Cefas contract report <C3529 >

FES220: A review of the land-based, warm-water recirculation fish farm sector in England and Wales.

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1 Executive summary

The warm-water Recirculation Aquaculture System (RAS) sector has shown considerable growth within England and Wales over the last decade. Environmental, political and social factors within England are combining to provide conditions favourable to future development of the sector which ticks many boxes for environmental and social sustainability. RAS represent a highly productive means of growing animal protein on small areas of land. If energy (fossil fuel) use and the associated carbon footprint can be reduced, RAS systems would appear to meet the requirement for 'sustainable intensification', recognised as a key means of addressing food security [1].

Nevertheless, it must be recognised that financial viability of RAS has so far been marginal. RAS businesses have a poor record for longevity, and a number of ventures have failed. This project identified poor system design, lack of attention to economic factors (e.g. electricity costs), and low demand for products (resulting in low price and sales volume) as the causes of failure. However, this pessimistic view of the UK experience maybe skewed as the sector has been numerically dominated by freshwater tilapia systems where system design issues were common; very few seawater systems producing higher value products are operating to judge the viability of marine RAS.

New entrants need to proceed with caution and optimise system design, economies of scale, input costs, and marketing and sales plans. In addition, experienced staff, system flexibility and further development of surrounding industry (i.e. fry supply and technological progress) remain critical if the RAS sector is to grow. Issues that remain can be addressed through a combination of research and development and adoption of accreditation and quality labelling schemes.

Grant awarders (and investors) should ensure that applicants have researched systems adequately, have first-hand experience, and that back-up systems are in place. Applicants also need to minimise input costs and produce realistic business plans that address markets. Pilot studies should be encouraged. Projects should not be dismissed that are innovative or transfer technology from other industries to support sustainability.

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[1] Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327: 812-818

Table of contents

2 Introduction

Most of the existing UK finfish aquaculture industry is based upon open, flow-through systems where natural water bodies provide a clean water supply, and remove and assimilate wastes. Such culture systems have been criticised as they are dependent upon this subsidy from nature and, if intensive, can incur an environmental cost on the supplying / receiving environment[2]. An alternative model for intensive finfish production is closed Recirculation Aquaculture Systems (RAS). In RAS, water is recirculated and technology is used to remove wastes and maintain oxygen levels. RAS are often perceived as having strong 'green credentials'[3] and RAS products are promoted as sustainable by environmental organisations such as Seafood Watch[4] and Greenpeace because, as closed systems, they

- abstract little, if any, water from natural water bodies
- produce minimal effluent, with readily managed waste streams
- reduce the potential environmental impacts from escapee and pathogen release

RAS also offer many potential benefits to the producer and supply chain:

- control of the fishes' environment allows consistent and predictable production, essential for modern food production;
- removal of dependence on a natural, clean, flowing water supply eliminates seasonal vagaries (e.g. floods, droughts) associated with natural water supplies, widens potential locations, and enables location closer to markets ;
- improved biosecurity in closed systems reduces the risk of pathogen ingress and disease outbreaks;
- closed systems eliminate losses to, and conflicts with, predators;
- containment within buildings aids temperature control, thereby avoiding seasonality in production;
- heating allows alternative tropical fast growing species such as Nile tilapia (*Oreochromis niloticus*) to be farmed.

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[2] Pelletier N, Tyedmers P (2008). Life cycle considerations for improving sustainability assessments in seafood awareness campaigns. Environ Manage 42, 918-931.

[3] Little DC, Murray FJ, Azim E, Leschen W, Boyd K, Watterson A, Young JA (2008). Options for producing a warm-water fish in the UK: limits to "green growth". Trends in food Science & Technology 19, 255-264.

[4] Pelletier & Tyedmers (2008). op. cit.

Despite these apparent benefits, RAS may attract criticism on environmental grounds – due to high energy usage and its associated environmental impacts (carbon and acidification emissions) [5]- and for ethical reasons – RAS are typically intensive systems, which may be viewed as "factory farms".

Over the last 10 years there has been a notable increase in both the number and size of land-based, warm-water RAS farms in England and Wales. In 2000 there was a couple of small scale farms, but a decade later this is approaching 20 farms which vary in scale from 10 to 1000 tonnes p.a. . These new farms represent a diversification in the UK aquaculture industry, and provide an additional route to produce a healthy food product, thereby strengthening UK seafood security. However, despite the optimism surrounding RAS, a notable proportion has gone into administration[6] [7]. Various potential factors have been suggested anecdotally as contributing to the recurrent failure of commercial RAS in the UK [8] [9]:

- poor design
- too high running costs
- labour-intensive technology
- steep technical learning curves
- lack of experienced staff
- over-ambitious production schedules
- over-optimistic market forecasts for product sales
- poor management decisions

To date, there has not been an objective examination of the factors that contribute to the failure (and success) of commercial RAS in the UK. This project was funded by the Defra Fisheries Challenge Fund, administered by the Marine Management Organisation (MMO, formerly Marine Fisheries Agency) to address this gap, and review the technology, operation, production, problems and sustainability of warm-water recirculation aquaculture systems in England and Wales. This report is intended to provide a source of UK-specific information on RAS for prospective farmers, investors, policy makers and lobby groups to aid decision-making.

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[5] See Ellis et al. (2011) Initial investigation of the sustainability of English aquaculture. Cefas contract C3743 report to Defra.

[6] Little DC, Murray FJ, Azim E, Leschen W, Boyd K, Watterson A, Young JA (2008). Options for producing a warm-water fish in the UK: limits to "green growth". Trends in Food Science & Technology 19, 255-264.

[7] E.g.http://www.fishupdate.com/news/fullstory.php/aid/10782/Barramundi_farm_brings_in_administrators.html

[8] http://www.slideshare.net/Cefas/large-scale-intensive-recirculation-systems-and-their-potential-development-within-england-2373881

[9] Little et al. (2008) op. cit.

2.1 Disclaimer

Whilst every effort has been made to present an accurate summary of information, Cefas and the authors cannot be held responsible for inaccuracies or omissions. Readers interested in RAS are encouraged to conduct their own investigations and/or seek specialist advice.

3 Methodology

The project was composed of four successive stages:

- a desk-based literature review;
- identification of all warm-water RAS farms in England and Wales registered (and de-registered) between 2000 and 2010, and collation of production to assess the contribution to the finfish supply chain. [The Cefas Fish Health Inspectorate's (FHI) Live Fish Movement Database (LFMD) was used to identify all registered (and de-registered) warm-water RAS farms in England and Wales and relevant data was extracted];
- a survey of representatives of the warm-water RAS industry, i.e. farmers and consultants, to gather information on technology, operation, production, problems and sustainability.
- collation of the information into this report, and review by representatives of the industry.

The aim of the survey was to cover a large proportion of the RAS sites in England and Wales and include both operating and non-operating (in receivership or ceased trading) sites, to gather diverse feedback on the issues faced by this sector. The approach to the sampling methodology was discussed with a Cefas statistician and recommendations incorporated.

Of the 29 farms identified on the database , a sample of farms was selected for preliminary discussion (n=18) and these were contacted by telephone to request agreement to participate. Two farms were unwilling to participate in the survey. A schedule of field visits was then arranged. During scheduling two further farmers withdrew from the survey, as they were unavailable in the allotted time-frame or were no longer able to provide required information. It was judged that the remaining 14 farms were adequate for the review. Production figures and other relevant data were gathered during the initial telephone conversations for the non-participants and are included (with permission).

The field visits were conducted over a two-week period in late Autumn 2010. Fourteen sites producing a variety of species, located throughout England and Wales (e.g. Devon, Cambridgeshire, York, Durham and Anglesey) were visited (Table 1). The schedule was arranged to minimise travelling where possible, and visits were combined with the routine annual FHI inspection where applicable.

Site visits were conducted by two Cefas project staff (the project leader and an experienced RAS operator), and comprised an inspection of the site and recirculation system and a semi-structured interview with the farm manger. The interview was structured around a questionnaire providing prompts for the main issues identified from personal knowledge and the literature review. The presence of two project staff facilitated capture of information. Farmers were additionally asked to identify and rank their "Top 10" critical factors for the success or failure of a warm-water recirculation fish farm from a list of 34 putative factors identified from the literate review and personal knowledge. Space was provided to add additional factors and comments. Production figures were collected up to and including 2010; for sites that had ceased operating, final production was recorded.

RAS consultants were present at two of the farm sites, and their input was gathered following the same semi-structured interview format.

Table 1: Breakdown of RAS operators interviewed, by species farmed and operational status.

Type of farm	Operational	Closure Imminent	Non operational	**Total**
Tilapia	3	2	1	**6**
Tilapia & catfish	1	1	1	**3**
Turbot		1		**1**
Turbot, sole, prawn & sea-bass	1			**1**
Sea-bass & turbot	1			**1**
Barramundi			1	**1**
Prawn	1			**1**
Totals	**7**	**4**	**3**	**14**

4 Status and prospects of the warm-water RAS industry in England and Wales.

Details of all warm-water recirculation fish farms (those producing food fish) registered in England and Wales between 2000 and 2010 were extracted from the LFMD and supplemented with site specific data. Data for Wales was included alongside that for England due to the coverage of the database, and the nature and importance of these operations.

4.1 Numbers of RAS sites in England and Wales

Within England and Wales, 29 warm-water RAS sites were registered during the period 2000-2010 (Table 2). These have targeted a variety of species, with a clear inclination towards tilapia. Of these 29 sites, only 18 are still operational and 11 have ceased operating.

Table 2: Numbers of warm water recirculation fish farm sites registered between 2000 and 2010, and categorised as either operational in 2010 or non-operational. NB: Data contains one hatchery that moved location.

	Species held	Number sites registered between 2000 and 2010	Sites operational in 2010	Sites not–operating in 2010
England	Tilapia	18	9	9
	Tilapia & catfish	3	3	0
	Barramundi	1	0	1
	Hybrid striped bass	1	0	1
	Prawns	1	1	0
	Turbot	1	1	0
	Grass carp	1	1	0
	Sub-total	**26**	**15**	**11**
Wales	Sole , bass, prawns & turbot	1	1	0
	Turbot & bass	1	1	0
	Bass	1	1	0
	Sub-total	**3**	**3**	**0**
Total		**29**	**18**	**11**

The warm-water RAS industry in England and Wales has shown considerable development over the last decade, with a 10-fold increase in the number of operating farms (Fig 1A). However, this marked increase does hide the fact that around 40% of farms have ceased operating (Fig 1B).

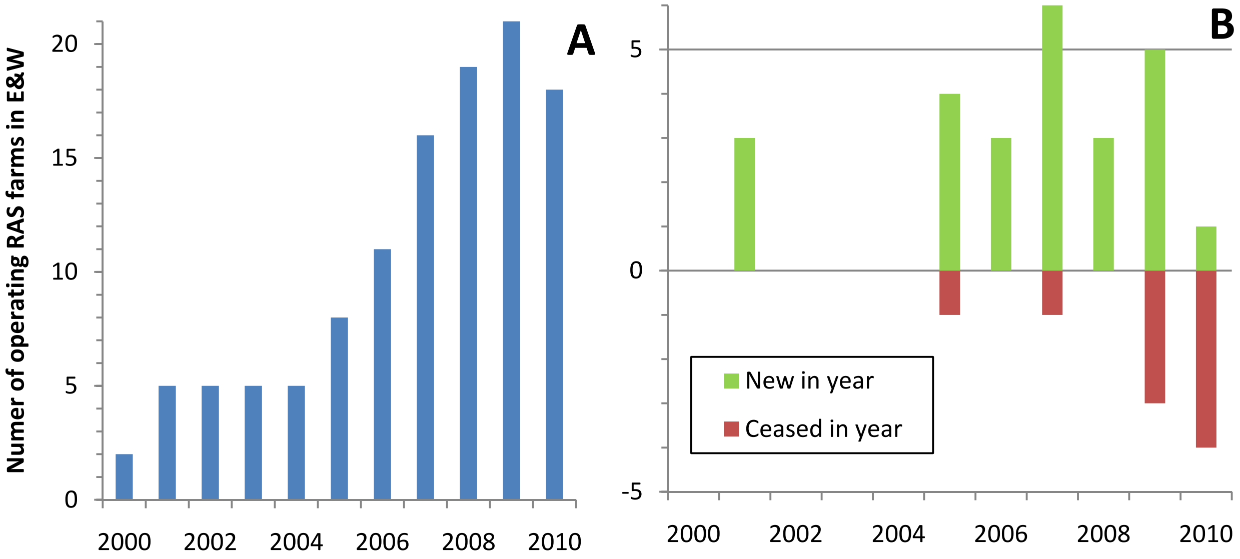

Figure 1: A: Number of warm-water RAS farms operating in England and Wales in the years 2000-2010. B: For each year, the number of new RAS farms registered, and the number that ceased operating.

