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REVIEW

Impact of Climate Change on Aquaculture: The Need for Alternative Feed Components

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Abstract

The impact of Climate Change on all fisheries activities, both capture and aquaculture is expected to be extreme, including: higher water temperatures, increased water acidity and migration of species from established to new waters. For aquaculture there is the added problem of providing feeds under these new conditions. The supply of fishmeal and fish oils is already considered a barrier to the growth of aquaculture at a time when an expanding world population needs feeding and capture fisheries are at their maximum and may decline in the future. The current use of plant-based aquaculture feeds (PBAF) to replace fishmeal relies on a few major crops such as soya, maize and wheat which could be used for direct human consumption and all will be affected adversely by Climate Change.

There is a need to investigate alternative crops to those used now and this will include those which are currently classed as, “underutilised”. Such crops already have beneficial characteristics such as drought and temperature resistance, the ability to grow and yield on poor soils and good nutritional properties. For aquaculture feeds they need investigation for process ability, the presence of anti nutritional components, storage stability and application to the correct fish species in aquaculture.

This paper will discuss these aspects with examples of possible underutilised crops for aquaculture feeds and the need for experimental work on the impact of Climate Change on aquaculture practices.

Keywords: Climate Change, aquaculture, plant-based feeds, underutilised crops.

Introduction

The impact of Climate Change (CC) on all aspects of human activity has been at the forefront of political, social and intellectual debate for many years. The impact on agriculture and the ability of humanity to feed itself with the limited number of favoured crops (such as rice, wheat, maize, soybean)under the new climatic conditions, as temperatures and irrigation become problematical, has been of particular concern. The impact of CC on marine and freshwater capture fisheries has wide implications but in terms of the food fish capture fishery the main effect will be on fish populations and distribution (FAO, 2012). Aquaculture, being a controlled environment, may be better placed to adapt to CC but where open ponds or marine environments are used the effects of CC on water characteristics such as acidification (Ishimatsu *et al*., 2008) oxygen availability, temperature, salinity and sea level must be addressed (Bosma and Verdegem, 2011). Other impacts could be through changes in monsoon rain patterns (Cochrane *et al*., 2009) and the impact of disease under new climatic conditions (Stentiford *et al*., 2012). Responses to CC must of course always take into account the socio-economic importance of capture fisheries and aquaculture which provide livelihoods, income and food for very many people (Badjeck *et al*., 2010; Brander, 2010) and should support resilience to, and the opportunities provided by, CC (Williams and Rota, 2012). Sumaila and Cheung (2010) costed the impact of CC on capture fisheries and concluded that the lost revenue and cost of mitigation would run into billions of US dollars. A combination of CC and overfishing would compound loss of production and would only be countered by strong fisheries management on the high seas.

A further complication arises because the rapid increase in aquaculture production seen in recent years (Table 1) has come about through the use of feeds based on fishmeal (FM) and fish oil (FO) which are becoming scarceand expensive as capture fisheries are at their maximum and may even decline due to overfishing (FAO, 2012). This is reflected in Table 1 where the capture fishery is static around 90 million tonnes per annum as is the quantity of fish for NFU

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(which is principally for FMFO production) and produced by the capture fishery. Aquaculture by its controlled nature does not generate by-catch or trash fish for conversion to FMFO although the use of processing by-products for FMFO is possible from this sector. The increase in fish used for DHCseen in Table 1 is due to the increased production from aquaculture and has led to an overall *per capita* intake of fish from 17.4 to 18.8 kg between 2006 and 2011. These encouraging figures for fish production and human consumption will be at risk if reliance on FMFO is put at risk through overfishing or CC. The threat to aquaculture production through the limitation of FMFO supply became known as the, "Fishmeal Trap", (Wijkstrom and New, 1989; New and Wijkstrom, 1990) and the validity of the argument depends on several factors such the availability of suitable alternatives and the aquaculture systems in which they are used.

Although this paper concentrates on FM in aquafeeds the demand for fish oil in certain feeds (for salmon, marine fish and shrimp) is a parallel concern as the demand is expected to double to about 908,000 tonnes by 2020 due to increased production of the marine finfish and shrimp species (FAO, 2012). Fish oils are rich in the long-chain highly unsaturated fatty acids (HUFA) such as eicosapentaenoic acid (C20:5n-3) and docosahexaenoic acid (C22:6n-3) considered essential for human health. Replacements from PBAF must maintain the HUFA profiles to retain the quality/nutritional value of the final product. Candidates for fish oil replacement could be high omega-3 vegetable oils from conventional sources (Table 2) selected through breeding or genetic manipulation or through underutilised crops (UUC) with an appropriate HUFA content or precursors.

