Economic, regulatory and legal review of feed management practices

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ABSTRACT

An analysis of the legal and regulatory frameworks that have been developed to optimize feed management practices and reduce the negative environmental impacts that add to poor feed management is presented. To date, such frameworks include: (a) establishing minimum feed performance criteria (e.g. feed conversion ratio (FCR), nutrient digestibility); (b) placing restrictions on nutrient composition in formulations (e.g. nitrogen and phosphorus levels); (c) restricting feed use; (d) restricting environmentally unsustainable feeding practices; and (e) promoting better management practices (BMP) and codes of conduct to improve feed management. In many production systems, feed management affects the quality of farm effluent streams; thus regulatory frameworks focusing on the monitoring and control of effluent streams may also indirectly impact on feed management practices. Such regulations include: (a) treatment regulations to treat effluent streams prior to discharge; (b) limiting the quality and or quantity of effluent that can be discharged; (c) limiting farming activities in an area based on effluent carrying capacities/dispersion; and (d) promoting BMP and monitoring protocols to manage effluent streams. The efficacy of introducing these legal and regulatory frameworks to improve feed management practices is discussed.

A financial analysis of feed management practices was undertaken for an intensive land-based recirculating marine finfish farm culturing the Japanese meagre (*Argyrosomus japonicus*), and a comparison was made between the economic efficiency of using semi-intensive and intensive pond culture techniques for Nile tilapia (*Oreochromis niloticus*) culture. A bio-economic model was developed to describe the financial efficiency of the meagre farming operation under variable production scenarios. The model was used to interrogate the effect that feed management practices have on the economic viability of the production system. In addition, a sensitivity analysis was undertaken to establish the effect that feed type, cost, feed conversion and growth have on the economic viability of the farming operation. With respect to tilapia farming, a rate of return ratio analysis under variable feed conversion scenarios suggests that benefit-cost ratios in semi-intensive farming systems are lower than those observed in the intensive farming systems; this indicates that the intensive farming practices are more economically efficient. Thus, while input costs are higher, returns are greater, and to optimize economic outputs farmers should be encouraged to intensify their farming practices.

1. INTRODUCTION

In recent years, the global growth of the aquaculture industry has resulted in an ever increasing concern about the environmental impacts accruing to the development of the sector. While these impacts have been extensively reviewed (Barg, 1992), the efficient use of aquafeeds is often viewed as one of the major challenges to the development of sustainable production systems. Effluent streams arising from aquafeeds comprise a solid particulate fraction including uneaten and undigested feed and faeces, and a dissolved fraction comprising metabolic by-products, principally ammonia, urea and phosphate (Bergheim and Brinker, 2003). The quality and quantity of the effluent will vary in response to a number of factors, including the culture species, the production system, and the physical and nutritional characteristics of the feed, and, in this regard, much work has been undertaken to determine both the quantitative and qualitative impacts of feed-derived effluent streams in aquaculture (Azevedo *et al.*, 1998; Lemarié *et al.*, 1998).

In 2008, global compound aquafeed production was estimated at 29.2 million tonnes (Tacon, Hasan and Metian, 2011). As the sector grows, this figure is projected to rise to 71.1 million tonnes by 2020 (Tacon, Hasan and Metian, 2011). The projected expansion of the aquaculture sector and the concomitant increase in the use of compound aquafeeds suggests that all aspects of aquafeed production and feed management will become increasingly important in the future, in terms of limiting the overall environmental impact of the sector.

Traditionally, government agencies provide the legal, policy and regulatory frameworks under which aquaculture and aquafeed use is controlled. In recent years, the emergence of certification bodies, such as the World Wildlife Fund (WWF) aquaculture dialogues, the Aquaculture Certification Council and the Global Aquaculture Alliance (GAA), has seen a new approach to environmental governance. In many respects these ‹non-state, market driven› systems (Vandergeest, 2007) now compete with traditional governmental regulators, in what some authors have termed ‹the privatization of governance’ (Gereffi, Garcia-Johnson and Sasser, 2001). While governments retain the legal mandate to regulate the industry, increasingly, these certification bodies are setting the environmental agenda in terms of influencing the behaviour of farmers and placing limitations on the environmental impacts of their activities.

Notwithstanding the role of the various regulatory bodies, this paper focuses on two themes relating to the use of on-farm feeds and feed management systems. The first theme addresses governance, and outlines the regulatory and legal instruments that are available to control aquafeed use and minimize their impact on the environment; the second theme addresses the economic efficiency of selected farm feed management practices, and provides an economic assessment of the impact that feed management practices have on the economic efficiency of farming operations.

2. A REGULATORY AND LEGAL REVIEW OF FARM FEED MANAGEMENT PRACTICES

The development of legal, policy and regulatory instruments that can be used to control aquafeed use and the environmental impacts that add to their use can be broadly divided into two categories. The first category, best described as the ‘direct approach (or practice-based governance)’, comprises instruments that focus on aquafeeds *per se* and regulate farmers in terms of the feeds and the associated feed management practices that they can apply in their farms. Examples in this category include the establishment of feed performance criteria, the regulation of feed management practices and feed formulations, and the restriction of feed use through the introduction of feed quotas. The second category, best described as the 'indirect approach (or result-based governance)' addresses feed management through the regulation and control of the impacts that add to the farming activities; while these instruments do not regulate aquafeed use *per se*, when viewed holistically their introduction encourages farmers to optimize feed use and minimize the environmental impact of their use. Examples in this category include the establishment of regulations to treat effluent streams, temporal and spatial discharge limitations, and the establishment of discharge limitations according to the carrying capacity of a waterbody. It should be noted that while the 'direct approach' targets feed use *per se*, and the 'indirect approach' targets the outcomes of feed use, they are both based in the application of regulatory frameworks, system performance criteria and the introduction of better management practices (BMP). In the following sub-sections, we provide a brief summary of the pros and cons of each approach.

2.1 The Direct Approach

2.1.1 Feed performance criteria

Proscribing minimum feed performance criteria and thereby ensuring the quality of aquafeeds that are used can provide an effective way to mitigate some of the environmental impacts of their use. Feed performance criteria that can be applied typically include limitations to feed conversion ratios (FCR), nutrient digestibility and retention, and the physical characteristics of the feed, such as the percentage of fines in the feed. In a review of aquaculture legislation across the European Union (EU), Tacon and Forster (2003) noted that Denmark was the only country that used feed performance criteria as a component of their aquaculture regulatory systems. Indeed, Danish farmers must demonstrate that their FCR do not exceed 1.2:1 – 1.5:1 (depending on the culture system), that the aquafeed feed has a minimum digestibility of 70 percent and that the fines in the feed are less than 1 percent of the total feed (Pedersen, 2000).