Simple line graphs are included (Annex 1) to illustrate site numbers by species farmed, and the period of production of each site.

4.2 Production of table fish in RAS in England and Wales

Annual production data for the different RAS farms was extracted from the live fish movements database (LFMD). This was supplemented with data collected during interviews with the RAS farmers (Figure 2).

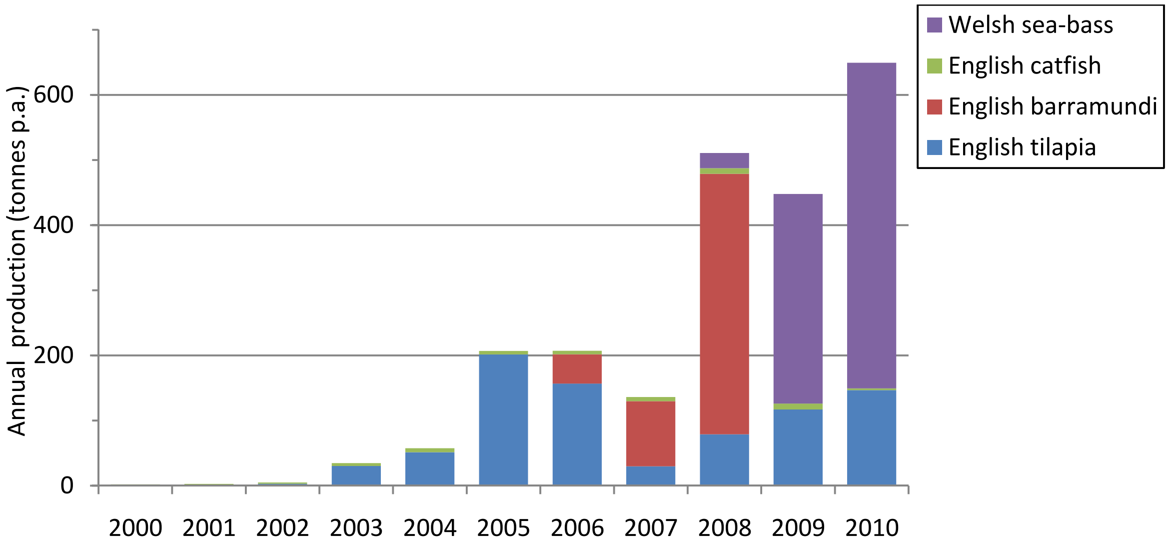

Figure 2: Annual production of table fish in RAS by species and country, for the years 2000-2010. Please note production of other species is not included as it is negligible.

At that start of the decade, RAS production amounted to 2 tonnes of catfish. At the end of the decade, RAS production was over 600 tonnes, which equates to an 80% p.a. increase in output. Production in 2010 was comprised almost entirely of sea-bass (77%) and tilapia (23%). There was a notable production (400 tonnes) of barramundi in 2008 from a single farm, which then ceased production.

4.3 RAS contribution to table fish production

Although production from RAS has increased markedly, it is still only a minor contributor to table fish production in England and Wales (Figure 3). Table fish production is dominated by rainbow trout, with RAS (all species combined) contributing approximately 12%. Nevertheless, different trends are apparent: RAS production has been increasing against a backdrop of declining trout production.

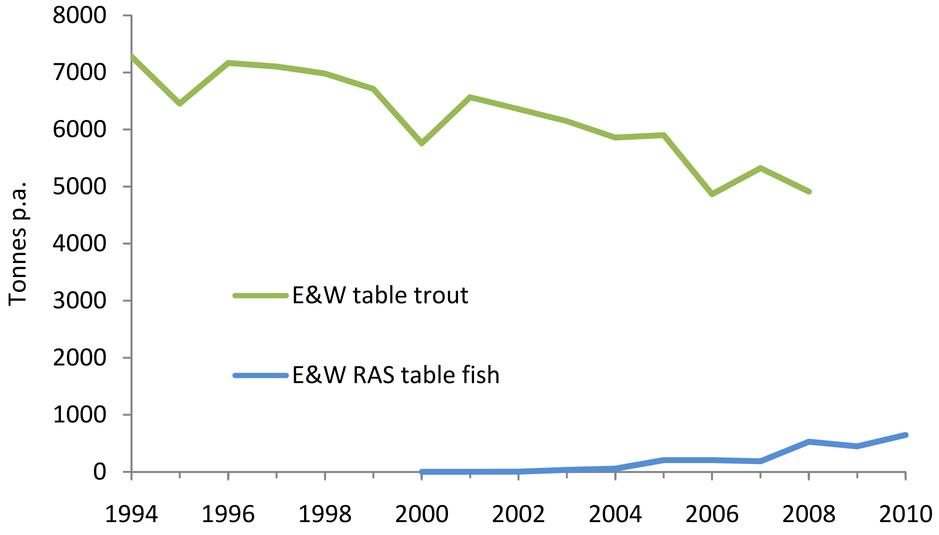

Figure 3: Annual production of table trout and table fish in RAS in England and Wales 1994-2010[10].

4.4 The RAS industry in Europe

Although there has been an increase in RAS production in England and Wales over the last 10 years, it cannot be assumed that this trend will continue. The Benelux countries and Denmark have a similar climate (and geography) to England and Wales, and lead Europe in the production of table fish in RAS[11]. (Possible contributing factors to enthusiasm for RAS fish farming in these countries are: a diet with a traditional fish component; lack of upland areas for cool, clean water supply for salmonid farming; coastline inappropriate for cage culture; a strong environmental lobby; a long

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[10] Source: FHI production figures, Finfish News and collected during survey.

[11] Martins CIM, Eding EH, Verdegem MCJ, Heinsbroek LTN, Schneider O, Blancheton JP, d'Orbcastel ER, Verreth JAJ (2010) New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability. Aquacultural Engineering 43, 83-93.

standing eel farming sector which uses RAS). Experiences from these countries merit consideration when reflecting on the potential future development of the RAS sector in England and Wales.

In the Netherlands, the finfish aquaculture sector is unique within Europe as it is based almost entirely on the culture of various species in RAS. Production of table fish in Dutch RAS (ca. 8,000 tonnes p.a., Table 3) exceeds the total production of all table fish (flow-through and RAS) in England and Wales (5,500 tonnes p.a., Figure 3).

However, the Dutch RAS industry has shown a very recent downturn. The number of farms has halved, and production capacity has reduced by more than 16% within 2 years (Table 3). Various reasons have been proposed for this decline[12]:

- issues over the sustainability of eel production due to dependence on endangered wild elvers
- high production costs for species such as turbot, sole and tilapia
- novel species, e.g. white leg shrimp, being unable to establish in niche markets

Table 3: Production (tonnes p.a.) of the most important species in Dutch RAS[13].

Species	2007 – 2008		Expected for end of 2009		% Change 2007-08/2009	
	No. of farms	**Production**	**No. of farms**	**Production**	**No. of farms**	**Production**
Eel	43	4250	19	<3000	-56%	>-29%
African catfish	18	3100	5-6	1000	-67-72%	-68%
Nile Tilapia	4	840	0	0	-100%	-100%
Turbot	4	210	2	210	-50%	0%
Barramundi	2	135	0	0	-100%	-100%
Pikeperch	2	130	3	130	+50%	0%
Dover sole	1	10	1	20	0%	+100%
European catfish	1	100	2	3000	+100%	+2900%
Totals	**75**	**8775**	**33**	**7360**	**-56%**	**-16%**

A tilapia farming project was launched in Belgium in 2006, which claimed to be the largest RAS in the world; the project cost €15 million and planned production was 3000 tonnes p.a.. However, it went into administration in 2009[14], and the failure was attributed to disease problems and the low price of competing fish products[15].

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[12] http://www.oecd.org/dataoecd/19/21/45032957.pdf

[13] The Dutch case for practices in finfish aquaculture using RAS, Schneider, O et al, Abstract at 8th International recirculating aquaculture conference.

[14] http://www.fishnewseu.com/latest-news/world/2097-end-of-the-line-for-vitafish.html

[15] http://www.fishnewseu.com/latest-news/world/1684-price-of-cod-blamed-for-bankruptcy-of-vitafish-tilapia-farm.html

4.5 Prospects for the RAS sector in England and Wales

The Dutch RAS industry – producing more than 10 times that of the English and Wales RAS sector – indicates potential for further expansion in the UK. However, it must also be recognised that Dutch RAS production is dwarfed by cage farmed salmon in Norway (800,000 tonnes p.a.) and Scotland (145,000 tonnes p.a.)[16]. Historically, RAS have a poor track record in the UK, with few farms persisting for more than a few years; this is not unique to the UK. RAS products may also have to increasingly compete with cheap imports, such as *Pangasius* catfish from Asia (also known as basa, river cobbler or panga). Consequently, projecting the future size of, and production from, the RAS sector in England and Wales is extremely difficult with either growth or decline foreseeable. The commercial viability of RAS in the UK will largely depend upon domestic demand for RAS products and farm gate prices achievable.

4.6 Prospects for RAS use in the Scottish salmon sector

Scottish salmon production can be viewed as a 3-stage process: the freshwater hatchery, freshwater ongrowing (smolt production), and marine (sea-cage) production. All three stages have traditionally been based upon open systems: as salmon are a coldwater species and do not need additional heat, open flow-through systems are generally accepted as being more financially viable than RAS culture. However, due to environmental concerns, there is increasing pressure to produce salmon in closed containment systems and research is ongoing in North America[17] to develop and make these systems commercially competitive. In the Faroe Islands and Norway freshwater production has been shifting towards RAS technology to alleviate problems associated with freshwater resources, i.e. shortage, poor quality and variable temperature[18]. It has been suggested that RAS production offers benefits to the industry through improved freshwater growth rates and smolt quality (improved survival and growth rates once in sea-cages)[19]. However, a recent report by the Scottish Salmon Producers Organisation (SSPO) considers land based RAS for ongrowing stages not financially viable, with the high energy use and carbon footprint making it an environmentally unfriendly option[20].

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[16] 2008 European finfish aquaculture production. Finfish News 9, 54-55.

[17] http://www.fishupdate.com/news/fullstory.php/aid/15659

[18] Martins CIM, Eding EH, Verdegem MCJ, Heinsbroek LTN, Schneider O, Blancheton JP, d'Orbcastel ER, Verreth JAJ (2010) New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability. Aquacultural Engineering 43, 83-93

[19] Martins *et al.* (2010) op. cit.

[20] http://www.scottishsalmon.co.uk/userFiles/885/Salmon_Annual_Report_2009(1).pdf

5 Technology, performance and operation of RAS

A recirculating aquaculture system is an artificial growing environment that recycles used water. As water is retained, RAS potentially makes heating water for fish farming cost-effective [21]. A warm-water RAS allows the production of tropical species in cooler climates. It may also be used for temperate species: as fish are cold-blooded animals, growth rate is linked to temperature, so increasing the water temperature above ambient increases growth and production.

Water quality does need to be maintained to provide optimum conditions for fish growth, and assure fish health and product quality. This is achieved by removing the waste products (uneaten food, faeces and excreted metabolites) by treating the water using filtration and cleansing technology. The system water passes through the treatment process many times per day, at a recirculation rate typically equating to one system volume every 1 to 2 hours. In addition, a percentage of the total volume must be replaced with new make-up water to prevent excessive build up of nitrates and dissolved organic compounds. When RAS systems were first being developed, they were described in terms of the volume of water exchanged during each circuit (e.g. 10% of system volume / pass). Current RAS require much less make-up water, and are described by the daily replacement rate (e.g. 5% system volume / day)[22].

Although RAS offer a number of advantages as described above and in the Introduction, they also suffer from potential drawbacks:

- large setup /investment costs, with a need for back-up systems.
- high running costs
- production limited by the capacity of systems: the load that filters can process will limit the production of a RAS
- short-term increases in fish production are limited: the bio-filter needs time to adapt and change capacity to deal with wastes
- experienced staff are needed to run RAS which act as life-support systems

5.1 The fundamentals of RAS

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[21] Little DC, Murray FJ, Azim E, Leschen W, Boyd K, Watterson A, Young JA (2008). Options for producing a warm-water fish in the UK: limits to "green growth". Trends in food Science & Technology 19, 255-264.

[22] http://www.slideshare.net/Cefas/large-scale-intensive-recirculation-systems-and-their-potential-development-within-england-2373881

In RAS, the water from the production units is treated to remove suspended solid particles (uneaten food, faeces), to remove or convert dissolved chemical wastes and gasses (e.g. ammonia, nitrite and CO_2) and to increase dissolved oxygen levels, before return to the production units. The filtration is carried out by two main processes:

- Mechanical filtration, whereby the suspended solids are removed (c.f. a sieve)
- Biological filtration, whereby the dissolved substances and organic chemical wastes are converted to less toxic substances. Biological filters, through their design, usually also increase oxygen, and reduce carbon dioxide, levels.