In 1960 FM use was almost equally split between chicken and pig feeds. By 2010, over 73% of FM was used in aquaculture, 20% for pigs and 5% for chickens. The massive increase in aquaculture FM usage was providing aquafeed for crustaceans (29% of total use), salmon and trout (24%) and marine fish (23%) and, notably, 12% for carps and tilapias. Attempts have been made to regulate FM fisheries to maintain production but they are still at the mercy of events such as, "El Nino", ocean variations which devastate seasonal catches in the principal fisheries of Peru and Chile (Merino *et al*., 2010). A reduction in the use of FM for certain aquaculture species has been promoted and continues to be applied although the limits of substitution may have been reached for some carnivorous species. Thus, for crustaceans the FM inclusion level is expected to drop from 27 to 8% by 2020; for salmon from 45 to 12% and for marine fish from 50 to 12% (Bendikson *et al*., 2011; Tacon, *et al*., 2011). Steps are also being taken to increase the amount of fish processing by-products (from capture and aquaculture) which are converted to FM – currently running at about 25% of all FM production (FAO, 2012; Olsen and Hasan, 2012). Health concerns dictate that feeds containing FM from aquaculture species must be fed across species boundaries to prevent the spreadof disease within species (intra-species recycling). Finally, the use of plant-based aqua feeds has been proposed over many years (Naylor *et al*., 2000; Gatlin *et al*., 2007; Naylor *et al*., 2009; Tacon *et al*., 2011) to replace FM in the diets of appropriate species – after all the specific loss of protein in FM must be made up from other sources.

The use of plant-based aqua feeds (PBAF) has nutritional and palatability limitations (Gatlin *et al*., 2007) although a range of plant processing by-

Table 1. World capture and aquaculture production (million tonnes), after FAO, 2012

	2006	2007	2008	2009	2010	2011
Capture	90.0	90.3	89.7	89.6	88.6	90.4
Aquaculture	47.3	49.9	52.9	55.7	59.9	63.6
Total	137.3	140.2	142.6	145.3	148.5	154.0
DHC*	114.3	117.3	119.7	123.6	128.3	130.8
NFU**	23.0	23.0	22.9	21.8	20.2	23.2
Per capita food fish supply(kg)	17.4	17.6	17.8	18.1	18.6	18.8

*DHC: Direct Human Consumption
** NFU: Non-Food Use

Table 2. Plant proteins used in aquaculture feeds, after FAO, 2012

Plant protein	Inclusion level in aqua feed (%)
Soybean meal	3-60
Wheat gluten meal	2-13
Maize gluten meal	2-40
Cottonseed meal	1-25
Lupin seed meal	5-30
Canola protein concentrate	10-15
Groundnut meal	*c*. 30
Mustard oil cake	*c*. 10

products have traditionally been used (Table 2). Initially, this was seen as a benefit as it used up materials which were generated as the primary agricultural products were fractionated to give higher added-value products for human consumption – note the terms, "meal", "cake", and, "concentrate" used. However, the demand for these traditional components for aquaculture and animal feeds has led to them being the principal use of these crops, representing a loss of direct nutrition for humans; a good example is soya which can be eaten in several forms by humans but is increasingly grown solely for animal feed. Furthermore as these PBAF are based on the same limited range of crops used for human consumption they are at the mercy of CC in exactly the same way – a double whammy. Thus it can be seen that CC presents challenges for the capture fisheries, aquaculture and agriculture individually and also when the relationship between the three production systems converge, asin the provision of aqua feeds. Merino *et al*. (2012) modelled the combined effect of CC, fisheries management and changes in aquafeed technology required to sustain the current/increased high per capita consumption of fish by a growing human population and concluded that improved capture fisheries management and reduced reliance on FM from the capture fishery were essential to accomplish this goal.

Climate Change and Agriculture

The current world agriculture system is based on the globalisation of the food supply chain which has led to a loss in diversity of the crops grown, traded and researched. Historically, this can be seen as a descent from the bio-diverse hunter-gatherer lifestyle through an agri-pastoral phase followed by agro-forestry and intercropping to the current monoculture of crops. At the same time there has been a loss of knowledge as the many (6000 plus) spoken languages of the world have been reduced to seven major languages of scientific discourse (Mandarin Chinese, Spanish English etc) spoken by over 50% of humanity. Much practical knowledge of many plants has been passed down by word of mouth and loss of language means loss of this knowledge. When the global research effort in food crops by CGIAR (Consultation Group on International Agricultural Research) is investigated it can be seen that major centres are spread across the world to study specifically: rice, maize, wheat, potato and also tropical crops such as cassava, yam, plantain, banana and certain beans. The vast number of alternative crops is largely ignored.

The overall impact of this process on the food industry is that:

- supply chains have become long, complex and interdependent
- a limited number of crop species dominate
- monoculture is increasingly practiced
- Knowledge systems are becoming limited; with one predominant language - English.