The use of performance criteria such as FCR, fish-in fish-out ratios (FIFO), or forage fish equivalence ratios (FFER), forage fish dependency ratios (FFDR) and fish protein indices (FPI) as indicators of on-farm feed efficiency is becoming increasingly popular with some of the certification bodies. In its certification criteria for tilapia, catfish, shrimp, and 'Pangasius catfish' (www.gaalliance.org/bap/standards.php), the GAA recognizes the use of FCR and FIFO as a monitoring tool. However, as opposed to proscribing absolute levels for these indicators, the GAA proposes using them as guides to monitor feed efficiency. In contrast, the WWF certification programmes (www.worldwildlife.org/what/globalmarkets/aquaculture/aquaculturedialogues.html) propose applying absolute levels to these types of performance ratios in their certification criteria. While FCR provides the most simplistic indication of the feed efficiency, FFER/FFDR provide more complex indicators that give information pertaining to the use of dietary fishmeal and fish oil during the culture process, and thus a means of monitoring and ultimately limiting the level of fishmeal and fish oil used in aquafeeds. The monitoring and assessment criteria that the WWF applies are species-specific. For example, the draft salmon dialogues (WWF, 2010a) propose FFDR values for fishmeal and fish oil of <1.31 and <2.85, respectively. The salmon dialogues focus on FFDR values, as the industry has historically been reliant on forage fish as the primary dietary protein source. Thus inclusion of this criterion is an attempt to reduce the levels of forage fish in dietary formulations and, in doing so, reduce fishing pressure on the associated capture fisheries. In contrast, the *Pangasius* standards (WWF, 2010b) prefer to use economic food conversion ratio (eFCR) and FFER to monitor feed efficiency (eFCR <1.75:1 per production cycle; FFER must not exceed 0.5). The adoption of FFER in the *Pangasius* dialogues recognizes the need of the sector need to reduce its reliance and impact on forage fish fisheries. In this regard, the use of forage fish or trash fish as a sole feed source is also prohibited by the dialogues. Finally, the draft trout standards (WWF, 2010c) prefer to use both eFCR (eFCR <1:1 up to 500 g; <1.2:1 between 500 g and 4 kg) and protein digestibility (≥85 percent), and further specify that dietary nitrogen and phosphorus retention should be a minimum of 40 and 45 percent, respectively. The WWF (2010a) also advocates the use of fines in the feed as a measure to reduce feed losses to the environment. In this regard, the proposed salmon standards require that less than 1 percent of the feed comprises fines.

The use of feed performance criteria represents a useful regulatory tool in those instances in which commercially produced dry compound aquafeeds are being used to provide the complete nutritional requirements of the fish. Under such circumstances, it is relatively easy to calculate feed performance criteria with accuracy. However, their use becomes problematical when moist farm-made aquafeeds are used, as it becomes difficult to determine feed composition and ingestion rates accurately. The use of these criteria is problematic in semi-extensive and extensive culture systems where the fish derive feed from both compound aquafeeds and the natural productivity of the systems. In such cases, it is difficult to assess accurately the relative nutritional impact of the compound aquafeeds and the feed derived from the natural productivity in the system. Nevertheless, poor feed performance criteria in these systems can be used as an indication that the farming practices are suboptimal. The application of feed performance criteria is therefore both species and systems dependent.

2.1.2 Feed practices – regulating feed type

Regulating the types of feed that can be used and encouraging farmers to adopt sustainable feed management practices can improve feed efficiency and the overall environmental sustainability of the farming operations. For example, in tank-based production systems, Warrer-Hansen (1982a,b) reported values of food wastage as 1–5 percent, 5–10 percent and 10–30 percent, respectively, for dry diets, moist diets and wet diets, a situation that is likely to be compounded in cage culture systems (Islam, 2005). The use of wet diets and, most notably, trash fish is particularly problematic and can lead to environmental problems such as nutrient enrichment (Gao *et al.,* 2005) and disease transfer (Kim *et al.,* 2007). For reasons related to nutrient loading and energy loss, the practice of feeding trash fish has been banned in some countries, such as Denmark (Pedersen, 2000), but remains permitted in others such as China, Indonesia Thailand, Viet Nam (Hasan and Halwart, 2009; Hasan, 2012). The WWF (2010b) *Pangasius* certification standards ban the direct use of fish and fish products (trash fish) on the grounds of poor environmental sustainability and negative impacts to fish biodiversity. Nevertheless, there are likely to be some artisanal activities – such as the nascent crab fattening industry in Tanzania and Kenya– where the quantities of trash fish required are minimal, and thus the potential negative impact of their use should also be minimal. Furthermore, there are also countries (e.g. Viet Nam and Japan) where many finfish mariculture operations are almost totally dependent on trash fish as feed for the cultured carnivorous fish (De Silva and Hasan, 2007; De Silva and Turchini, 2009). In such cases, a simple ban would be difficult to impose and negatively affect production; it would therefore be expedient to investigate alternatives to the use of wet feeds and trash-fish feeds, and encourage farmers to start to use moist and dry feeds.

2.1.3 Feed formulations

Regulating feed formulations or setting levels of specific nutrient inclusion rates in them provides a mechanism that could potentially be used to maximize nutrient uptake and limit effluent streams. This approach to regulating feed is seldom applied; for example, Tacon and Forster (2003) established that only Denmark amongst the EU countries reviewed had implemented regulations to limit nutrient inclusion rates in aquafeeds. Under the Danish regulations for polluting industries (Ministry of the Environment, 1990), the energy content of compound feeds may not exceed 5.6 Mcal/kg and the dry matter inclusion rates of nitrogen and phosphorus must not exceed 8 percent and 0.9 percent, respectively (Pedersen, 2000). There are two major drawbacks to this approach to feed management. Firstly, the nutritional requirements vary according to a number of factors that include species, animal size, health and nutritional status, culture conditions and environmental parameters. Variations in these parameters mean that the nutritional requirements are not static across all production systems. Setting a rigid set of nutritional parameters to which feeds must comply will almost inevitably result in inefficiencies in feed utilization, as feed manufacturers may not be able to optimize feed formulations in terms of nutrient utilization and growth. A second factor that needs to be considered is that formulation technologies are changing rapidly, and it is difficult for regulators to respond readily to these changes. For example, the addition of microbial phytase in aquafeeds to increase the digestibility of phytate-bound phosphorus in plant protein sources has the potential to increase the bioavailability of these phosphorus sources and reduce the phosphorus levels in effluent streams (Cao *et al.,* 2007). These types of technical advances have the potential to make nutrient inclusion regulations redundant, as the technical rationale for setting specific inclusion rates for a specific nutrient will inevitably change.