RAS may also use additional processes: aeration / oxygenation, sterilisation (to remove pathogens and undesirable bacteria), chemical buffering (of water quality parameters), etc. These additions depend on the requirements and the 'loading' of the system [23]. Although loading of RAS is often considered in terms of fish biomass, it is primarily the amount of food that is the limiting factor[24]: food mass dictates the metabolic rate (and oxygen requirements) of the fish, the rate of waste production, and the fish biomass that can be held in the system.

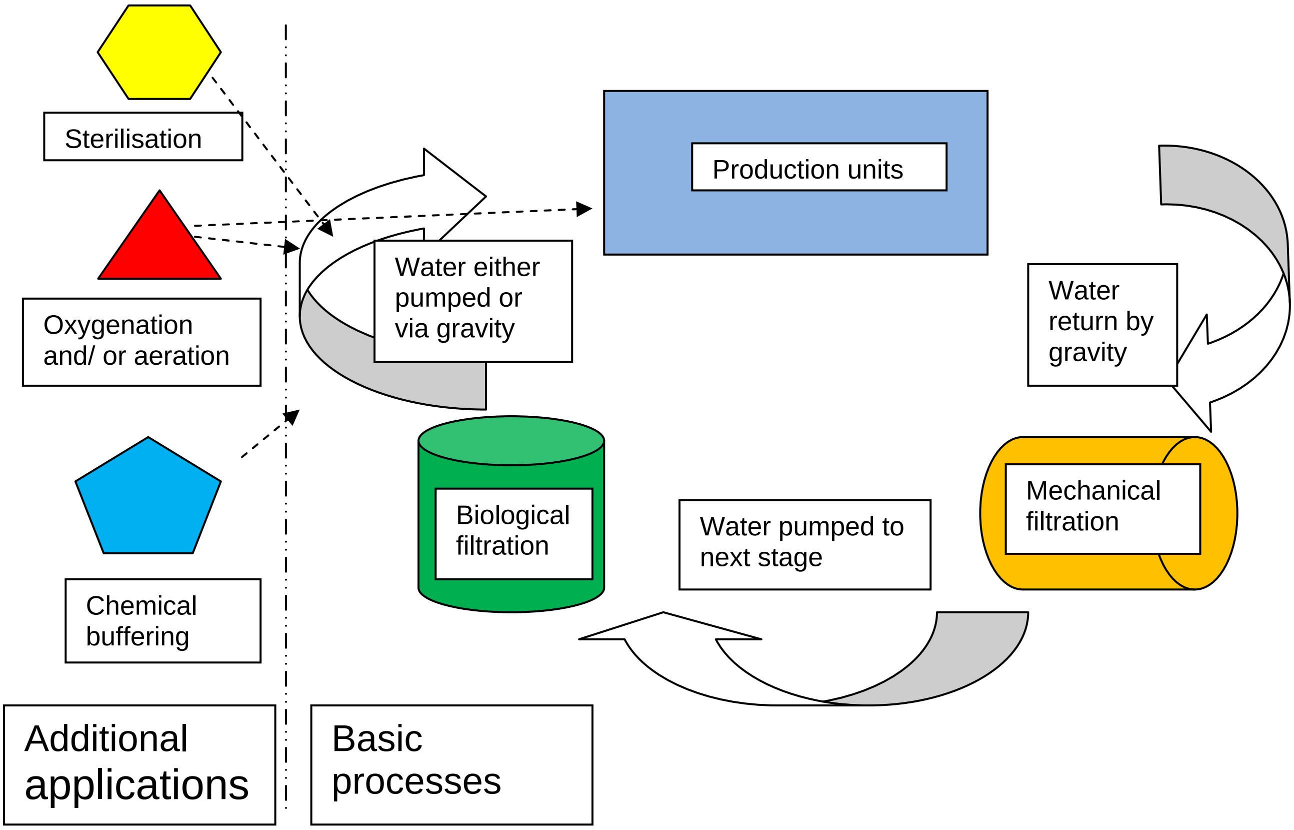

Figure 4: Feature of recirculation aquaculture systems

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[23] "with aeration stocking densities of 50-60kg/m^3 (50kg/m^3 is the maximum capacity used in the design) can be achieved whilst maintaining high fish welfare standards. Higher stocking densities up to 120 kg/m^3 can be achieved with the use of oxygen" Tilapia info pack – University of Stirling http://www.tilapiascotland.org/resources

[24] Ellis et al. (2010). Sustainable finfish aquaculture workshop. Finfish News 9, 4-22.

5.2 Mechanical filtration

Whatever the RAS design, the removal of suspended solid waste (SSW) by mechanical filtration is one of the most important parts of water treatment. All designs should aim to keep solid wastes as intact as possible prior to mechanical filtration. If SSW are broken up, the smaller particles are not as easy to sieve out, and the larger surface area facilitates dissolving of soluble organic compounds. Dissolved organics add to the load on the biological filter and encourage the growth of less desirable heterotrophic bacteria which increase the oxygen demand of the system and compete with the nitrifying bacteria in the bio-filter.

There are many types and designs of mechanical filtration to remove SSW, suited to different operating systems. The two key factors to consider when selecting mechanical filtration are:

- the expected SSW loading
- the flow rate of water that the filter will have to process.

The mechanical filter should remove SSW as quickly as possible without damaging the particles.

Various mechanical filtration methods are available:

- drum filters
- screen/belt filters
- bead filters
- sand filters
- vortex/settlement filters

For large scale RAS, only drum filters offer a practical method for removing large quantities of SSW at a high flow rate. Drum filters have the added advantage that, depending on the screen area and mesh size, a high percentage of SSW can be removed. Screen/belt filters are generally designed for low flow rates. In the other three methods, SSW are trapped in the filter but not removed from the system immediately, which allows leaching of soluble organic compounds. The latter four methods are therefore generally only suited for smaller RAS or those with a low loading.

Industry observations

All sites visited recognised that prompt removal of SSW was an important factor. Approximately half of the sites used drum filters. Although they generally had no problems, one issue was inappropriate selection of drum filters by the system designer, i.e. under-sized filters or too fine mesh in screens, which resulted in the drum filters having to run constantly. Constant cleaning of drum filter screens requires a high water usage and, where tap water was the only supply, this became a significant cost. Nevertheless, this provided the route for water exchange for the RAS and 50% of these sites installed a water recovery process for drum filter screen washing. As drum filters are expensive, most RAS had to be operated as a single unit rather than several discrete units; this was highlighted by some farmers as undesirable, as it has implications for disease spread and control, and there was less flexibility in the system.

Three smaller sites had used alternatives such as bead filters to remove SSW. However, as the quantity of fish (and feed) increased, these filters could not cope with the SSW loading, and were typically replaced with drum filters, which was a costly process. Two sites used screen/belt filters; although one found them generally adequate, the other site highlighted them as a major problem - they were inadequate for their role and ripped and failed on a weekly basis. The replacement screens could only be sourced from a specialist supplier and proved very expensive (£1,800-2,000 ea) and time consuming (taking 3 men half a day) to replace. One site used vortex/settlement methods to remove solids and found this adequate at the modest scale of production, provided the solids were backwashed out regularly.

5.3 Biological filtration

Biological filters are generally placed downstream of the mechanical filter so they do not become clogged with SSW. Nitrifying bacteria within the bio-filter convert toxic ammonia to nitrite, and in turn nitrate[25]. The basic principle of biological filtration is to provide a surface for nitrifying bacteria to grow. This is achieved by using a substratum with a very high surface area: volume ratio to maximise the amount of bacteria within a limited space. There are many different designs of biofilter: the installation of off-the-shelf systems is the exception, and most tend to be bespoke.

Many biofilters combine a submerged (wet) stage and a trickle (non-submerged) stage. The submerged stage usually comprises a vessel containing plastic filter media specifically designed for its high surface area with a flow passing through the vessel. Most designs also use strong aeration to constantly mix the media (a fluidised bio-filter) which gives various benefits:

- filter media is kept clean, preventing SSW settlement and heterotrophic bacteria build up
- mixing ensures all media is utilised by nitrifying bacteria
- increased oxygen (O_2) levels within the filter ensures a higher conversion of ammonia to nitrite and in turn nitrate (nitrite to nitrate requires a high O_2 environment).
- CO_2 and any other undesirable gasses are sloughed off by the aeration

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[25] "ammonia is present in two forms - free (NH_3) which is very toxic to fish, and ionized(NH_4^+) which is still toxic but less so. The higher the pH, the greater the ratio of the more toxic free form to the ionized form. *Nitrosomonas* bacteria oxidize ammonia into nitrite (NO_2^-) by the addition of oxygen, and *Nitrobacter* bacteria oxidize nitrite into nitrate (NO_3^-). These two types of bacteria are referred to as "nitrifying bacteria,"" http://www.pondsystems.com/news_biofilt.html#The Nitrogen Cycle

- O_2 levels in the water are boosted (for return to the fish)

Trickle (non-submerged) filters again make use of specific media but these are free standing, either within a vessel or stacked with curtain sides, rather than submerged. Trickle filters are generally positioned after a first stage submerged filter and often use gravity to feed water to the top of the filter which then simply trickles down through the media. The main advantage of a trickle filter is the high surface area in contact with air which allows both degassing and aeration of water and provides an oxygen rich area to complete the process of converting ammonia to nitrate.

Industry observations

Approximately 60% of sites visited used fluidised biofilters of various designs and capacities. One commercial media (Kaldness K1 plastic media) was common to all systems. Sites producing tilapia just used a submerged filter (no trickle filter). All seawater RAS used trickle filters, and no issues were highlighted with these.

A common finding was over-expectation of performance of biofilters in the original system design, with the installed biofilter failing to deliver anticipated performance. Nearly every site had to increase biofilter capacity by adding more media and/or increasing the filter size. Factors that contributed to reduced performance were:

- inadequate mechanical filtration, so SSW added to the biofilter loading
- lower than expected oxygen levels
- inadequate flow rates through the RAS which allowed ammonia to build up in production units and reach the biofilters at a high level. (Unprocessed SSW could also build up).
- dead spots in filters.

5.4 Aeration/oxygenation

Adequate oxygen levels are obviously critical for fish production, health and welfare, as well as biofilter performance. Various methods are employed ranging from aeration via diffusers delivered from a compressor/blower to the application of pure oxygen via fine diffusers or injection systems. Care has to be taken with the application of pure oxygen as over-oxygenation is possible; an automatic monitoring / control system that doses the correct amount is required. It is preferable to apply oxygen either directly to the production unit or to the return water rather than the whole unit.

Industry observations

All sites used aeration as the main source of oxygen, and also to operate fluidised biofilters and opposing flow production systems (where aeration creates opposing circular currents along production units in order to distribute fish more evenly). Several sites had needed to increase aeration above that originally designed and installed. At least one site had experienced the total loss of a batch of fish which was attributed to low oxygen levels due to installation of an inadequate aeration system which had since been upgraded. One site moved its air blowers outside the RAS building to reduce humidity and improve turnover of air and reduce CO_2 build up within the whole building. One site installed a hydrogen peroxide delivery system for both routine and emergency oxygenation, which was considered to be a simple and economical solution for that site.

5.5 Heating

Heating can obviously be delivered in numerous ways; space heaters were used by the 65% of sites as it is generally considered more economical to heat the entire unit than just the water. This assumes that the building is well insulated. The space to heat is therefore a factor to consider in the initial design: there should not be an excessive space (air volume) to heat, although there should be sufficient exchange to prevent CO_2 build-up. Nevertheless, approximately 80% of units used pre-existing buildings so the air spaced was already fixed; one site had installed lower ceilings to reduce it. At 60% of sites, space heaters were situated in the main production building; however 3 sites had moved them outside the building to direct fresh air into the building and protect the heaters from the humid environment inside the RAS building.

One site used the heat given off by on-site generators. Heat recovery (from waste water or ventilated air) was installed at several sites. One site expended considerable effort in recovering discharged heat to reduce heating costs, and 4 of the larger sites, where heating was recognised as a significant cost, were exploring heat recovery.

Almost every site situated header tanks for new make-up water inside the RAS unit so it could warm up, but often the water was in circulation before it had reached temperature.

5.6 Sterilisation of inlet/return water

Water is sterilised to kill pathogens, remove undesirable heterotrophic bacteria and improve water quality. The two main methods are exposure to UV light and ozone. Both methods have their advantages and disadvantages and suitability depends on the situation. UV is generally the cheaper option, but is only effective with clear water; in turbid water penetration of UV is insufficient. Ozone is more expensive and has obvious health and safety implications, but it is more effective and works in turbid water. Ozone may have the additional benefit of improving water quality by removing flavour taints such as geosmins [26] and organic toxins. In seawater RAS, ozone is often combined with protein skimmers to boost their performance in fractional removal of proteins. One site used ozone to disinfect incoming water which was drawn straight from sea.

