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INVITED EDITORIAL

# Future Feeds: Suggested Guidelines for Sustainable Development

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**ABSTRACT**

Whilst the aquaculture sector continues to grow and make an ever increasing contribution to world food supplies, there is a need to ensure that the sector continues to develop in a socially, economically and environmentally sustainable manner, in line with the United Nations sustainable development goals. The present paper focusses on the major perceived sustainability issues related to feed inputs for finfish and crustacean aquaculture species, including sustainability issues related to feed formulation and ingredient selection, feed manufacture and feed quality, on-farm feed use and impacts, and fish quality and food safety.

**KEYWORDS**

Aquaculture; sustainable aquafeeds; fish-in fish-out (IFFO); sustainable development; feed manufacture; on-farm management

## Introduction

Since its first publication of technical guidelines for aquaculture development (FAO, 1997), the Food and Agriculture Organization (FAO) has published two feed-related guidelines, the first concerning good aquaculture feed manufacturing practice (FAO, 2001) and the second concerning the use of wild fish as feed (FAO, 2011). It is hoped that the current paper will provide additional guidance concerning feed ingredient selection and use, and the sustainable development of the aquafeed sector in line with the UN sustainable development goals (the lead author of this paper having been previously involved in preparation of all of the above guidelines).

In particular, considerable controversy has arisen since the use of the term "fish-in fish-out" (FIFO) as a metric for the use of fishmeal and fish oil in compound aquafeeds (Tacon et al. 2006), and the perceived long-term sustainability of the aquaculture sector dependent upon these wild fishery resources (Boyd et al. 2020; Deutsch et al. 2007; Naylor et al. 2009; Tacon and Metian 2008a). In particular, controversy has arisen concerning the methodology used for converting fishmeal and fish oil use back to live fish weight equivalents (Aas et al. 2019; Bendiksen et al. 2011; Byelashov and Griffin 2014; Jackson 2009; Kaushik and Troell 2010; Kok et al. 2020; Obach 2012; Sarker et al. 2013; Torrissen et al. 2011; Turchini et al. 2019; Ytrestøyl et al. 2015).

For example, in the Salmon Aquaculture Dialogue paper of Tacon (2005) and Tacon et al. (2006) live fish weight equivalents were calculated by summing the totals for fishmeal and fish oil use and then multiplying by 4 or 5 (yields of fishmeal and fish oil varying from species to species, season to season, and from country to country; Péron et al. 2010). In our later paper (Tacon and Metian 2008a), we followed, however, the methodology used by the Salmon Industry in Chile (SalmonChile; Anon 2006) where transformation yields were also calculated separately for fish oil, resulting in higher FIFO values in the case of salmonids where large quantities of fish oil were consumed.

From the FIFO controversy, a series of derived ratios/indexes have been developed aiming at better assessing the dependency of aquaculture species upon capture fisheries for the supply of their major dietary source of protein and lipids (e.g. forage fish dependency ratio -FFDR-, marine protein dependency ratio -MPDR-, eFIFO). According to Ytrestøyl et al. (2015) most of them are providing a good picture of the pressure on the wild resource while they are failing to really fully cover sustainability aspect.

Nevertheless, existing ratio or indexes are similarly unperfected presenting objectively advantages and disadvantages (see review of Ytrestøyl et al. 2015). The major issue for all of them is that they depend on data subjected to high levels of uncertainty and that are challenging to collect (Merican and Sanchez, 2016), probably due to a lack of transparency or to the confidential character of feed formulation. Aside from

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the debate on the best approach or the limited access to data, their values greatly vary due to a series of other reasons including methods used, data inputs, scale, generalization. For a given method, the best approach is to look at the evolution with time in order to see the improvement with time although this can be challenging too due to previously cited issues of data access.

It is important to note that the FIFO ratio was never intended to be a precise measurement of how much wild fish is required to produce a given amount of farmed fish. The ratio itself was to bring attention to the reliance of the aquaculture feed industry on wild capture fisheries. Further with much of the aquaculture sector seeking to portray farmed seafood as a solution or alternative to wild capture fisheries, the FIFO ratio highlighted the specific dependence aquaculture has on wild capture fisheries. Additionally, some critics of the aquaculture sector have been primarily focused on the wild fish dependency because of a marine conservation focus. The narrow focus of these critics fail to recognize that there are tradeoffs in environmental impact in the substitution of ingredients for wild fish, i.e. soy and deforestation/conversion, manufactured novel ingredietnts and energy consumption, etc. So while useful as a guidepost and a magnitude snapshot of aquaculture's reliance on wild fisheries, there is a broader lens by which the aquafeed sector should be viewed to account for these tradeoffs and other impacts of ingredient production and feed manufacturing.

## Need for a more holistic "feed-in fish-out" approach

Notwithstanding the above, it is clear that the FIFO metric, like other ratio/index, is not an indicator of sustainability *per se* unless it is linked with the sustainability or not of the specific fishery and/or processing waste targeted for fishmeal and fish oil production (FAO, 2011; Ytrestøyl et al. 2015). Moreover, apart from the current dependence of high trophic level aquaculture species upon fishmeal and fish oil use (Auchterlonie 2016; Olsen 2011; Naylor et al. 2009; Tacon et al. 2011), there is a need for a more holistic approach and to consider other feed-related factors to ensure the long-term sustainable development[1] of the aquaculture sector.