2.1.4 Time-based feed use restrictions/quotas

Historically, applying feed quotas and regulating the amount of feeds a farm can use over a given period of time has proved an effective tool with which to control production and emissions. Feed quotas are usually calculated by multiplying a prescribed FCR value to produce an annual feed quota that is commensurate with the production volume allocated to a farm. The FCR applied may vary according to the production system employed and the anticipated FCR that can be achieved. For example, in Denmark, feed quotas that are allocated to cage culture sites apply an FCR of 1.5:1, while their land-based counterparts have to apply an FCR of 1.2:1 (Pedersen, 2000).

Both Norway and Denmark have applied feed quota legislation, and in this regard, it is instructive to review the impact that this legislation has had on sectoral growth. In 1996, the Norwegian Government introduced feed quotas in a response to accusations by the EU of dumping under-priced Norwegian salmon into the EU markets. In addition, a salmon trade agreement increasing export tariffs to the EU was introduced. At the time, feed quotas were viewed as a mechanism with which to limit production and regulate the market (Aarset and Jakobsen, 2009). Apparently, the quota system was effective in limiting production; prior to the introduction of the quota system (1992 to 1997), production in the industry increased nearly threefold. On adoption of the quota system in 1996, the growth of the sector between 1999 and 2002 was restricted to a mere 13 percent. While other factors, such as the increased export tariffs to the EU, may have played a role in reducing sectoral growth, the feed quota system is likely to have also played an important role in restricting growth (Aarset *et al.,* 2005; Aarset and Jakobsen, 2009). In 2004, the quota system was removed, and although the sector remains tightly regulated in terms of emissions, feed use *per se* is no longer restricted.

A principal concern with the use of quotas is that while they successfully limit emissions and the negative environmental impacts that may accumulate to feed use, they also restrict the ability of the farmer to increase production, and hence negatively impact sectoral growth. As production is limited by feed availability, the quotas will incentivize farmers to maximize feed use; while increasing feed efficiencies will probably result in reduced emissions, quotas will fail to incentivize farmers in terms of investing in emission reduction technologies that reduce the environmental impact of their activities. This being the case, placing quotas on the amount of feed that can be used primarily becomes a vehicle with which to constrain production, and their use would probably have a minimal effect on promoting environmental sustainability.

Arguably, a more effective way to regulate the industry would be to remove the feed quotas and instead focus on regulating emissions. Under this scenario, farmers would be motivated to increase both production and investment into emission reduction technologies; this would enable them to increase production while remaining within their emissions targets. In this regard, the current regulatory frameworks that are used in Denmark are viewed as limiting the development of the sector (Jorgensen, Hojgaard and Jepsen, 2005), and thus Denmark is currently in the process of reviewing the regulatory systems and changing the focus from feed quotas to emissions targeting.

2.2 The Indirect Approach

2.2.1 Regulations to treat effluent streams

Regulations to treat effluent streams prior to discharge can be used to control the potential negative impacts associated with aquafeed use. Typically, such regulations would make it mandatory to install wastewater filtration systems based on mechanical filtration (e.g. settlement ponds, drum filters) and biofiltration technologies. Generally, regulations to treat effluent streams are either enforced at the sector level, encompassing all producers, or on a discretionary basis relating to individual farms and depending upon a specific need to protect a given waterbody.

With respect to imposing effluent stream regulations at the sector level, an example is evident in Germany, where all farms that use pond-based culture systems are required to pass their pond cleaning effluent water through a sedimentation system prior to discharge (Bergheim and Brinker, 2003). In Greece, regulators recommend wastewater treatment options for land-based farms (Papoutsoglou, 2000), and some of the prawn-producing countries, such as Australia (Donovan, 1997) and Thailand (Tabthipwon, 2008), have developed BMP/codes of practice and legislation that require effluents containing suspended solids over a certain concentration to be passed through settlement ponds prior to discharge.

An example of the controlling of effluents at the farm level is the United Kingdom, where fish farms are required to apply for a discharge licence. The quality of the discharge water is subject to an environmental quality standard (EQS[1]) and, for a given waterbody, an environmental quality objective (EQO) is set. The licence conditions reflect these standards and objectives in terms of designating water quality parameters such as levels of biological oxygen demand (BOD), dissolved oxygen (DO) and ammonia in the effluent stream. In terms of conforming to the licence conditions, regulators may specify the use of water treatment systems to ensure that the water quality parameters are met (Bergheim and Brinker, 2003). It should be noted that specifying water treatment systems is only one of the regulatory options that are available to the regulators; thus not all farms will be required to install treatment systems.

Regulations to treat effluent stream have limitations in that they are only suitable for land-based operations such as tank, raceway and pond culture systems, where effluent streams are easily defined, monitored and regulated. They are not suited to open-water culture systems such as cage culture operations, where waste products are immediately released and assimilated into the wider environment.

2.2.2 Limiting the concentration of nutrients in discharge waters

Limiting the concentration of nutrients in discharge waters is a common mechanism with which to regulate the impacts of farming activities and, indirectly, aquafeed use. Depending on the regulatory framework in place, limitations normally focus on total nitrogen and phosphorus emissions, the levels of suspended solids, regulating the BOD of the effluent and ensuring minimum DO and ammonia concentrations. Among

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[1] Regulated by the Department of Environment, Food and Rural Affairs (www.defra.gov.uk) and the Scottish Environment Protection Agency (www.sepa.org.uk).

others, these types of regulations are used widely across Europe (EC, 1995; OSPAR, 2000), in Canada (Anon. 1994), some states in the United States of America, Australia (Anon, 2000) and Thailand (Tabthipwon, 2008). In addition to government regulations, certification agencies such as the WWF use effluent streams as indicators with which to measure the environmental sustainability of farming operations (WWF, 2010c).

