future if suitably cleaned.

7.2 Seaweed Drift Collection

Seaweed of differing types can be deposited at differing rates on a seasonal basis. Different district councils have a different policy towards the removal of weed on an area basis but also from beach to beach. Some areas are particularly prone to excessive weed build-up due to the configuration of the coast (e.g. Portreath), whilst some beach allow removal for either aesthetic reasons (e.g. some recreational beaches) or for agricultural purposes (e.g. Long Rock). In essence, the acceptability of beach drift collection will require local negotiation with agencies and local land owners to agree an acceptable level of removal.

In the case of Porthkerris much of the drift weed requirements can be satisfied at certain times of the year from deposits upon its own beach. However, it would be useful to establish the levels and types of weeds available at a number of adjacent beaches in the area in order to drift levels on a seasonal basis following storms with differing sea conditions.

Maenporth has been subject to extensive accumulations of *Ulva* particularly in the late summer. These 'green tide' situations occur when optimum conditions for rapid growth occur when nutrients are available and sea temperatures and light intensity are at their maximum. In such circumstances low energy sea states can allow a build up of seaweed which is not rapidly dispersed and can therefore be deposited on certain beaches at very high rates.

Although some weed is buried within the sand of the beach and is available for invertebrates to fed upon and subsequently support feeding seabirds.

7.3 Seaweed Culture

Seaweed culture has a long history overseas but has only recently received widespread attention in industrialised nations. Seaweed culture is considered in more depth within Section 3.3. There may be scope for seaweed culture in the Fal/Helford area either using longline techniques offshore or within onshore tanks.

The ability of seaweed to absorb nutrients has made them good candidates for tertiary polishing of effluents, particularly from fish farms. The added benefit for abalone is the enhanced protein content of the seaweed produced. The potential for longline culture would need to be trialled in order to ascertain storm losses and growth rates. Navigational issues would also need to be resolved with local boat users. In consequence, this technique remains a long term option that should be further investigated but which cannot be relied upon in the short term.

Tank culture of weeds such as *Ulva* is a good possibility as a tertiary biofilter for the polishing of effluent prior to discharge. The use of such weed as a feed would require the resolution of some hygiene issues and would only provide a low mass of seasonal production. In consequence, although this technique is of interest at Porthkerris it cannot be relied upon to provide all feed requirements.

7.4 Artificial Feeds

Consideration of artificial feeds is provided in detail within Section 4. The scope for using artificial feeds within the Fal / Helford SAC is largely dependant on whether land based recirculation culture is adopted. Alternatively, there is the potential for developing a new generation of artificial feed possibly designed for sea based applications.

Discussions have been held with local experts on seaweed and feed formulation in the University of Plymouth, Department of Biological Sciences about the potential to formulate a seaweed based artificial feed. In addition, the proposed SUDAVAB European Community funded SME research project includes a component to source and formulate a new artificial feed using sustainable sources. This project includes Spanish, French, Irish and German partners who all have experience in this sector. Although it is planned for SWAGA to participate in these growth trials there may be a requirement to undertake comparative tests of a range of commercially available artificial feeds in order to assess technical and market considerations.

8. Conclusions

The European abalone or ormer naturally eats seaweeds of which the best are the less abundant delicate red varieties. Other more abundant seaweed types are available and can be used for feed although they all present certain challenges.

Seaweed drift collection may be appropriate in certain areas with the agreement of local authorities, relevant landowners and agencies. The seasonality of supply would however indicate that seaweed drift alone would be insufficient as a sole source of feed. It could however be a complimentary feed supply to a commercial operation.

Seaweed harvesting in the SW could provide some feed requirements in certain settings. Biomass estimations and harvest rates from work in France and Norway would indicate that this resource could be sustainably utilised to some degree. It is suggested that any potential abalone culture operation considering seaweed harvesting for feed should undertake small scale harvesting trials in conjunction with Natural England to provide limited material for culture whilst also demonstrating sustainability. In the short term the best option for seaweed harvesting is in association with other marine activities where seaweed may be a by-product of existing operations (e.g. oyster dredging).

Onshore seaweed culture for effluent polishing offers great potential to polish nutrients whilst producing a high protein seaweed. However, the economics of production and technical challenges will require careful assessment in a UK context. This study area is to be included in the forthcoming Framework 7 SME SUDEVAB project.

Offshore seaweed culture could provide a useful feed addition to certain sites with suitable waters. A major consideration relates to cost, production rates (storm loss) and navigational difficulties. There is potential to explore synergy options with other industrial sectors such as offshore power generation where fixed infrastructure is in place which could prevent gear destruction. The placement of seaweed culture and offshore abalone cages in association with power generation could also tie in well with Marine Protection Areas (proposed in the Marine Bill White Paper) which are closed to mobile fishing gear. Plans are in development for offshore power generation in the SW with wind farms (north of Ilfracombe), wave power generation (wavehub north of Hayle) and tidal current turbines (off Lynmouth).

Artificial feeds offer a number of advantages to operators although there are also some concerns which should be assessed during feed selection. Artificial feeds provide a good feed alternative to land based culture operations. The use of artificial feed in offshore cage settings is however more problematic and still presents significant challenges.

The assessment of feed requirements for any prospective abalone culture operation will be a site specific process that will require consideration of local resources, legislation and market issues. It is probable that for many operators a range of feed sources may be utilised sometimes varying on a seasonal basis.

A co-operative approach with the conservation agencies is proposed to allow establishment of a sustainable industry and transparency in a decision making process based upon sound science. A pragmatic approach to limited resource utilisation trials should allow development of industry whilst gathering sound monitoring data to help inform future assessments.

Acknowledgements

Much of the information presented has been gathered over the last 10 years during the 1997 MAFF study, 2003 Cornwall Sea Fisheries trials and the 2005 SWAGA Limitations study. These bodies are thanked for their previous support.

A large number of people have helped in discussions relating to this project all of whom are thanked for their assistance. Particular thanks are due to Aqua-Gold (Fisheries) UK Ltd. and Porthkerris Divers for their support in scheme development.

This report was produced on behalf of South West Abalone Growers Association with financial support from SEAFISH.

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