5.7 Pumping

Pumping of water to ensure circulation of water within RAS is obviously an extremely important factor for both design and operation. The right pump needs to be selected: undersized pumps result in a poor turnover in the system and lead to under-performing filters, water quality issues and reduced production. Oversized pumps are uneconomical to run. There is a wide variety of pumps available for different purposes:

- high pressure pumps are more suitable for a ring main system
- lift pumps are suited to moving large volumes of water but with little height (head)
- sludge pumps are designed to move highly viscose liquids laden with solids.

Approximately 30% of sites said they had the correct type and size of pumps in place. A small number of sites would have preferred to have a series of smaller pumps to give greater flexibility in the system and act as back-ups in case of failure. Three (co-operating) sites shared a spare pump as contingency for pump failure.

5.8 Tanks

Tank and holding systems varied across sites. However, the most common types for tilapia units were above ground rectangular concrete or fibreglass raceways. Marine sites mostly operated either circular or hexagonal tanks with one large site constructing tanks partially below ground level. Smaller sites used a variety of circular fibreglass holding units. Depuration tanks usually involved a separate filtration system using new clean water to supply smaller fibreglass tanks.

5.9 Pipe-work

Pipework is often overlooked within the design of an RAS. Inadequate pipework and fitting can slow flow rates. It is difficult to clean closed pipework so, where possible, open channels should be used

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[26] Schrader KK, Davidson JW, Rimando AM, Summerfelt ST (2010). Evaluation of ozonation on levels of the off-flavour compounds geosmin and 2-methylisoborneol in water and rainbow trout *Oncorhynchus mykiss* from recirculating aquaculture systems. Aquacultural Engineering 43, 46-50.

to enable routine cleaning, especially for dirty return water. At one of the sites, deep channels returned waste water at a slow rate to the filters: this allowed SSW to settle which added to maintenance and leached organic compounds which increased biological oxygen demand. The inappropriate location of pipework can cause operational issues: at 2 sites it was positioned on top of the production units' walls: this reduced access and was therefore considered a poor design. Over half of the sites had changed pipework to improve such aspects, which required extra time and expenditure.

5.10 Monitoring systems

Alarmed monitoring systems are obviously a critical part of any RAS design. In comparison to a simple open/flow-through fish farm, there are a lot more technological components that can fail, the response time is shorter (due to typically higher fish densities), and there is likely to be more than one issue to resolve if systems stop. A comprehensive alarm system should cover electricity source, all pumps and their output, other key equipment, oxygen levels in all (or at least the largest) production units, and pH. The alarm system should be linked to dial out control.

Nearly all of the sites did have alarm systems covering the electricity supply and pumps, but differed in what else was covered. All but two sites dialled out to a list of telephone numbers; the exceptions used an onsite audible alarm with the disadvantage of requiring personnel to be within ear-shot.

5.11 Automatic feeding systems

Automatic feeding systems were used on relatively few sites. These were suggested as beneficial by freeing up staff time and allowing feeding to be controlled (amount and timing) which can be important for ensuring consistent water quality when running RAS.

5.12 Water sources, replacement and discharge

The freshwater sites visited were either using mains, spring or borehole water and were typically only replacing between 1½ to 10% of system water per day. Two coastal seawater sites pumped seawater ashore, whilst the other inland sites mixed their own from purchased salt and mains water. The seawater sites replaced 2 – 10% of system water per day.

Discharge of replaced water (usually drum filter backwash) was most commonly to a settlement tank or lagoon and occasionally to a sewer. Any excess water after settlement was discharged to a mains sewer, into a constructed wetland area or drainage ditch. The concentrated settled solids were disposed of by spreading onto fields or being taken away for offsite disposal.

5.13 Lessons to be learnt

The majority (80%) of sites that used a pre-existing building had to accommodate aspects of the building design (e.g. low ceilings and support pillars) into the system layout. The disadvantages of using a pre-existing building will be site-specific, and must be balanced against the cost of a custom-made building.

RAS must be considered as a self-contained ecosystem, with the biofilter at its core. A key factor that was highlighted by some of the sites is that RAS must be run as 'fixed' operations, i.e. inputs (i.e. feed) and outputs (harvest) must be consistent to ensure reliable production.

To ensure that the production potential of a RAS is reached, it must be designed, constructed and operated well. Every site visited recognised that design, construction and use of correct/adequate equipment were extremely important in running a RAS: where there had been failures, a problem with one of these factors had been a major contributor.

A high percentage of sites identified poor design of the RAS itself as the main cause of ongoing issues: these tended to emerge as the biomass in the RAS increased, and required a considerable amount of time and money to address. Examples of design errors were:

- ammonia build up in production units due to inadequate water flow through the system
- oxygen levels becoming low as biomass/feeding rate increased due to insufficient aeration
- pH dropping caused by CO_2 build up due to inadequate ventilation/aeration (could also be addressed by buffering)
- one site stopped using a venturi delivery system as this was causing high levels of O_2 (supersaturation).

Making changes to RAS once in use is obviously undesirable: on top of the additional cost, it is logistically difficult and can compromise production. Some fundamental flaws could not be rectified without total shutdown of the RAS, which was not a realistic option for a running business. One site did have to resort to total shutdown to address failing design and poor construction, which pushed the business towards financial failure.

Approximately 60% of RAS had been designed to run as one large single unit. Although this may economise on construction costs, it was recognised as a compromise as it makes systems inflexible. An example is when small fry need to be on-grown (rather than fingerlings) - fry rearing facilities separate to the main production RAS needed to be set up by some sites. In hindsight, approximately 30% of sites would have preferred smaller, separate RAS despite the additional capital investment required, to give greater flexibility and manageability, particularly while new business ventures were findings their feet.

RAS often seem to be designed to run at the limit of capacity, with filtration just adequate to manage the maximum biomass/feed loading on a system. Running a RAS at this level leaves no margin - for fluctuations in water quality, error in practices, maintenance, and for unforeseen events such as equipment failure. The reality is that things will not proceed smoothly at all times, and spare capacity does need to be built into the design.

Sites that constructed vessels (for fish and filters) of concrete were particularly restricted compared to sites constructed of freestanding vessels. Concrete production units were generally of a raceway design, but one site used large concrete circular tanks. Modifications to the filtration units, frequently identified as sites approached their expected maximum biomass (and feeding rate), were particularly difficult and restricted if constructed from concrete. However, concrete may be the only viable option for large RAS. Notably, at one large site constructed of concrete, the filtration had been carefully designed and was working well within expected parameters.

Forgetting operation considerations during design led to two common, and potentially important, design flaws:

- storage capacity for inlet water is often under-estimated, so make-up water does not have sufficient time to warm up to temperature before use
- a lack of capacity to retain water when tanks needed to be drained for harvest or maintenance. If drained tank water is lost from the system, then it must be replaced. Replacement may represent a significant cost in terms of lost water and heat, on top of the time for replacement (particularly if tap water is the only water source).

Examples of other design flaws related to ignoring how staff would access areas, conduct routine activities and maintenance:

- pipes fitted to tops of walls prevented access along them

- hexagonal tanks, neatly filled space, but prevented access to those in the middle
- a walkway, post-fitted to provide access, necessitated staff having to operate 4 m above the water surface, making activities such as mortality removal very difficult. This tricky operation was compounded by the outlets being installed at the bottom of the vessels.
- tank shape (e.g. hexagonal with awkward corners), making confinement of the stock difficult during harvest
- lack of any provision in design for mechanised harvest, necessitating manual hauling.

In conclusion the majority of RAS operated well and produced fish once the right combination of mechanical and biological filtration was in place. Sites that achieved the right filtration from the outset were a minority; most required considerable adaptation and modifications to a poor initial design. Underestimating filtration capacity for the production target (=overestimating production for the designed filtration capacity) was common. Whether initial design was good or bad, changes always needed to be made; minor changes can be accommodated, but large unforeseen changes can prove costly. Poor construction was a problem for some, but not all, sites.

5.14 Next generation RAS

Active research is ongoing in Europe, North America and elsewhere to further develop RAS. Progress is being made in areas such as denitrification reactors, sludge thickening technologies and ozone treatments. These will all contribute to reducing water use, waste discharge and energy use in RAS (recently reviewed by Martins et al. 2010)[27]. However, whilst such developments offer promise for the next generation of UK RAS, they are not yet widely available to the existing sector.

Nitrogenous waste removal: Two new approaches are being applied to remove nitrogenous wastes from RAS. The first is based on recent developments in deammonification in other waste-water treatment applications. The EU FP7 DeammRecirc project is developing deammonification reactors for fresh- and sea-water RAS, which convert ammonia to nitrogen gas in one step. If the technology is proven, deammonification reactors could benefit commercial RAS by reducing: the need for clean make-up water and associated pumping and treatment costs, oxygen and buffering chemical use and cost, carbon footprint, and levels of nitrate in effluent[28]. The second approach is denitrification reactors which remove the nitrate that builds up in RAS by conversion to nitrogen gas. Various types of denitrification reactors have been developed that allow high nitrate concentrations to be

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[27] Martins *et al* (2010) New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability, Aquaculture Engineering 43 (2010) 83-93.

[28] http://deammrecirc.com/Project-Description

counteracted, e.g. the upflow sludge blanket denitrification reactor. Martins *et al* (2010) discuss the benefits of these systems and suggest that installation costs are rewarded by lower operating costs due to reduced water exchange. However, both these new approaches to remove nitrogen and reduce water replacement may precipitate other problems such as accumulation of growth inhibiting factors (an area that requires further research).

Suspended solids waste treatment: Sludge thickening technologies such as belt filters, geotextile bags or tubes all help to dewater and reduce the volume of SSW that needs storage and disposal. These technologies may also change the waste into a form more suitable for use as a fertiliser or in integrated aquaculture.

Effluent treatment: Constructed wetlands and micro-algal controlled systems are commonly used to treat municipal waste water and offer opportunities for treatment of waste-water from RAS.

Energy efficiency: Research being carried out at the Freshwater Institute (Virginia, USA) on improving the sustainability of land-based closed-containment systems for salmonid table fish production is targeting 'the potential for greater energy efficiency in water recirculation systems through improved low-lift pumping and gas transfer processes'. The US Department of Agriculture scientists have shown that a combination of low-head pumps, proper plumbing and larger diameter pipes used 30% less energy than high head centrifugal pumps.

6 Financial sustainability of RAS

The aim of this section is to provide an overview of the financial experiences of the 14 different warm-water RAS. It should be noted that the extent and detail of the financial data provided varied between interviewees due to confidentiality, position within the business, and available records.

6.1 Funding sources

Funding of the operations varied considerably between businesses from those who just used their own money to mixtures of investor funding, bank loans, mortgages and grants. Approximately half had borrowed in one form or another to get the business up and running. Fewer than half the sites had obtained some sort of grant funding: grants varied from as little as £1,000 to many £100,000s for the largest sites. Access to contingency funding was mentioned as important by one site.

6.2 Build and set-up costs

The scale of the sites visited varied from those costing £70,000 – 80,000 built to produce 10-50 tonnes p.a., to sites costing £10 to £14 million designed to produce 1,000 tonnes p.a.. Underestimation of the build and set-up costs was common, with figures for overspend varying between 15 and 40%. The reasons given varied and included:

- designs not including cost of installation of specific electrical supplies
- addition of supplementary de-nitrification filters
- modifications to faulty systems.

6.3 Running costs

Electricity: Most of the sites visited considered electricity to be a **major** cost: typical figures quoted were 15 -20% of running costs. Monthly costs of £500 - £1000 were typically quoted, even by sites producing less than 100 tonnes p.a.   Some sites expressed concern that inappropriate, power-hungry pumps had been supplied, which unnecessarily doubled the electricity bill. Some sites were investigating the use of alternative energy sources.

Heating: The necessity for supplementary heating varies between sites and with species held. However, most sites considered that heating was a **minor** cost, and the largest site did not consider heating a significant cost at all. Figures typically quoted were 5% of running costs or 50% of pumping costs. With good insulation, a lot of the sites only used supplementary heating for 2½- 4 months in winter. Some smaller sites found cheaper alternatives, e.g.

- burning woodchip
- switching from an LPG (liquid propane gas) heat source to diesel.

Water: A good supply of water is critical even for a recirculation system as it is required for top-up, emergency use, shipping etc. Water quantity and quality issues must be resolved before locating an aquaculture facility[29]. The majority of sites had no issues with supply and often benefitted from agricultural rates. Water supply costs did not represent a significant proportion of running costs for the majority of sites. However, a small number of sites did experience unexpected water costs, e.g.:

- a switch to mains water supply
- making up saltwater on site, costing up to £2.10 per m^3
- underestimating the cost of pumping water from the source into the farm.