While limiting the concentration of nutrients in effluent streams will encourage farmers to improve their utilization of aquafeeds and invest in wastewater treatment systems, it also requires structured monitoring protocols and programmes, and regulatory authorities to provide compliance services. The costs associated with setting up the water quality monitoring programmes usually accrue to the farmers. For small-scale producers that have limited resources – both financially and technically – the implementation of these types of monitoring programme are likely to prove problematical. Furthermore, such systems require government agencies to develop and invest in compliance mechanisms. While many governments in the developed world could in all likelihood afford to undertake these types of interventions, other countries with limited financial and technical resources may find them difficult to implement.

2.2.3 Limiting effluent discharges per production volume or over time

In many respects, limiting effluent discharges over time or per production volume represents a similar regulatory mechanism to placing limitations on the concentration of nutrients in discharge waters. The principle difference is that the former has a temporal/production component, in that farmers are provided with discharge limits that they are not allowed to exceed in a given period of time or production volume, and the latter provides discharge limits that must be adhered to at all times. All these regulatory mechanisms require some form of verification through compliance monitoring. However, those regulations that are define limits to discharges based on production volumes, or production volumes over time, can be assessed using simple mass balance equations and a minimal physical monitoring of effluents or production system efficiencies. For example, the WWF trout aquaculture dialogues (WWF, 2010c) propose limiting the amount of total nitrogen and phosphorus discharged per tonne of production. The amount of nitrogen and phosphorus produced per tonne of trout is based on the amount of nitrogen and phosphorus content of the feed that is used, how much is removed by the filtration systems of the farms, and the production and retention rates. In terms of monitoring discharges, the only monitoring that is required is to estimate the efficacy of any filtration and disposal systems that are used. All other components of the monitoring process can be accessed from the farm records and the feed suppliers. Thus, in terms of compliance, regulating effluent discharges over time or production volume may prove easier and more cost effective for famers to implement than systems based on the continuous monitoring of effluent streams.

In addition, limiting discharges per production volume is also a useful tool to regulate discharges in open-water production systems such a cage farms, where effluents are discharged directly into the environment. Monitoring effluent discharges in these types of system is technically difficult; thus applying a discharge limit per tonne of production that can be calculated using mass balance techniques provides a simple and verifiable method to control discharges. In this regard, the United Kingdom has adopted a coastal nitrogen waste limit for fish culture of 123 kg of nitrogen per tonne of fish produced (Islam, 2005).

Concomitant with other regulatory measures, limiting effluent discharges per production volume or over time is often used by regulators as one of a number of regulatory options that are available. Among others, these regulations have been adopted by Norway (Bergheim and Brinker, 2003), Denmark (Pedersen, 2000), Finland (Varjopuro *et al.*, 2000) and the United Kingdom (Islam, 2005).

2.2.4 Spatial limitations: licences based on the carrying capacity of a waterbody

The 'assimilative capacity' of a waterbody is defined as the ability of an area to maintain a 'healthy environment' and 'accommodate' wastes (GESAMP, 1986). Licensing aquaculture operations based on the 'assimilative' or 'carrying' capacity of a given waterbody provides regulators with a mechanism with which to set discharge consents, limit the number of farms/production volume in a given area, and motivate farmers to effectively manage their feed use and management practices. A considerable amount of research has been carried out to model the assimilative capacities of coastal (Islam, 2005; Geĉek and Legović, 2010) and inland waterbodies (Dillon and Rigler, 1974a,b; Vollenweider, 1975; Hakanson, Carlsson and Johansson, 1998; OECD, 1982; Beveridge, 1984; Hamblin and Gale, 2002; Johansson and Nordvarg, 2002).

The modelling-based approach was first articulated by Beveridge (1984) and is based on mass balances, nutrient loadings and nutrient-algal models. It is generally recognized that due to the slow water exchange rates in freshwater systems, lakes and reservoirs are usually more sensitive to point source emissions than marine locations (Persson, Håkanson and Pilesjö, 1994). In freshwater systems, this modelling approach is deemed to work well by some authors (Davies, 2000), and less well by others (Yan, 2005). It is important to note that these models only account for water quality dynamics in the water column, depending on nutrient-chlorophyll relationships to predict algal biomass in the water column, and that they do not model biological transfer of nutrients, sediment dynamics or sediment-water interactions (Kelly, 1995; Hakanson, Carlsson and Johansson, 1998). Yan (2005) reviewed the status of these models and concluded that there are important scientific uncertainties about the applicability of conventional mass balance models to cage fish culture. In some lakes, the classical models appear to work but in other cases they have significantly overestimated the impacts of cage operations on lake water total phosphorus levels and concomitant algal levels.

In marine environments, models capable of reflecting nutrient dynamics, primary and secondary production, organic matter decomposition and oxygen dynamics are used in conjunction with hydrodynamic models that predict water flow. Variations in the hydrodynamics of an area (e.g. bathymetry and morphological characteristics) suggest that while these types of model are site specific, the combination of hydrodynamic and nutrient flow models provides an efficient tool to determine the carrying capacity of an area (Geĉek and Legović, 2010).

These types of assessments are increasingly being applied to set carrying capacities. For example, the WWF trout aquaculture dialogue (WWF, 2010c) requires cage farmers to adhere to production levels that are based on the respective carrying capacity of a waterbody.

With respect to the future of these types of intervention, it is probable that as the models are developed further and become more accurate, they will become increasingly important in regulating aquaculture developments. However, the current models, and particularly those that are applied to coastal environments, require significant amounts of data that can be time consuming, technically difficult and costly to collect and collate. Furthermore, there can be significant variations in the carrying capacities as calculated by the various models that are currently available. Thus for the analysis to provide meaningful results, the choice and application of a given model has to be carefully considered, and must be made on the quality of the available data.

2.2.5 Codes of conduct and better management practices

Codes of conduct and best or better management practices (BMP) are increasingly being developed to complement legal and regulatory frameworks. Such codes are self-regulatory, and typically provide guidance on specific operational procedures that are designed to ensure that the industry remains environmentally responsible and accountable. These codes can be applied at international, regional or national industry association and farmer levels. At the international level, Article 9 of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) provides the overarching principles required to develop a sustainable industry. Likewise, at a regional level in Europe, the Federation of European Aquaculture Producers (FEAP) has developed voluntary codes of practice that broadly address feed management issues within the EU (Hough, 2001). At the national and farmer association levels, many countries and industry bodies have developed specific codes of conduct and BMP that, among other issues, specifically target feed management. Examples include South Africa (multispecies: Hinrichsen, 2007), Australia (prawns: Donovan, 1997; DPIF, 2006), and Hawaii (multispecies: Howerton, 2001). In addition, specific BMP focusing on feed management (Davis, 2001) and feed manufacturing (FAO, 2001) issues have been developed.