What could be the impact of CC on such a system of agriculture? A number of CC models have been developed which give a range of climatic temperature predictions and impacts on the yields for the important crops mentioned above and suggest a median crop yield reduction of 2% per decade. For example, in sub-Saharan Africa the impact of CC on crop yields was predicted to be from 0% to -30% for the period 2046-2065 compared with 1961-2000 for maize, sorghum, millet, groundnuts and cassava, with the latter being least affected (Schlenker and Lobell, 2010). Evidence from free-air carbon dioxide enrichment (FACE) experiments show that the increased carbon dioxide levels expected in the middle of this century will reduce the zinc and iron levels in C3 (high photosynthesis/low water efficiency) crops such as wheat, rice, field peas, soybean, maize and sorghum with concomitant health problems from humans which are already well documented (Myers *et al*., 2014).

This evidence suggests that any food supply chain reliant on the major food crops faces poorer yields and nutritional quality due to CC and this applies equally for animal/aqua feeds, and if so, priority should be given to DHC for these crops. Under these circumstances UUC which are grown in specific locations, little traded and poorly researched could present solutions to CC/agriculture problems and the FMFO limitation on aquaculture when proposed for PBAF. The potential for UUC to contribute to food security for humans through a number of roles has already been strongly argued (Mayes *et al*., 2011).

In choosing PBAF based on UUC some criteria may be set so as not to exacerbate the agriculture production balance, for example;

- No new land should be brought into cultivation for crops for PBAF – perhaps using UUC suitable for marginal land
- No competition with crops for DHC
- Recognise that there may be competition for UUC for terrestrial animal feeds or for biofuels (the latter may be temporary as second generation fuels are developed)
- Processability is important using simple processes and equipment, preferably farm-based, yielding multiple products with nutritional improvement.

Tacon*et al*, 2011) in an FAO Fisheries and Aquaculture Technical Paper gave recommendations along similar lines for aquafeed selection, as follows:

- Reduce dependence on imports for food security
- Select ingredients which can be supplied sustainably and with low environmental impact

- Reduce the environmental impact of the aquaculture system by high nutrient density and digestibility (also includes wider issues such as energy use in aquaculture)
- Support small-scale farming systems and farm-made aquafeeds (do not use raw trash fishas feeds) with better feed management systems and better quality ingredients
- Maintain quality and safety of aquafeeds for a more attractive and safer product.

All this effort to escape from the, “Fishmeal trap”, by the use of PBAF rests on an understanding of what system of aquaculture is being applied.

The Nature of Aquaculture

Aquaculture systems are not the same across the world with variations in technology levels, species cultivated and aquafeed formulations. In order to understand the role of FM and PBAF as substitutes it is necessary to clarify the defining elements of these systems. Table 3 lists the top ten aquaculture producers in 2010 and the immediate feature is that eight of the ten are Asian countries and that China is the major aquaculture producer by far. This implies that aquaculture practices in Asia (and China in particular) will determine whether a limitation in FMFO production is critical and suggests that changes in current practices there will make the situation better or worse. In terms of world population, Asia currently has 61% with Africa at 14% (but expected to double by 2050) whilst in other regions the population is expected to remain stable or fall. Thus aquaculture is a major and growing food provider for the majority populations of the world with a vital role to play in human nutrition provision. At the same time, Africa and Asia may be most affected by CC, including agriculture and aquaculture production, so once again the nature of their aquaculture systems will have a major impact on the FM/PBAF dynamic and CC resilience may need to be built in OR may already be a feature requiring further support and promotion elsewhere.

Table 4 describes the aquaculture environments available based on water salinity and divided into fresh, brackish and marine waters. Fresh water finfish aquaculture dominates production volume (62%) as it is the traditional system in China growing various carps (in polyculture) which require low inputs, especially no formulated feeds. This multitrophic system is being replaced by monoculture of valued species (e.g. tilapia and penaeid shrimps) dependant on formulated feeds (Ling *et al*., 2015) and even carp production is becoming reliant on feeds. Marine water aquaculture represents 30% production whilst brackish water yields 8% of production yet the value is 13% of total aquaculture production. This is because this sector cultivates commercially-valuable species such as white leg shrimp and giant tiger prawns compared with the more prosaic carps in freshwater culture. Lessons to learn from this analysis are that small changes in feeding practice (the introduction of small quantities of formulated feeds) on the China scale have a large impact. Economic factors are also important; is aquaculture a money-

Table 3. Top ten world aquaculture producers in 2010 (after FAO 2012)