Staff: Responses varied between sites: some thought staff costs were not high, while others emphasised the time commitment in running RAS and the need for trained, experienced backup available at all times. One site, between development phases, did express concern about the intensity of manpower required. Entry level pay into aquaculture is acknowledged to be low[30] and many sites have benefitted from cheap east European labour. Two larger sites, in operation with good financial management systems, both estimated staff costs at 15% of running costs.

Fry: Of the 14 RAS sites visited, 5 had sourced UK fry and one had used their own broodstock, while 10 had imported eggs or fry. Some sites had on-grown both imported and UK fry. Fry supply therefore frequently necessitated imports, due to a lack of UK hatcheries. Fry had been imported from France, Holland, Israel, USA, South Africa and Indonesia. The method of shipping varied: road delivery from European countries and airfreight from further afield. Although fry would have been moved at a small size, transport in water adds to shipping costs. One larger site stated that fry costs were 8% of total running costs.

Feed: The price of aqua-feed was a concern to all businesses and comprised a sizeable proportion of running costs. The actual costs of feeds varied between the species, and did not correlate with the percentage of running costs quoted, varying between 20% and 40% of running costs. Factors thought to contribute to relative differences between sites include economies of scale in food purchase (bulk buying), how much the fish were fed (% body weight per day), as well as the magnitude of other cost categories. Issues around feed costs included:

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[29] http://www.aces.edu/dept/fisheries/aquaculture/documents/Wheaton.pdf

[30] http://www.sparsholt.ac.uk/pages/template.aspx?idSection=69&idPage=139

- large increases in feed prices outside farmer control
- a switch in diets necessitated by nutritional problems which increased feed costs from £1,000 to £1,600 / tonne.
- one tilapia farmer, experienced in sourcing terrestrial livestock feed expressed frustration at an inability to source his own ingredients and considered that aquafeed supply options were too limited.
- producers of turbot and barramundi experienced problems in sourcing appropriate diets because they were the only market in the UK. This also meant there was no choice in formulation.

Maintenance: The reliability of equipment, its lifespan and the maintenance costs needs to be known and assessed by all operators prior to purchase. Examples of maintenance cost issues raised are:

- Pump maintenance costs were highlighted by several sites
- One large farm had to replace filter belts on an almost weekly basis. This took 3 men ½ day each and cost £1,800 - £2,000 a time. Although a cheaper belt supply was eventually found, the time and costs had already had a crippling financial impact.

Solids waste disposal: Disposal of settled solids from most freshwater recirculation systems was not seen as a significant cost as they were able to spread onto fields. (Some sites did mention that the systems adopted had increased their associated pumping costs). However, for saltwater sites disposal was far more complicated due to the presence of salt. For one site pumping out the settlement tank approximately every two months cost £1,500 a time. In addition, regulators have not applied policy uniformly across regions with some freshwater sites having their waste categorised as industrial waste which requires a special license costing £4,000 p.a..

Mortality disposal: Disposal of mortalities was considered a minor issue by some sites that had ready access to facilities, while others suggested that it incurred a significant cost although this could not be quantified.

Rental: Over 90% of the sites owned their own building so consequently rental costs were not an issue and almost all of these had utilised existing vacant buildings. However, for one larger site, rental costs were considered excessive at approximately £25,000 per month.

Oxygen: Oxygen was not used at many of the businesses, but did amount to up to 5% of running costs at some sites. One farm mentioned hydrogen peroxide use, but this was not considered a major cost.

Un-expected costs: Sites often found running costs were greater than initially budgeted, which occurred due to a variety of, often site-specific, reasons:

- sales costs (for marketing, packaging, ice machines and delivery) were commonly wrongly anticipated. One site quoted sales costs at £0.25/kg of fish.
- supermarket compliance costs
- modification of newly installed systems and adjustments to technology, e.g. delivering additional ozone to protein skimmers. There was typically a significant additional set-up cost to address teething troubles.
- Bio-filters could require up to several hundred m^3 of media, costing up to £300 /m^3
- fry costs higher than anticipated

6.4 Planned v actual sales price

Although one site achieved and one site exceeded their predicted sales prices, many of the sites had been unable to obtain their planned sales price. One site planned a sales price of £16/Kg, revised this down to £6/Kg, but the best price achieved was £3.20/Kg, with a final average of £2.40/Kg. Prices quoted were clearly higher for premium marine species such as turbot and bass. Sites producing lower value species such as tilapia or catfish indicated that sales at £3.00/Kg would provide a viable business, but many were struggling to achieve £2.20 - £2.80/Kg. The pressures and problems caused by supermarkets were mentioned, e.g. promotional offers which reduced prices the farmers received and caused a short term increase in sales. Several sites had managed to obtain higher prices by delivering to live fish markets.

6.5 Production costs, payback and accounting rate of return

Accurate figures for financial appraisal were difficult to obtain with many farmers either unwilling or unable to supply these. In some cases figures were with accountants. However, three sites no longer in operation quoted production costs of between £1.50/Kg for tilapia and £7.70/Kg for turbot.

Payback is the period taken for a project to recover its original cost in future cash flows. Two sites mentioned that they had expected to achieve this within two years but a payback period of 5 years was more realistic. One site, currently between development phases, was concerned about the length of time before a return was achieved (interpreted by interviewers to mean achieving payback).

Accounting rate of return measures the percentage return the project achieves over its life in terms of profitability. Two sites that are no longer operating did provide crude figures on rate of return stating that it was just 25-50% of the levels promised by the system sales person / installer.

The large scale, operating sites with better financial management did not quote figures, but were optimistic and firmly believed in the future of RAS. One did indicate that the current RAS systems did need to evolve further for another 10 years to assure financial sustainability. One interviewee gave the main reason he sold up as teething problems that went on too long so he ended up with half the expected sales and double the costs.

6.6 Literature review findings

The University of Stirling, has examined the potential for development of warm-water production systems as a diversification route for UK agricultural farmers[31]. One part of the programme looked at the economics, with sensitivity scenarios. Using typical farm gate prices for tilapia of £3.00, £3.70 and £4.50/Kg, sales price emerged as the most critical sensitivity item. Many of the tilapia farmers interviewed in the current study had struggled to achieve even the lowest modelled sale price.

The Stirling research showed that continuous production was more profitable than batch production: for profitable batch production, the smallest units would need to achieve a sales price of £3.20/Kg to bring them to profitability, compared to £2.65/Kg for continuous production. The analysis showed that profitability is closely related to production scale, but also indicated that risk increases with the scale of operation. The research also pointed out considerable scope for increasing profits by increasing energy efficiency and integrating combined electricity and heat biomass systems.

The (somewhat crude) industry survey information summarised above and the Stirling project do not support strong financial sustainability of freshwater RAS in England. However, the situation could change markedly if sales prices are increased by external drivers. The pressure on wild fish stocks is mounting as global demand for seafood products grows[32], human populations increase[33], and per

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[31] http://www.tilapiascotland.org/relu
[32] http://www.fao.org/docrep/007/y5767e/y5767e0d.htm
[33] http://www.statistics.gov.uk/cci/nugget.asp?id=1352

capita demand increases due to the recent message for increased fish consumption[34]. There have already been prices rises[35] and shortages[36], which could lead to higher farm gate prices. The promise offered by RAS is further illustrated by investment in research and development, e.g. :

- A recent feasibility study of closed-containment options for the British Columbia aquaculture industry [37] compared open cages to RAS. Overall, the study found a significant advantage for cages in terms of pre-tax income. Although RAS technology was marginally viable financially, it represented a higher level of risk. RAS benefitted from more efficient biological feed conversion ratio (FCR), temperature stability, and improved environmental control, but this was at the cost of higher expenditure on capital, energy and labour which impacted overall profitability. Nevertheless, as with most emerging technologies, once wider RAS uptake is achieved, capital and operating costs may go down. If closed-containment technologies achieve a critical mass of production, operators may benefit from economies of scale for acquiring capital items, and increasing expertise could reduce operating costs[38].
- In Manitoba, Canada, a model inland recirculation trout farm is being developed, with encouragement from the authorities, from which data is being recorded.
- In Norway, NOFIMA have just opened a state of the art recirculation aquaculture research facility and acknowledge that recirculation will be implemented within the industry in the near future[39].

6.7 Overall assessment of financial sustainability

Historically, the financial viability of recirculation aquaculture has not been good: it is a developing sector that has made many mistakes. Current sales prices for many species make the return on investment marginal. However if capital costs reduce, and technology and energy efficiency reduces running costs, the outlook may improve. Furthermore, sales prices may increase: consumers are becoming increasingly more adventurous with their eating habits and RAS offer an opportunity to grow a diverse range of species close to markets. Potential investors should therefore proceed with caution and pay particular attention to minimising input costs and develop prudent business plans that reflect the market.

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[34] http://www.food.gov.uk/news/newsarchive/2006/mar/oilyfish
[35] http://www.talkingretail.com/news/industry-news/fish-prices-to-rise-by-5-as-demand-increases-and-inflation-bites
[36] http://www.enn.com/top_stories/article/41773
[37] http://www.dfo-mpo.gc.ca/aquaculture/lib-bib/nasapi-inpasa/BC-aquaculture-CB-eng.htm
[38] http://www.dfo-mpo.gc.ca/aquaculture/lib-bib/nasapi-inpasa/BC-aquaculture-CB-eng.htm#executive
[39] http://www.fishnewseu.com/index.php?option=com_content&view=article&id=4838:berg-hansen-opens-recirculation-research-centre&catid=46:world&Itemid=56

7 Factors leading to historical failure of some RAS

7.1 "Top 10" critical factors

During the visits, the 14 interviewees were asked to pick and rank their top 10 key factors contributing to the success (or failure) of a warm-water RAS table fish farm. Rankings were converted to scores (high score = important factor) which were summed for display (Figure 5).

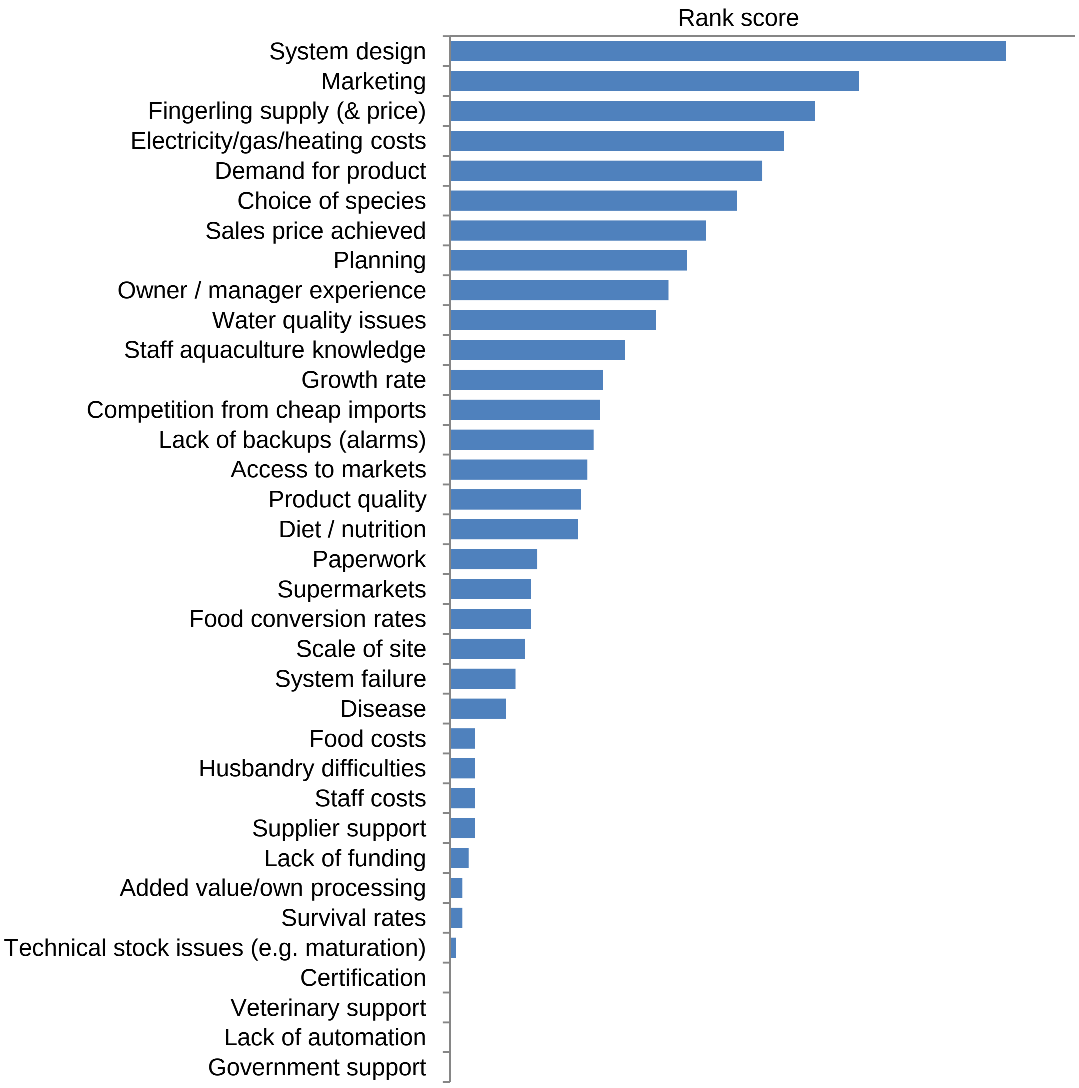

Figure 5: Critical factors for the success or failure of warm-water RAS, as scored by RAS industry interviewees.