While the majority of BMP represent voluntary codes, in some cases there may be legal requirements for their implementation. For example, in the United States of America, the effluent limitation guidelines for concentrated aquatic animal production systems (CAAP) that are used by state permitting authorities to regulate the sector are based on management practices and record keeping as opposed to numerical discharge limits – although discharge limits may also be applied (EPA, 2006). In terms of developing BMP, facility operators are legally required to design BMP to include practices such as feed management, feed monitoring, solids control and material storage.

3. ECONOMIC ASSESSMENT OF FEED MANAGEMENT PRACTICES

As feed represents one of the highest operating costs in aquaculture systems (Davis, 1990), feed choice and feed management practices are likely to have a significant impact on economic performance. To establish the scale of these impacts, a bio-economic model of an intensive recirculating fish farm culturing the Japanese meagre (or dusky kob) (*Argylosomus japonicus*) was used to assess the impact that these parameters have on the economic viability of the farming operation. The bio-economic model was based on a mass balance analysis, the biological performance indices (e.g. growth, mortality, FCR), environmental tolerances and the optimal conditions for growth of the species. This information was integrated with the infrastructure requirements (e.g. tanks, biofiltration units) and infrastructure costs. The model had 57 variables, including financial modifiers, biotic production variables and abiotic production variables, which could be changed to predict the effects on the income and expenditure, cash flow schedules, internal rate of return, return on equity, and break even production. For the purpose of the analysis, a 600 tonne per year facility producing 750 g fish at a stocking density of 45 kg/m^3 was modelled. Average growth rates over the production cycle were projected at 2.8 g/day, survival was projected at 85 percent, and a base FCR of 1:1 using a feed containing 42 percent protein was applied. With respect to water quality and the level of biofiltration that was required to operate the system, biofilter efficiency was estimated at 65 percent, and nitrate levels in the system were set so as not to exceed 40 mg/l. A water replacement rate of 10 percent of system volume per day was applied.

For the purpose of the analysis, four production scenarios were considered:

1. A base scenario in which FCR increases from 1:1 to 1.6:1 – this scenario was used to provide an indication of the effect that a general deterioration in on-farm feed management has on economic viability of the operation.
2. Optimal production parameters – this scenario was used to demonstrate the effect that operating the system under suboptimal culture conditions, in this case temperature, had on feed use and the economic viability of the operation.
3. Feed formulation – this scenario was used to demonstrate the effect that feed formulation in terms of protein and energy levels has on feed use and the economic viability of the operation.

4. Feed management – this scenario was used to demonstrate the effect that feeding frequency and feeding intensity had on the economic viability of the operation.

Finally, a fifth production scenario comparing the effect of feed management on the economic efficiency of an intensive tilapia culture system using either pressed or extruded feeds, and a semi-intensive system based on the use of fertilizers and pressed feeds was undertaken. This scenario is based on different production and economic models to those used in scenarios 1 to 4.

3.1 Scenario 1 – base scenario

A deterioration in on-farm feed management resulting in poor feed utilization will manifest itself as a deterioration (increase) in FCR. The impact of an increase in FCR on the economics of the operation is presented in Table 1. Assuming that an annual production volume of 600 tonnes is maintained, an increase in FCR from 1:1 to 1.6:1 results in an increase in feed use from 600 tonnes per year to 960 tonnes per year. At a feed cost of US$1.35/kg, this equates to an increase in feed costs of US$490 446, increasing feed costs as a percentage of total production costs from 36.2 percent to 46.1 percent. In addition to the increase in feed costs, the decrease in feed efficiency will result in increased waste products – principally ammonia-N and uneaten feed and faeces – that will need to be removed from the system. The bio-economic model characterizes these waste products as ammonia-N, and assuming that water turnover rates remain constant, the removal of this excess ammonia-N will require the installation of additional biofiltration capacity. An increase in FCR from 1:1 to 1.6:1 requires a 53 percent increase in biofiltration capacity, raising the farm capital expenditure costs (CAPEX) by 4 percent. In addition to the increased CAPEX costs, a 23.9 percent increase in the annual operational costs is required to service the increased feed requirement and operate the additional biofiltration systems. The increase in CAPEX and operational costs associated with an increase in FCR to 1.6:1 results in an increase in the total investment requirement to develop the farm of 15.7 percent. In terms of the economic indicators, the increase in FCR results in a decrease in the net operating cash flow over ten years of 35.5 percent, and a reduction in the internal rates of return (IIR) from 35.3 percent to 15.2 percent. Assuming that investors require IIRs of approximately 30 percent, the model suggests that a deterioration in feed efficiency resulting in an FCR of above 1.3:1 (the IIR at an FCR of 1.3:1 is calculated at 25.5 percent) would make it difficult to access finance for this type of farm.

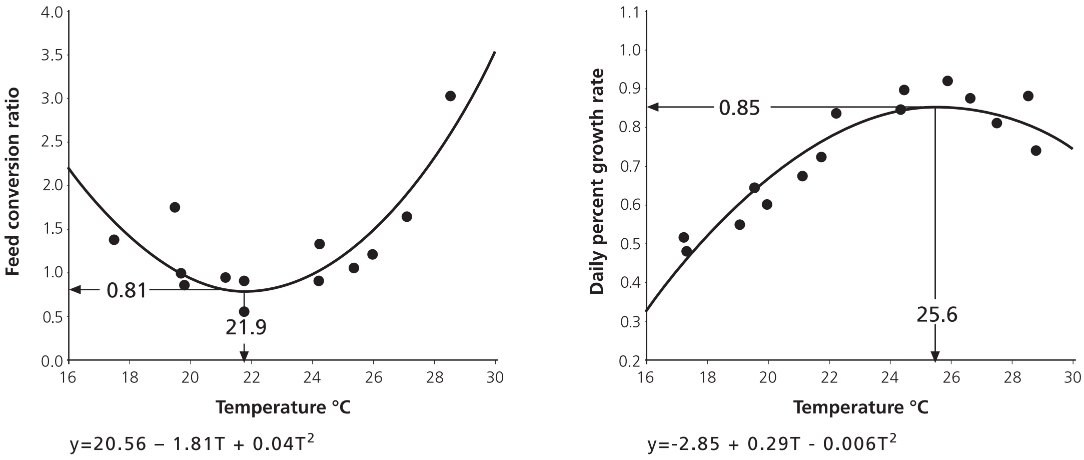
TABLE 1
The effect of variable feed conversion ratio (FCR) on the economic performance of a 600 tonne per year recirculating Japanese meagre farm