Country	Tonnes (million)	Percentage (%)
China	36.73	61.4
India	4.65	7.8
Vietnam	2.67	4.5
Indonesia	2.30	3.9
Bangladesh	1.30	2.2
Thailand	1.29	2.1
Norway	1.01	1.7
Egypt	0.92	1.5
Myanmar	0.85	1.4
Philippines	0.75	1.2
Other	7.40	12.3
Total	59.87	100

Table 4. Production by culture environment (after FAO, 2012)

Parameter	Freshwater	Brackish water	Marine water
Production (million tonnes)	36.9	4.7	18.3
Production (%)	62	8	30
Value (%)	58	13	29
Dominant types	Finfish (92%)	Crustaceans (57%)	Molluscs (76%)
Important species	Carp spp, Pangasius (catfish)	White leg shrimp, giant tiger prawn, Milkfish, tilapia	Oysters, mussels, clams, salmon

generating economic activity or a simple food production exercise. These questions will determine the species cultivated and hence the demand for FM or substitutes. Pond management and feeding practices also determine the feed conversion ratio (FCR) of the fish and hence the efficiency of the system.

Fed versus Non-fed Aquaculture

About one-third of farmed food fish (20 million tonnes) is produced without the use of artificial feeding. This includes various molluscs which derive their food entirely from their environment and filter-feeding carps (silver carp and bighead carp) utilising plankton from deliberate fertilisation of ponds or the wastes from other fish species (in polyculture). This system is best exemplified by the traditional Asian system of rice growing combined with fish culture. Such an approach leads to food security being based on a low trophic level fish species and has been proposed as a model for integrated farming/ aquaculture in Latin America and Africa under suitable conditions (FAO, 2012) and with scope for some intensification to improve yields.

Feed-based aquaculture accounts for about 60% of global production (32 million tonnes) using farm-made or industrially-made aquafeeds and is increasing in practice as mentioned above for previously non-fed species (this leads to some confusion over the absolute volumes of fed and non-fed species produced which is compounded by poor statistics and reporting). The amount of farm-made feeds used is difficult to estimate although they are important in the culture of many fish with low commercial value - for example in India over 97% of carps are raised on farm-made feeds (FAO, 2012). The feeding of low-value raw fish (not converted to FM) is also poorly recorded but important in Asia.

Prepared feeds are usually fed to omnivores (tilapia, catfish, craps and milkfish) and to carnivores (salmon, trout and sea bass) and crustaceans (shrimps and prawns). As more omnivorous fish become, "fed species", the demand for FM increases and this is indeed the case in China as mentioned previously (Ling *et al*., 2015) with the potential to draw in large amounts of FM.

The Case for Underutilised Crops in Aquafeeds

As mentioned earlier the use of PBAF as substitutes for FM has been proposed for many years but limitations have been set by palatability and antinutritional factors associated with particular plant materials as drawn together in Table 5.Gatlin *et al*. (2007) proposed criteria for PBAF components such as: being practically available at a reasonable price, transportable and fitting into the feed production plant; having low fibre, starch (especially non-soluble polysaccharides)and antinutritional compounds; high protein content with a favourable amino acid composition and good palatability and digestibility by the target species. A range of measures to overcome limitations have been proposed including: genetic manipulation of the plants and the fish species to remove or deal with antinutritional compounds; the use of pre- and probiotic materials alongside the PBAF and the use of processing treatments to remove antinutritionals and improve palatability before incorporation in the feeds. Table 5 also demonstrates that certain essential amino acids (EAA) are commonly lacking in PBAF and must be added as supplements so that possible UUC with a good EAA profile may find use as providers of these EAA. It must be recognised that any of these approaches must not endanger the quality of the fish as food and nutrition for humans.

Some of the criteria which might be applied to the use of UUC in aquafeeds have been laid out already, especially the need to not take new land into cultivation, not to compete with crops for DHC and to employ agricultural and aquaculture practices which give feed security. Aquafeed production at the farm level has also been promoted using raw material

Table 5. Antinutritional compounds and effects in Plant-based aqua feeds, after Gatlin *et al.* (2007)

Plant	*NSP	**Oligo's	Anti-Metabolites	Antigens	Protease inhibitors	Lectins	Oestrogens	Phytic acid	***EAA (lacking)	Saponins
Soya	¬ 20%	Raffinose Stachyose	e.g. lipoxygenases	e.g. to proteins	X	X	X	X	Lysine, Threonine, Methionine	X
Barley									Lysine Arginine	
Canola			Glucosinolates Erucic acid					X		
Maize			Pigments (xanthophylls)						Lysine	
Cottonseed			gossypol							
Peas/lupins		Stachyose Alpha-Galactosides	Alkaloids (heat stable)						Lysine, Methionine	
Wheat									Lysine	

*NSP: Non-starch polysaccharides; **Oligo's: Oligosaccharides; ***EAA: essential amino acids for fish produced close to the demand and developing commercial activity around aquaculture.

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