Technical (system design) and some **economic** factors (marketing, energy costs, demand for product), along with **fingerling availability/price**, emerged as the key issues. Staff knowledge and biological factors appear to be considered as less critical; regulatory and certification issues appear to be of minor importance.

7.2 Additional factors contributing to failure

Other key issues contributing to failed operations were identified during interviews. These are categorised in Table 4.

Table 4: Other key issues identified during interviews as contributing to failed RAS operations.

Reasons for closing the operation	**Site specific problems**
• Operational design issues	• Inappropriate water supply
• Cash flow and debts	• Restricted access to facilities
• Sales volumes	• Site too small
• Market prices	• Waste treatment and drainage problems
• Overheads	• Distance from markets
System-specific problems	**Mistakes made**
• Modifications to original build	• Only consulting one supplier/designer
• Inadequate filtration system	• Not piloting before scale up
• Quality of system build	• Unrealistic expectations
• Pipe-work and flow design	• Not enough attention to detail
• Lack of automated systems for harvesting and mortality removals	• Inputs and costs too high
• Inflexibility of system	• Not checking access to markets

Of the major reasons identified, the technical and economic reasons (costs) for failure have been discussed above. Other issues that merit discussion relate to markets and economies of scale.

7.3 Markets

Fish farmers naturally focus on producing fish and sales is recognised as an area where they often "drop the ball"[40]. Many sites appeared not to have understood the market at the beginning of the operation and had consequently changed or struggled to find outlets. Few operations appeared to have invested effort in the four Ps (Product, Price, Placement and Promotion)[41].

Intended markets varied between sites, largely due to differences in the scale of operation.

- Smaller sites were unable to supply supermarkets with the volumes demanded, so focussed on local or ethnic live markets. Sites that targeted ethnic markets had good initial uptake, but then

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[40] http://aquaculture.ext.wvu.edu/r/download/59173

[41] http://www.eldis.org/go/topics/resource-guides/health-systems/key-issues/market-development-approaches/tools/4-ps

hit a ceiling. Several found the process of distribution to local or premium markets onerous and ended up supplying wholesalers, processors or supermarkets as a last resort.

- Many sites cited difficulties in dealing with larger supermarkets such as being unable to supply when they demanded, and coping with promotions. However, contracts had been set up to facilitate two-way communication and understanding of the problems - supply by the farm, and the supermarket’s need for promotions.

Other issues with markets that emerged during interviews included:

- Breaking in - Some of the larger tilapia producers felt that the market was there, but was difficult to access, possibly because they did not have a diverse “basket” of products to offer.
- Dependence - A few sites were reliant on a single outlet for their product, and were left floundering if this avenue closed.
- Product quality - One site released fish onto the market before the depuration system was operational and as a result acquired a reputation for tainted fish that proved difficult to shift.
- Competition – The low cost of imports in relation to domestic production was raised several times.

Two sites did recognise the importance of marketing their products:

- One site allocated 10% of production costs to marketing and, as a result, had always achieved or exceeded their farm gate prices.
- Another of the larger sites had a dedicated sales manager to keep customers happy which was perceived as a key to success.

7.4 Adding value: processing, accreditation schemes and branding

Nearly all operating sites did the minimum amount of processing – they sold whole fish with negligible amounts of de-scaling and packing. A few sites stated that they did not want to get involved in processing. In contrast, several sites were contemplating processing, with one group considering a shared facility.

Approximately half of the sites visited had never been involved in an accreditation scheme. Two of the larger ones had joined up with the Quality Trout UK (QTUK) scheme, and other sites were considering joining.

Some sites were considering developing their own, or local (group) brands. Several tilapia farmers considered that highlighting their products as locally / regionally produced (e.g. bred in Norfolk, raised in Suffolk) would be a marketable attribute. Several farmers were keen to convey the sustainability attributes of their products and make the most of green credentials through eco-labelling[42]. However, this was not yet occurring, because either they were unclear of how to go about it, or it was being left as something for the future.

7.5 Economies of scale

Whilst this did not rank highly as a “top ten” factor, the vast majority of sites suggested that economies of scale were very important in terms of financial sustainability and critical in supplying supermarket chains. A few non-operational sites expressed the opinion that if they had piloted the project or started small this would have reduced the costly mistakes made later. Two farmers expressed the opinion that being small had reduced their losses to mostly their own labour, although one of these sites did qualify this by saying that he could have had a viable operation if production had increased from 10 to 20 tonnes p.a..

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[42] Mungkung RT, de Haes HAU, Clift R (2006). Potential and limitations of Life Cycle Assessment in setting ecolabelling criteria: a case study of Thai shrimp aquaculture product. Int J LCA 11, 55-59.

8 Sustainability issues relating to RAS

The EU Aquaculture strategy calls for development of a **sustainable** industry. A widely-used definition of sustainable is “*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*”[43]. Sustainability is an ideal aimed at ensuring satisfactory environmental, social, and economic conditions, and can be envisaged as addressing four objectives[44]:

- effective protection of the environment
- prudent use of natural resources
- social progress which recognises the needs of everyone
- maintenance of high and stable levels of economic growth and employment.

Economic issues related to RAS are discussed above; here we discuss environmental protection, natural resource use, social issues and employment in relation to RAS.

Nearly all of the farms visited were aware of the environmental and resource use credentials of their products, e.g. locally produced and low food miles, reared on low fish meal diets, low water usage, efficient use of space. However, farmers often struggled to discuss social sustainability issues, but did so when prompted by interviewers with examples.

8.1 Environmental protection

RAS farms score strongly in terms of environmental protection, largely due to their inherent features.

Finfish aquaculture is often criticised over the issue of **escapees** and their impacts on local stocks though competition, interbreeding and dilution of local gene pools. Due to their closed design, typical location remote from natural water bodies and culture of tropical species, none of the RAS sites had experienced any problems with escapees.

Open finfish farms are often perceived to act as reservoirs of **pathogens** that infect wild stocks. Again, the closed design, location away from natural water bodies, treatment of effluent and culture of tropical species, negate this issue for the RAS farms visited.

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[43] http://archive.defra.gov.uk/sustainable/government/publications/uk-strategy/documents/NewGlossary.pdf
[44] http://archive.defra.gov.uk/wildlife-pets/zoos/documents/zoo-handbook/3.pdf

Containment of warm-water RAS within buildings also eliminates **interactions with wild predators**, with no site reporting predator problems. Two sites did mention a need for pest control and used professional contractors to control rats around the farm.

Open aquaculture systems may necessitate **modifications to natural water bodies and changes in flow,** due to construction of channels for abstraction and discharge. Again, RAS avoid such impacts.

In open aquaculture systems, **discharge of veterinary products** can be a concern. Again, the location of RAS farms away from natural water bodies coupled with retention of water within the system eliminates this potential issue. Furthermore, RAS are generally designed to have high biosecurity being within a building, drawing water from sources without fish pathogens or sterilising if drawn from natural water bodies. A large proportion of the sites visited had therefore not used any veterinary products.

In open, flow-through fish farms, there is **discharge of effluent** containing suspended solids, dissolved inorganic and dissolved organic wastes into natural water bodies which can reduce the quality of the local environment. Again, the location of RAS farms away from natural water bodies coupled with treatment of wastes within the system eliminates this issue. RAS do need to discharge a small percentage of the recirculating water (≤10% / day) to prevent excessive build up of nitrates and other compounds. This effluent could have potential eutrophication impacts, but RAS tend to discharge to sewers, settlement tanks, ditches, or constructed wetlands rather than natural water bodies. Constructed wetlands provide a natural means of cleaning effluent, and can provide a new habitat for wildlife.

RAS systems capture and concentrate suspended solids wastes which require disposal. Some RAS farms use waste disposal systems already in place as part of their agricultural farms; some spread their solid waste onto fields (representing re-use as fertilizer); some have waste taken away as per a septic tank; others have had the waste classified as industrial waste and have to pay for a special licence and disposal.

One environmental weakness of RAS is their high energy use (see below) which contributes to **global warming** due to the burning of fossil fuels. RAS typically have double the carbon footprint of flow-through systems[45]. The key to reducing carbon footprint of RAS is to switch to renewable energy

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[45] See Ellis et al. (2011) Initial investigation of the sustainability of English aquaculture. Cefas contract C3743 report to Defra

sources. Every site visited had investigated or experimented with alternative energy sources, i.e. woodchip burners, solar panels / photovoltaics, wind turbines, biogas plants, anaerobic digesters, ground source heat pumps, and use of waste heat from an ice rink. Although reuse of waste heat from third-party sources may be green, asymmetries between the co-operating businesses have typically made previous attempts unsuccessful[46].

One potential advantage of growing tilapia in the UK over import of foreign production is that the associated **food miles** are markedly less. However, simply focussing on food miles travelled by the final product ignores the mode of production, mode of transport, and transport of inputs such as feeds and fry. One study assessed the global warming impacts of cage tilapia production in Indonesia and transport to Europe[47]. In the context of the full production cycle, transportation impacts were negligible, as transport of frozen fillets in ocean freighted containers is efficient. This means that UK production in RAS contributed more to global warming than production in Indonesia combined with importation[48]. Nevertheless, RAS production in the UK was associated with less eutrophication. Furthermore a separate study has indicated that production of African catfish in Dutch RAS results in lower carbon dioxide emissions than *Pangasius* catfish farmed in ponds in the Mekong Delta[49] also taking into account transportation costs.

8.2 Natural resource use

RAS systems are in a mixed position in terms of resource usage. As intensive systems, they do require input of natural resources, so the emphasis must be on maximising efficiency.

RAS farms represent an efficient **use of land.** Comparative production figures for tilapia are 1340 tonnes/ha/year for RAS versus 17.4 tonnes/ha/year for a conventional tilapia farm[50].

Water use in RAS is evidently efficient in comparison to open / flow-through aquaculture: comparative data are 0.5 m^3 /Kg RAS v 31 m^3 /Kg tilapia production in a conventional intensive farm[51]. RAS also compare favourably to terrestrial animal products such as pigs and eggs[52].

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[46] Little DC, Murray FJ, Azim E, Leschen W, Boyd K, Watterson A, Young JA (2008). Options for producing a warm-water fish in the UK: limits to "green growth". Trends in food Science & Technology 19, 255-264.

[47] Pelletier N, Tyedmers P (2010). Life cycle assessment of frozen tilapia fillets from Indonesian lake-based and pond-based intensive aquaculture systems. J Industrial Ecology 14, 467-481.

[48] See Ellis et al. (2011) op. cit.

[49] Poelman M, Schneider O, Abstract at 8th International Conference on Recirculating Aquaculture.

[50] Sustainable finfish aquaculture workshop. Finfish News 9, 4-22; http://www.slideshare.net/Cefas/large-scale-intensive-recirculation-systems-and-their-potential-development-within-england-2373881

[51] http://www.slideshare.net/Cefas/large-scale-intensive-recirculation-systems-and-their-potential-development-within-england-2373881

[52] http://www.oecd.org/dataoecd/19/21/45032957.pdf

However, simple comparisons of volume of water used in production are too simplistic[53]. The metric for water use - m^3/ Kg production - does not account for the impact of abstraction on the source of the water (i.e. mains, groundwater, river, lake, sea) which will be relative to its availability. Furthermore, open / flow-through aquaculture is a non-consumptive use of water as it is promptly returned to the same water body from which it was abstracted; in contrast, RAS could be considered as a consumptive user of water, although some discharged water will find its way back into the water table via sewage works or spreading on the land.

RAS farms have a high **energy use** as they rely on technology to move water and maintain its quality. Energy use across the production cycle has been examined in a number of studies and RAS farms typically require 2 to 3 times more energy than flow-through /open aquaculture systems[54]. The key to reducing energy use in RAS is to improve energy efficiency. At some of RAS systems visited, expert consultants had been involved in making improvements to improve energy efficiency. Heat exchangers were commonly being investigated, e.g. in settlement tanks. One tilapia farmer said that the heat exchanger on the air exchange unit enabled 60% recovery of heat. With increasing energy prices, incorporation of energy efficiency into designs will also contribute to financial sustainability.