Indicator	FCR						
	1:1	1.1:1	1.2:1	1.3:1	1.4:1	1.5:1	1.6:1
Feed (tonnes per year)	600	660	720	780	840	900	960
Cost (US$)	817 410	899 151	980 892	1062 633	1 144 374	1 226 115	1 307 856
Cost increase (US$)	–	81 741	163 482	245 223	326 964	408 705	490 446
Cost of feed (% of production)	36.2	38.1	39.8	41.8	43.2	44.5	46.1
Infrastructure requirements							
Biofilters	19	20	22	24	26	27	29
Blowers	8	9	10	10	11	12	12
Operating requirements							
Electrical requirements (kW/hour)	400	435	470	490	512	547	547
Water requirement	72	79	86	93	100	107	114
Financial indicators							
CAPEX (US$)	1 476 949	1 487 305	1 498 618	1 500 811	1 524 111	1 534 480	1 536 672
(% increase)	–	0.7	1.5	1.6	3.2	3.9	4.0
Working capital	2 106 141	2 195 752	2 285 484	2 355 505	2 450 356	2 539 968	2 609 989
(% increase)	–	4.3	8.5	11.8	16.3	20.6	23.9
Total capital required (US$)	3 583 090	3 683 057	3 784 102	3 856 317	3 974 467	4 074 447	4 146 661
(% increase)	–	2.8	5.6	7.6	10.9	13.7	15.7
Net operating cash flow (10 years)	2 107 929	1 976 131	1 844 264	1 736 010	1 599 956	1 468 158	1 359 904
Reduction (US$)		131 798	263 664	371 919	507 973	639 771	748 025
Internal rate of return (IRR) (%)	35.3	31.8	28.3	25.5	21.7	18.1	15.2

3.2 Scenario 2 – Optimal production parameters

In order to maximize the economic efficiency of a production system, it is necessary to ensure that the system is operated under conditions that optimize production efficiencies; in this regard there are often trade-offs between production parameters. For example, growth is generally maximized at a higher temperature than feed conversion efficiencies (Jobling, 1996; Deacon 1997; Van Ham *et al.*, 2003). Under intensive tank culture conditions, Collete (2007) demonstrated that this was indeed the case with juvenile *A. japonicus*, and it was established that while FCR were maximized at 21.9 °C, growth was maximized at 25.6 °C (Figure 1). Using this as an example, the trade-off between maximizing production efficiencies in terms of maximizing growth or FCR needs to be established, and this can best be undertaken by establishing the economic efficiency of operating the system under different temperature regimes (Table 2).

FIGURE 1
The effect of temperature on feed conversion ratios and growth



Source: Collete (2007).

TABLE 2
The effect of temperature on feed conversion ratio (FCR), growth and economic efficiency of a 600 tonne per year farm

	Temperature (°C)			
	17	21.7	25.4	28
FCR	1.36:1	0.97:1	1.3:1	1.98:1
Growth (g/day)	1.76	2.53	2.94	2.57
Feed requirement (tonnes/year)	892	591	820	1 226
Cost of feed (% operational costs)	42.0	35.2	42.1	50.3
Residency (months)	15	10	9	10
Total capital (US$)	3 927 509	3 554 914	4 003 967	4 498 525
Total capital (% of optimal scenario)	+10.5	0.0	+12.6	+26.5
Internal rate of return (IIR) (%)	16.4	33.0	26.4	0.6

According to Collete (2007), operating the production system at the optimal temperature to maximize feed conversion (21.7 °C) results in an FCR of 0.97:1 and a corresponding growth rate of 2.53 g/day. At the optimal temperature for growth (25.4 °C), FCR is reduced to 1.3:1 and growth increases to 2.94 g/day. With respect to the operational efficiencies that add to operating the system at these temperatures, the increased growth rate at the higher temperature results in a shortening of the grow-out cycle of one month. However, the poorer FCR at this temperature increases the annual feed requirements from 591 tonnes (at 21.7 °C) to 820 tonnes (at 25.4 °C), increasing the proportion of feed costs (as a percentage of operational costs) from 35.2 percent to 42.1 percent. The cost savings that accumulate to operating the system to maximize the growth rate are not offset by the higher feed costs. Indeed, simply operating the system to maximize the growth rate as opposed to maximizing the feed conversion results in a 12.6 percent increase in capital requirements and a concomitant reduction in the IIR from 33 percent to 26.4 percent. Thus, under this production scenario, economic efficiencies are greatest at 21.7 °C as opposed to 25.4 °C, and thus farmers should choose to optimize feed conversion over growth rates. At a practical level, market demand issues may require farmers to supply product into the markets at certain times; at these times farmers may choose to maximise growth rates and sacrifice economic efficiencies.

3.3 Scenario 3 – Feed formulation

Feed formulation and the development of cost-effective feeds that optimize growth rates, feed conversion and feed costs are important considerations in optimizing economic efficiencies. Protein traditionally represents the most expensive dietary component in fish feeds. Furthermore, it plays an important role in growth and feed efficiency, and thus can potentially provide a good example of how subtle changes to feed formulations can impact the economic viability of a farming operation. The utilization of dietary protein is related to protein quality, inclusion levels and availability of non-protein energy sources. By optimizing the dietary protein:energy (P:E) levels, protein retention can be maximized, the deamination of amino acids minimized (Lee, Jeon and Lee, 2002), and growth rates and feed conversion efficiencies maximized.