There seems to be a belief that **feed use** should be more efficient in RAS than in open / flow-through systems [55]. Theoretically, RAS represent intensively managed systems where food provision is highly controlled (to minimise waste) and optimum conditions for growth are provided. Whether food conversion is truly better in RAS than other aquaculture systems remains to be demonstrated[56], with comparisons confounded by differences in diets.

Finfish aquaculture has attracted criticism because many species farmed are carnivorous and fed formulated feeds containing **fish meal and fish oil (FMFO)[57]**. Tilapia has been promoted as “green” due to omnivorous diet[58]. The RAS sites visited potentially present a dichotomy between those producing tilapia, and those producing carnivorous fish (e.g. sea-bass, turbot).

Most of the tilapia sites had changed diets several times to find the most suitable, and a few were content with their current diet. However, concerns were expressed that tilapia diets low in FMFO

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[53] See Ellis et al. (2011) op. cit.

[54] See Ellis et al. (2011) op. cit.

[55] D’Orbcastel ER, Blancheton J-P, Aubin J (2009). Towards environmentally sustainable aquaculture: comparison between two trout farming systems using Life cycle Assessment. Aquacultural Engineering 40, 113-119.

[56] See Ellis et al. (2011) op. cit.

[57] Naylor R, Burke M (2005). Aquaculture and ocean resources: raising tigers of the sea. Ann Rev Environ Resour 30, 185-218.

[58] Little DC, Murray FJ, Azim E, Leschen W, Boyd K, Watterson A, Young JA (2008). Options for producing a warm-water fish in the UK: limits to “green growth”. Trends in food Science & Technology 19, 255-264.

reduced growth rates and created more waste for the RAS to handle (presumably due to lower digestibility). There was some evidence of group (bulk) purchasing but this precipitated conflict due to differing emphasis between members on low FMFO and faster growth rates. The large scale bass farm had found that the formulation of the bass feed initially used (designed for cage systems) had to be altered for RAS, and now contained lower lipids and fish oil.

All sites visited were aware of the sustainability benefits of using feeds low in FMFO, and some had begun to market their fish accordingly. Two sites stated that supermarkets are keen on low FMFO feeds, and can dictate feeds. Other sites argued that the markets did not care about low FMFO diets, and sale price did not redress the slower growth and higher wastes. It must also be recognised that the promotion of fish consumption on health grounds is, to a large extent, due to the presence of marine derived omega 3 oils and trace elements which originate from FMFO.

As nitrate and phosphate levels build-up in RAS, there is the possibility of recovering these wastes in effluent water into additional vegetable crops, thereby maximising use of the original feed resources. The seawater sites visited had been involved in research projects growing seaweed and samphire[59] hydroponically in effluent. Several of the freshwater tilapia sites had investigated commercial hydroponic units[60] as a 'bolt on' to their farms, e.g. for tomatoes. However, three sites expressed concerns about the effort involved in making two systems run in harmony, and felt that making the fish RAS perform was more critical.

Aquaponics is the integral combination of RAS aquaculture and hydroponics: fish wastes are removed as nutrients by plants[61], and contribute to the biological filtration process, helping cleanse the water before return to the fish. Despite research interest and a growing number of hobbyists, aquaponics has not yet reached commercial reality.

Polyculture is the farming of more than one target species, using different habits and trophic levels to maximise the efficient use of space and/or feed[62]. Approximately half the sites had not considered polyculture, or dismissed it preferring to concentrate on one species. Some freshwater sites had considered producing catfish or carp in conjunction with tilapia, one had considered prawns, and another had experimented with producing snails in the warm air. The seawater sites

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[59] http://www.llyn-aquaculture.co.uk/index.php?p=111
[60] http://www.cropking.com/intro.shtml
[61] http://aquaponics.org.uk/
[62] http://en.wikipedia.org/wiki/Polyculture

had also investigated *Artemia*, clam, sea urchin and bio-diesel production. However, none of these have yet come to commercial fruition.

8.3 Social issues

Social issues address attributes of products that are important to consumers and the role of RAS farms in local communities. RAS score highly in relation to social sustainability.

Product quality covers tangible and perceived attributes of products of importance to consumers, and the latter will also include perceptions of environmental impact, natural resource use, and local production. Tilapia farmers considered local production was an attribute consumers may find attractive in their products.

A key issue for seafood quality is **freshness** and was recognised by many of the interviewees. UK RAS systems clearly enable fish products to reach the UK consumer quicker than imports (sea-bass from Wales v after road transport from the Mediterranean) or in a more desirable form (fresh UK tilapia v frozen fillets from Asia).

Food safety is another tangible quality issue, due to potential contamination with industrial chemicals, heavy metals, veterinary products and bacteria. Imported fish products have faced scaremongering over food safety [63] [64], although systems are in place to protect consumers[65]. UK consumers may nevertheless place more trust in domestic traceability systems:

- feed is an unlikely source of contaminants as recognised manufacturers abide by strict rules for levels contaminants in their raw materials.
- all UK RAS operators maintain records of veterinary medicine use under the requirements of their Aquatic Animal Health Authorisation.
- Two sites were part of an industry accreditation scheme and others were thinking of joining; another site was tied into supermarket quality assurance schemes

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[63] http://www.fishupdate.com/news/fullstory.php/aid/12949/Seafood_company_challenges_Scottish_Press_concerns_on_Vietnamese_fish.html

[64] http://www.fishupdate.com/news/fullstory.php/aid/14920/Vietnam_moves_to_upgrade_fish_safety_checks.html

[65] http://www.fishupdate.com/news/fullstory.php/aid/15471/EU_politician_admits_misplaced_criticism_of_Vietnamese_pangasius.html

One potential issue for RAS, due to the limited replacement with new water, is the accumulation of heavy metals in the water; however, recent research negates this as a food safety concern, as water levels do not translate into flesh residues[66].

One recognised issue for RAS is accumulation of non-toxic organic substances in the water which can **taint** the fish flesh, i.e. cause an off-flavour or muddy taste. A few farmers said that they had not received any complaints and taint was not a problem for them. However, most operating farms had depuration tanks for reducing taint. Two non-operational farmers mentioned this as a problem; one had placed product on the market before depuration tanks were set up and then had been unable to lose the stigma. Research is ongoing into the issues of taint in recirculation systems[67]. This potential problem appears to be resolved by good system design and the use of clear water technology such as foam fractionation and ozone.

The **health and welfare** of farmed fish may be a quality attribute important to some consumers[68], and supermarkets are increasingly including it in quality assurance schemes. Several interviewees were concerned about consumer perception of intensive production, and possible misinterpretation of fish aggregating at high density at the surface during feeding time or in response to a stockman.

RAS systems have high bio-security to prevent ingress of pathogens. RAS are contained within buildings and the water supply is either from sources with no pathogens (mains, ground water) or is sterilised before use. Of the sites visited, ¾ had not experienced any disease problems. However, the intensive nature of RAS means that if a disease does enter a system (most likely via introduced fry) it can proliferate and spread quickly. A small number of the tilapia RAS had experienced outbreaks of a bacterial disease (*Fransicella asiatica*) in fry, which was resolved by setting up separate nursery systems and changing supplier. Two sites mentioned that they had occasionally suffered from commonly occurring parasites but that these were manageable. One site mentioned eye problems which were resolved with help of a veterinary surgeon. Sites used either local vets, or more commonly specialist fish vets.

Most RAS farmers considered that the on-farm welfare of their stock as good because the fish were feeding and growing (provided the system functioned well). Most operators considered routine

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[66] Martins CIM, Eding EH, Verreth JAJ (2011). The effect of recirculating aquaculture systems on the concentrations of heavy metals in culture water and tissues of Nile tilapia *Oreochromis niloticus*. Food Chemistry 126, 1001–1005

[67] http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=409122

[68] Olesen I, Alfnes F, Røra MB, Kolstad K (2010). Eliciting consumers' willingness to pay for organic and welfare-labelled salmon in a non-hypothetical choice experiment. Livestock Science 127, 218-226.

mortality levels as low, although peaks had occasionally occurred due to human error, system failure and feed related issues. Five sites had experienced poor quality fry which did not grow (poor doers), and required culling. One site had experienced a batch of fry with a high level of physical deformities, but this had since been resolved by selective breeding. Welfare during transport was not a major issue: only fry are transported when small, as table farms typically slaughter harvested fish on site; there are occasional live sales to ethnic markets, but farmers expressed no concerns over this. Opinions on welfare at slaughter varied between farmers. Most sites slaughtered fish by placing them directly into ice slurry. Some felt this was fairly quick and humane, whilst others suggested that the time to death was unacceptable. Divergence in opinions may reflect previous experience: agricultural farmers are used to instantaneous slaughter, with one farmer (turkey as well as tilapia) stating that while turkeys died in 1-3 seconds, it could take up to 10 minutes for tilapia to die. At the request of a supermarket, one site was investigating stunning machines for tilapia. Several farmers had tried electrical stunning as a more humane slaughter method, but had returned to ice slurry due to problems with product damage. Turbot were slaughter by manual percussion stunning.

UK RAS systems may benefit consumers (and retailers) through **consistency of supply.** RAS farms create their own environment, so production and harvest are unaffected by season and weather and a standard product can be delivered. One interviewee suggested that most consumers just wanted a fresh and consistent supply. The production costs discussed earlier indicate that RAS farmers should be able to provide fish products within a **price** bracket that enables access by a large proportion of consumers.

UK RAS systems producing exotic species do increase **diversity in choice** for fish consumers. However several interviewees farming tilapia suggested that sales to ethnic markets were of primary importance due to the conservative tastes of the average UK consumer. One fish processor was believed to be producing an ethnic line to supply supermarkets. The turbot farmer also indicated that live fish sales into oriental live fish markets returned higher sales prices.

With regards to **interactions with local communities**, all but two of the 14 RAS sites had made use of redundant farm buildings. This meant that there was little or no aesthetic impact on the surrounding environment, with many people being completely unaware of their existence. Of the two new builds:

- one had experienced minor planning issues

- the other was built within a disused brown-field site and had received complaints from local residents alleging noise disturbance.

8.4 Employment

Nearly all the sites mentioned employment as the main social benefit to nearby communities. At the initial construction or conversion stage, local electricians and builders were generally used. Although employment is typically low for running systems (usually 2 or 3 staff and up to 10 - 15 for larger sites), several interviewees suggested that this could be locally important in remote rural areas (13 of the 14 of the sites visited were located in rural areas). Several sites have provided employment for migrants from other EU members states or even further afield. One site mentioned that the fish farm had secured the future for staff already employed on the agricultural farm.

One farmer did identify negative aspects of RAS operation on quality of life of workers: operating a RAS meant having to be on hand 24/7, which affected his social life; furthermore the possibility of system failures was a source of constant worry.

9 Strengths, weaknesses, opportunities and threats to the RAS sector

In this section, we attempt to integrate the information collated above and help readers make judgements on the potential for the RAS sector in the England and Wales by conducting:

- a PEST analysis, i.e. collation of Political, Economic, Social and Technological issues
- a SWOT analysis, i.e. collation of Strengths, Weaknesses, Opportunities and Threats

9.1 PEST Analysis

It is sometimes useful to carry out a PEST Analysis as a prelude to a SWOT analysis. Various political, economic, social and technological issues are listed in Table 5.

Table 5: PEST analysis of the recirculation aquaculture sector in England and Wales.

POLITICAL ISSUES	**ECONOMIC ISSUES**
Food security	Current financial situation
Water Framework Directive	Value of salmon aquaculture
Habitats Directive	Generating economic wealth
Environmental permitting	Regulatory burden initiatives
English Aquaculture Plan	Import of 40% – 80% of UK consumed seafood
European Aquaculture Framework	*Pangasius* production
Alien species legislation	Low interest rates
EFF funding for aquaculture	Banks reluctant to lend
Marine Protection Areas	Poor investment profile
Global instability	Track record
Conservative Government	
Air miles – Green credentials	
SOCIAL ISSUES	**TECHNOLOGICAL ISSUES**
Increasing population	Technology transfer from water industry
Healthy eating (FSA advice)	Freshwater institute research
Increasing affluence	SARF - EATP
Increasing ethnic diversity	Developing technology
“Fish Fight” campaign	Plug and play systems
Celebrity chefs	Material advances
Image problem	Limited manufacturers
Ethics & welfare	Automation
Media attacks	Alarms – backup
Red tractor labels	Innovation potential
Buy British	Global interest groups

9.2 SWOT Analysis

SWOT analysis is a strategic planning method used to evaluate the strengths, weaknesses, opportunities and threats involved in a project or business venture. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favourable and unfavourable to achieve that objective[69]. By stating that the objective for the RAS sector as "*for farmers to make money and contribute to the growth of sustainable aquaculture within England*" we can develop a SWOT analysis from the information collected during the field visits and literature search.