By manipulating dietary protein and lipid levels, Woolley (2009) investigated the P:E requirements of juvenile *A. japonicus* using variable P:E ratios (2.1–2.5 g protein/kJ/kg). In terms of production efficiencies (Table 3), a high protein/high fat diet (48 percent protein; 18 percent lipid; P:E ratio: 2.3) provided the highest growth rate (specific growth rate (SGR) of 1.1) and an FCR of 1.05:1 that was similar to the high protein:low fat combination. The formulation costs of this diet were, however, the highest of all the formulations in the trial. In contrast, with a SGR of 0.64 and an FCR of 1.93:1, the low protein:high fat combination (42 percent protein; 18 percent lipid; P:E ratio: 2.1) elicited the poorest production efficiencies. Thus, an increase in dietary protein level of just 6 percent, and a concomitant reduction in the P : E ratio of 0.2 resulted in a reduction in the SGR by 0.46 and an increase in the FCR of 0.88:1. With respect to the economic efficiencies of using these two formulations, using the optimal diet (high protein:high fat; P:E ratio 2.3) results in an annual feed requirement of 631 tonnes, which increases to 1 158 tonnes when the poorest performing dietary formulation is used. Feed costs as a percentage of operational costs using the optimum formulation represent 37.9 percent of total operational costs, a figure that increases to 48.7 percent when the poorest formulation is used. With respect to the IRR calculated over a ten-year period, the difference between the two formulations is 28.8 percent. While this analysis only relates to the manipulation of the dietary P:E ratios, it demonstrates that even relatively subtle changes to dietary formulations can have significant implications on the economic efficiency of the farming operation. Further, it should be noted that feed formulation may also affect the quality and hence the price of the farmed fish, and thus farmers need to take cognisance of the quality and price of the final product when they assess the most suitable formulation to use.

TABLE 3

Dietary protein energy ratios and the effect that these dietary formulations have on the economic efficiency of a 600 tonne per year farm

Diet	High protein low fat	High protein high fat	Low protein low fat	Low protein high fat
Protein (%):lipid (%)	48 : 6	48 : 18	42 : 6	42 : 18
Protein:energy ratio (P:E) (g protein/kJ/kg)	2.5	2.3	2.3	2.1
Feed conversion ratio (FCR)	1.05:1	1.05:1	1.31:1	1.93:1
Specific growth rate (SGR) (% body weight/day)	0.95	1.1	0.96	0.64
Cost/kg (US$)	1.41	1.43	1.35	1.37
Feed (tonnes per year)	631	631	787	1 158
Cost of feed (% operational costs)	37.2	37.9	41.4	48.7
Total capital (US$)	3 585 764	3 633 528	3 703 660	4 112 370
Internal rate of return (IIR) (%)	26.6	28.8	21.6	0.0

3.4 Scenario 4 – Feed management

Feed management practices play an instrumental role in ensuring that feed use is optimized. To ensure maximal growth, fish require a species and size-specific daily ration (Chua and Teng, 1982). In this regard, the feeding frequency and the ration that is delivered are important considerations. Increasing the feeding frequency and ration above the level that is required for optimal growth will result in poorer FCR. Thus, the best feeding regimen is the one that uses the lowest feeding frequency at which the daily ration can be provided without reducing growth or increasing FCR (Chua and Teng, 1982).

Collette (2007) undertook a study to determine the optimal ration and feeding frequency for juvenile *A. japonicus* (Table 4). It was established that feeding three times a day at a ration of 3.4 percent body weight (BW)/day produced the best results in terms of feed efficiency (FCR). While feeding to satiation three times a day produced a marginally higher growth rate, satiation feeding meant that the fish ingested 4.93 percent BW/day. The increased ration resulted in an increase in the FCR in this group. Indeed, feeding to satiation once, twice and three times a day resulted in a gradual increase in ration and a concomitant increase in FCR.

TABLE 4

Feed management practice and the impact that this has on the economic indicators of a 600 tonne per year farm

Feed rate	3 x daily @ 3.4% body weight/day	1 x daily satiation	2 x daily satiation	3 x daily satiation
Feed conversion ratio (FCR)	0.91:1	1.09:1	1.1:1	1.31:1
Specific growth rate (SGR) (% body weight/day)	3.75	3.02	3.61	3.76
Feed (% body weight/day)	3.41	3.28	3.96	4.93
Feed (tonnes per year)	546	654	660	787
Feed cost (US$)	743 039	889 097	898 179	1 069 649
Cost of feed (% operational costs)	34.9	38.5	39.0	42.5
Total capital (US$)	3 507 578	3 565 692	3 666 277	3 884 129
Internal rate of return (IIR) (%)	33.2	24.0	27.3	20.0

Feeding three times a day to a given ration based on BW was biologically and economically the most efficient feed management practice (Table 4). Based on a production volume of 600 tonnes per year, feeding three times a day at a ration of

3.4 percent BW/day would require 546 tonnes of feed; this requirement increased to 787 tonnes when the fish were fed to satiation three times a day. This increase in feed requirement increased feed costs by 44 percent and reduced the IRR of the investment from 33.2 percent to 20 percent. Thus, by simply feeding three times a day to a restricted ration based on BW, as opposed to feeding to satiation three times a day, there is a significant effect on the economic efficiency of the operation. It is therefore reasonable to conclude that simple changes to feed management practices can significantly improve the financial viability of a farming operation.

3.5 Scenario 5 – Tilapia culture systems

A comparison of the impact that feed management practices have on the economic efficiency of intensive and semi-intensive tilapia pond culture systems was undertaken. The comparisons were based on production parameters and associated costs for Nile tilapia (*Oreochromis niloticus*) production in Egypt (El-Sayed, 2010). The production parameters were incorporated into the 'User-friendly Aquaculture Investment and Management Tool' developed by FAO (Valderrama and Hishamunda, 2010). The Tool is an interactive, user-friendly model designed within Excel which enables users to conduct a complete financial analysis of a proposed or already-functioning aquaculture operation. User input data on production and economic characteristics of the aquaculture operation, including the size of the farm, the number of ponds, stocking densities, food conversion ratios (FCR), survival rates, the price of fingerlings and feeds, and selling prices, and an estimate of the investment required to build the facility, including the construction of the grow-out units (e.g. ponds) and the purchase of land and machinery is required. Based on the information provided, the model calculates enterprise budgets, income statements, a balance sheet and cash flow budget. The model was used to analyze feed production costs that were based on projected feed conversion ratios and feed costs accruing to the different feed types. The model outputs were used to develop a benefit-cost analysis. The production models were based on a single farmer model operating a 1 ha farm and producing fish of 200 g at a survival rate of 85 percent. The farm-gate price of the fish was estimated at US$2/kg. The intensive production model was based on a stocking rate of 5 fish/m^2 and a production of 14.5 tonnes/ha/year (Table 5). In contrast, the semi-intensive production model was based on a stocking rate of 2 fish/m^2 and a production of 5.8 tonnes/ha/year (Table 6).

Two feed types (extruded and pressed pellets) are used in intensive tilapia production systems in Egypt (El-Sayed, 2010). With respect to feed conversion, the use of extruded feeds typically results in FCR of 1:1–1.2:1. (Table 5) In contrast, the pressed feeds elicit FCR of between 1.2:1 and 1.5:1, indicating that they are nutritionally less efficient than the extruded feeds. With respect to the economic efficiency of their use, the extruded pellets are more expensive than the pressed pellets, and thus farmers need to be aware of the trade-off between using the relatively expensive extruded feeds that elicit higher feed efficiencies and the use of the cheaper, less efficient pelleted feeds. Using FCR as an indicator of feed management, the yields and benefit-cost ratios that accumulate to the use of the two feed types are presented in Table 5. At FCR that range between 1:1 and 1.2:1, the feed costs associated with the use of the extruded feeds range between US$7 892 and US$9 470/ha/year. In contrast, at FCR of 1.2:1 to 1.5:1, the feed costs associated with the use of pressed pellets range between US$6 873 and US$8 592/ha/year. At an FCR of 1.2:1, the feed costs associated with the use of the pressed pellets is approximately 37.8 percent less than that associated with using the extruded pellets. In terms of yields, the use of the extruded feeds yields a return of US$9 983 to 11 565/ha/year at a benefit-cost ratio of 0.84 to 1.12, while the pressed pellets produce a yield of US$10 864 to 12 585/ha/year at a benefit-cost ratio of 0.99 to 1.36. Evidently, while the pressed feeds are nutritionally less efficient than the extruded feeds, and assuming that they are used in the most efficient manner and elicit an FCR of 1.2:1, their lower cost outweighs the poorer performance, and thus in terms of maximizing the economic returns, their use would represent the most attractive option to the farmers.

TABLE 5
Feed type and use in intensive tilapia pond culture systems. Production based on a 1ha farm model stocked at a rate of 5 fish/m² and a production of 14.5 tonnes/ha/year

Feed conversion ratio (FCR)	Feed type[1]	Feed requirement (kg/ha/year)	Feed cost (US$/ha/year)	Total operational costs (US$/ha/year)	Yield (US$/ha/year)[2]	Benefit-cost ratio[3]
1.0:1	E	14 143	7 892	10 292	11 565	1.12
1.1:1	E	15 557	8 681	11 082	10 775	0.97
1.2:1	E	16 971	9 470	11 874	9 983	0.84
1.2:1	P	16 971	6 873	9 273	12 585	1.36
1.3:1	P	18 386	7 446	9 846	12 011	1.22
1.4:1	P	19 800	8 019	10 419	11 438	1.10
1.5:1	P	21 214	8 592	10 993	10 864	0.99

[1] For the purpose of the analysis, average prices of US$550 per tonne and US$405 per tonne were used for extruded (E) and pressed (P) pellet feeds, respectively.
[2] Yield is calculated as the value of the fish produced per hectare per year.
[3] Benefit-cost ratio calculated as farm income (yield)/total operational costs.

The economic implications of applying semi-intensive farming practices are presented in Table 6. FCR using this farming system range between 1.31 and 1.8:1 (El-Sayed, 2010), and in comparison to employing intensive culture practices (Table 5), feed requirements and yields are significantly lower, and the total operational costs are approximately halved. Based on a production of 5.8 tonnes/ha/year the benefit-cost ratios under all feed conversion scenarios in semi-intensive farming practices (Table 6) are lower than those observed in the intensive systems (Table 5), indicating that the intensive systems are more economically efficient. Thus, while input costs of the intensive systems are higher, returns are greater than in the semi-intensive system; thus to optimize outputs, farmers should be encouraged to intensify their farming practices. It should be noted that this analysis addresses only feed use and costs, and does not take into consideration additional risks and costs that may add to the intensification of the production systems. For example, intensification of the production system may increase the potential for disease transmission, and result in increased mortality rates. These risks and costs should also be taken into consideration when determining the level of farming intensity.

TABLE 6
Feed (pressed pellets) and fertilizer use in semi-intensive tilapia pond culture systems. Production based on a 1 ha farm model stocked at a rate of 2 fish/m² and a production of 5.8 tonnes/ha/year

Feed conversion ratio (FCR)	Feed Requirement (kg/ha/year)	Feed cost (US$/ha/year)[1]	Fertilizer cost (US$/ha/year)	Total operational costs (US$/ha/year)	Yield (US$/ha/year)[2]	Benefit-cost ratio[3]
1.3:1	7 443	3 015	272	5 005	3 738	0.75
1.4:1	8 016	3 246	272	5 238	3505	0.67
1.5:1	8 589	3 478	272	5 470	3 272	0.60
1.6:1	9 161	3 710	272	5 703	3 040	0.53
1.7:1	9 734	3 942	272	5 942	2 807	0.47
1.8:1	10 306	4 174	272	6 170	2 573	0.42

[1] Feed used in the analysis were pressed pellets costing US$405 per tonne.
[2] Yield is calculated as the value of the fish produced per hectare per year.
[3] Benefit-cost ratio calculated as farm income (yield)/total operational costs.

4. CONCLUSIONS

It is evident that optimizing feed use plays a significant role in maximizing the economic efficiency of a farming operation. In this regard, farmers need to consider a number of factors that affect on-farm feed utilization. Principal among these factors are systems design (e.g. extensive *versus* intensive farming systems), operational parameters (e.g. temperature, water quality), feed type and formulation (extruded *versus* pressed pellets, ingredient inclusion levels) and feed management practices (e.g. feeding schedules).

With respect to controlling the use of aquafeeds, policy-makers and regulators have a number of tools at their disposal. While interventions should promote environmental protection, they also need to be practical, be cognisant of the implementation and compliance costs, and the ability of the specific country or farming sector to absorb these costs. The potential impacts that the regulations could have on sectoral growth also need to be considered. The sector is characterized by a multitude of production systems, species, feed types and culture environments, and no single policy or regulatory dispensation can be applied to all cases. Thus, regulators need to assess interventions on a case by case basis. Tacon and Forster (2003) advocated the use of regulations to control effluent streams, as opposed to feed and feed management. The argument presented by these authors was that there are many ways to supply nutrients and managing these nutrients within the farm environment; and that the net effect of applying good farm management practices is that they will not negatively affect the environment. As poor feed management practices often manifest themselves in the effluent streams – particularly in cases where effluent treatment is also substandard – it would appear that, where practicable, effluent monitoring would provide a suitable vehicle with which to promote sustainable feed management practices while placing minimal regulation on the farming practice.

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