Table 6: SWOT analysis of the recirculation aquaculture sector in England and Wales.

Strengths	**Weaknesses**
Bio-security (protection from infection)	Capital set up costs
Control over discharge	Electricity Costs
No predator problems	Investor confidence / track record
No escapee problems	Intensive image
Optimisation of temperature for growth	System design still evolving
Protection from adverse weather conditions	Marginally profitable compared to cage systems
Conservation of water	Supply of fingerlings (dependence on imports)
Location close to markets (low air miles)	Not seen as organic
All year round production	Flesh tainting issues
Traceability and food safety	Culture knowledge for limited list of species
Low or no medicine usage	Experience/understanding of staff to run RAS
Efficient use of space	Lack of marketing experience
Safer working conditions than cage farms	Sensitive to prices changes
Opportunities	**Threats**
Reduction of capital costs	Increasing energy costs
Reduction of running costs	Cheaper foreign imports
Linking with alternative energy sources	Fish meal / oil costs and availability
Secure for farming new species	Component failure
Automation	Loss of electricity
Alarm systems/ backups	Human error
Improved marketing / product placement	Diseases
Genetic selection for RAS & stock improvement	Mis-selling of poor quality systems
Re-use of nutrients as fertiliser / aquaponics	Scale up problems
Increasing demand for healthy product	Extreme animal rights groups
Efficient management /record keeping of RAS	Availability of veterinary medicines

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[69] http://en.wikipedia.org/wiki/SWOT_analysis

9.3 Identification of R&D requirements

At the end of each site visit, interviewees were asked for research and development priorities to support the RAS sector of the aquaculture industry, which are collated in Table 7.

Table 7: Priorities for RAS research and development, identified by the 14 sites surveyed.

Economics & running costs • Improving energy efficiency. • Greater integration of alternative energy sources to reduce carbon footprint and running costs.
Technology & System design • Investigation of long-term effects on recirculation systems of small replacement volumes, e.g. build up of organics and heavy metals, loss of trace elements. • Better delivery systems for oxygen and ozone • Cheaper water quality monitoring equipment • Improvement and simplification of systems, and movement towards a common, standard design • Investigation of the long term prospects and issues for RAS
Stock • Selective breeding to improve growth rate of current RAS species, and to produce strains of open/flow through aquaculture species suitable for farming in RAS • New species: closure of the lifecycle in culture and domestication • Selection of saltwater tolerant tilapia strains, as such systems perform better
Feed • Development of fish meal and fish oil alternatives • Development of RAS specific diets • Use of sprouted grains and seeds for herbivorous fish
Product • Consistency of quality of product • Research into tainting (taste)
Discharge • Re-use of effluents for crops as very rich in nutrients • Aquaponics
Others • Improving the image of fish farming • Applied collaborative projects between research providers and the RAS sector

10 Conclusions

Although the RAS sector in England and Wales is small in comparison to the production of farmed salmon in Scotland, it has expanded greatly in the last decade. Over the same time trout farming in England and Wales has shown a gradual decline. Whether this expansion of the RAS sector is sustained will depend on the performance of existing farms and the construction of more farms.

RAS ventures do have a poor longevity record with a high proportion of businesses closing. Various factors contribute to failure: technical system design problems, economic difficulties (high energy costs, too low demand and price for products), and problems in fry supply.

Many operators have experienced considerable teething problems with their RAS. Whilst recognising that technology has developed rapidly over the last few years, we are still on the steep part of the learning curve and issues remain to be ironed out. For the sector to really take off, the technology needs to move away from bespoke set-ups that require adaptation during operation, towards reliable ‘plug and play’ units. Development of such units is likely to be aided by further technology transfer from other sectors, such as the water treatment and ornamental fish sectors.
Research is taking place to improve efficiency and reduce energy costs[70].

It should be recognised that the conclusions of this review may have been skewed by the recent dominance in the UK of freshwater tilapia RAS; several of the consultees expressed dissatisfaction with the advice and experience of the individual advisor involved.

Currently, the projects that appear to be the most financially viable are either small scale “one-man” niche operations based on small investments (< £100K), or the large-scale ventures (>£1M). The recent large-scale systems have benefitted from significant system improvements provided by expert consultants.

Current political, social and environmental drivers would appear to favour development of this sector of aquaculture, as RAS offer environmental and social benefits. Environmental sustainability attributes are largely due to the high level of containment in RAS which eliminates effluent discharges, pathogen release, escapees, interactions with wild predators, and enables low veterinary

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[70] http://www.freshwaterinstitute.org/

medicine use. Resource use (water, land, feed, fish meal and fish oil) is also typically low. One remaining issue with RAS is energy use and the associated carbon footprint, but this can be addressed by improving efficiency and use of renewable energy sources. RAS farms meet consumer needs for a safe, consistent, traceable, quality product and local UK production might prove to be a selling point. Eco-labelling and accreditation schemes may develop to reflect these attributes of RAS products, and allay consumer concerns over the welfare of fish farmed in intensive systems.

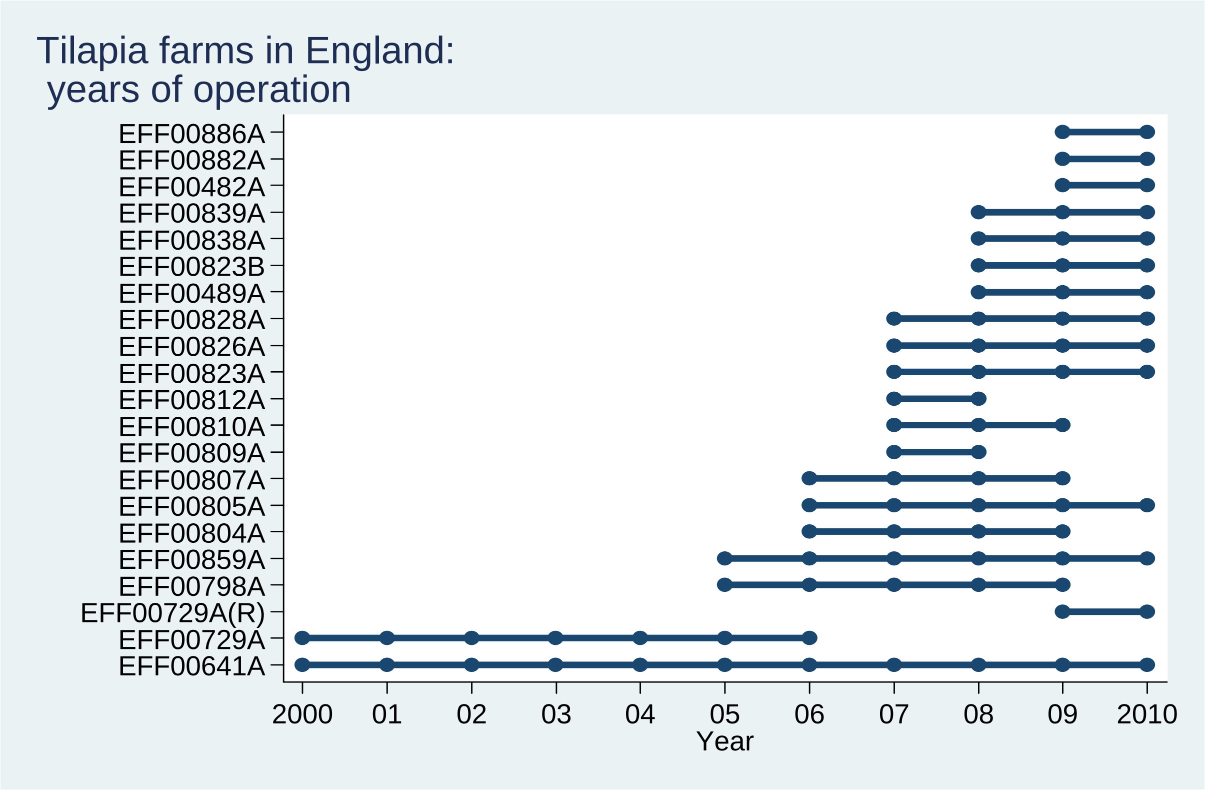
The sector can be foreseen as expanding, if technology improves, husbandry and marketing skills increase, and acceptance of RAS products by retailers and consumers develops. Anyone wishing to enter the RAS sector should proceed with caution and pay attention to minimising input and running costs, and ensuring markets. The RAS sector currently seems less profitable than sea-cage culture, and therefore more vulnerable to price changes (e.g. in energy, feed, sales). The best chance of financial success is probably offered by large scale developments (enabling economies of scale) which produce high value products. Such ventures will require significant investment funds, but given the demand, businesses with the right product, marketing and technology may have a long-term future.

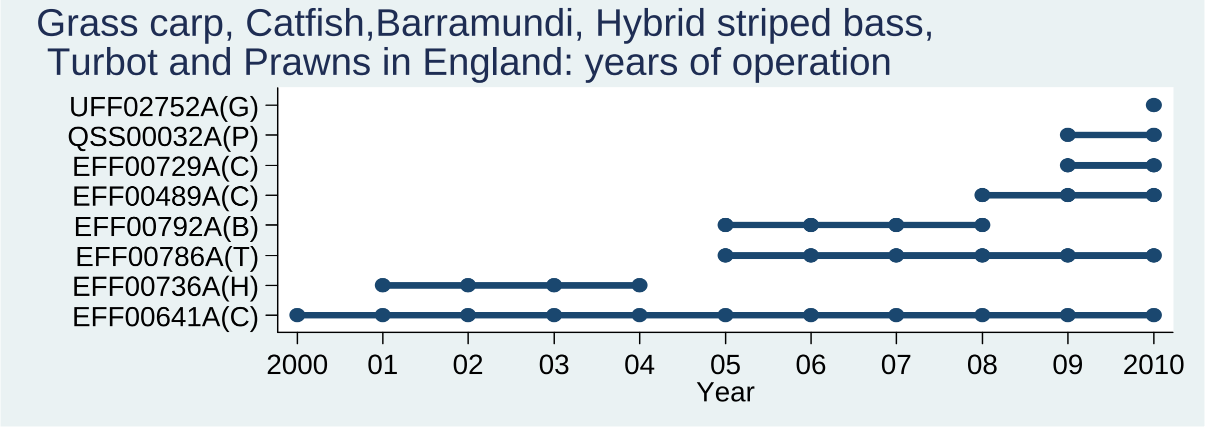
Grant funders (and investors) interested in the RAS sector should ensure that applicants have researched their suppliers and designers well, ensured energy and input costs (and carbon footprint) are minimised, paid particular attention to markets, and developed prudent long term business plans. Consideration should be given to whether a business plan requires an initial pilot study. Innovation and new technology development should be encouraged.

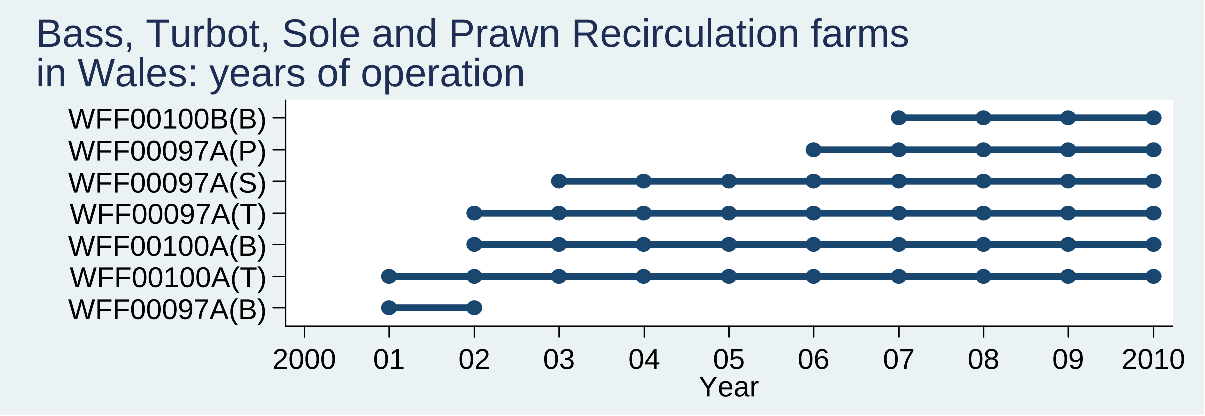
10.1 Acknowledgements

Thanks to all the interviewees who contributed their time and experience towards this project, and the Marine Management Organisation (MMO) for administering the funding (Defra Fisheries Challenge Fund).

11 Annex 1: Line graphs illustrating operating periods of individual farms


Tilapia farms in England: years of operation


Grass carp, Catfish,Barramundi, Hybrid striped bass, Turbot and Prawns in England: years of operation


Bass, Turbot, Sole and Prawn Recirculation farms in Wales: years of operation

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