[1]Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable (FAO, 1997)

In the view of the authors, the major perceived sustainability issues facing the commercial aquafeed sector can be viewed at four levels, namely:

### *Sustainability issues related to feed formulation and ingredient selection*

#### *Required*

- Need to prohibit the use of non-sustainble marine feed ingredient sources, including meals, oils and silages/hydrolysates derived from over exploited and/or non-sustainably managed wild-caught marine fish, crustaceans, mollusks, and aquatic plant species (FAO, 2011; Hasan and Halwart 2009; Tacon and Metian 2009);
- Need to prohibit the use of non-sustainble and/or adulterated terrestrial feed ingredient sources, including meals derived from endangered and/or protected wild animal species, the use of non deforestation/conversion-free feed ingredients, the use of highly subsidized imported feed ingredient sources, and the use of spoiled, adulterated and/or contaminated feed ingredients (Berntssen et al. 2010, 2021; FAO, 2001, 2019; Gonçalves et al. 2018; MOWI, 2020; Siegel et al. 2016);
- Need to prohibit the use of non-approved terrestrial feed ingredient sources (depending upon the producing/importing country) for perceived religious and/or food safety concerns, including feeds containing terrestrial animal byproduct meals, genetically modified plant feed ingredients, and animal manures (Boyd et al. 2020; Schofield 2002);
- Need to prohibit the re-feeding of feed ingredients derived from the same species for biosecurity concerns, including fishmeals produced from salmonid, pangasius, tilapia and/or shrimp aquaculture processing wastes (FAO, 2001; Global Aquaculture Alliance 2020; Tacon 2017);
- Need to prohibit the use of non-approved chemicals, medicants & feed additives (depending upon the producing/importing country), including antibiotics, hormones, antioxidants, binders, medicants, pigments, and non-protein nitrogen compounds (FAO, 1997, 2019);

#### *Recommended*

- Need to reduce the carbon footprint of aquafeeds through the reduced use of imported feed ingredient sources and the increased use and recycling of locally available agricultural and fishery resources derived from sustainably managed and operated agricultural and fishery operations (Boyd et al.

2020; FAO, 1997; Ghamkhar and Hicks 2020; Jones et al. 2020; Tacon et al. 2012);

- Need to limit the selection and use of potentially food-grade feed ingredient sources, including fisheries bycatch, small pelagic fish species, and food-grade cereal grains, starches, pulses, and oilseeds (FAO, 2011; Tacon et al. 2012);

### *Sustainability issues related to feed manufacture and feed quality*

#### *Required*

- Need to ensure that the feed manufacturing plant is run and operated following all national laws and local environmental/social standards, and according to standards, guidelines and criteria concerning the manufacture of compound aquafeeds developed by FAO (Technical Guidelines on Good Aquaculture Feed Manufacturing Practice; FAO, 2001; FAO/IFIF 2010), the Global Partnership for Good Agricultural Practice (GLOBALG.A.P; Compound Feed Manufacturing), the Global Aquaculture Alliance (GAA; Feed Mills BAP Standards and Guidelines), and/or the Aquaculture Stewardship Council (ASC; Responsible Feed Standard);
- Need to ensure oversight in feed ingredient supply chains to demonstrate to buyers and authorities that ingredients are not produced with forced or child labor;
- Need to ensure that feeds produced by the feed plant are formulated so as to meet the dietary nutrient requirements of the target species for optimum growth and health (National Research Council 2011), and for the intended farming system and stocking density (FAO, 2001);
- Need for the feed plant to have a dedicated laboratory for feed quality control, including the use of both Near Infra Red (NIR – for rapid analysis) and wet chemical analytical techniques (for certified anlaysis) for the routine analysis of feeds and feed ingredients, including proximate analysis, specific nutrient analysis (if so required), and screening for mycotoxins and possible adulterants/contaminants (De Jonge and Jackson 2013; Tangendjaja 2015);
- Need for transparency concerning feed ingredient use and the open-declaration of all major feed ingredients and feed additives used on feed bags and/or labels (listed from highest to lowest), as well as key essential dietary nutrient levels (FAO, 2001; Schofield 2002);

#### *Encouraged*

- Need to minimize the use of feed mill sweepings and processing wastes (includes floor sweepings and rejected processed feeds due to quality concerns) within finished feeds;
- Need for the feed mill to establish a dedicated research and development (R & D) program and facility for the routine in-house testing of novel feed additives, feed ingredients, and feed formulations, including for determining the apparent nutrient digestibility of the feed ingredients used by the feed plant;
- Need for the feed mill to dedicate sufficient funds and resources (incuding personnel) for farm data collection and technical support to farmers concerning the storage and management (feeding) of their feeds, including training for both large-scale and small-scale farmers (Bondad-Reantaso and Subasinghe 2013; Robb and Crampton 2013);

### *Sustainablity issues related to on-farm feed use and impacts*

#### *Required*

- Need for farmers to monitor and record feed consumption, fish/shrimp biomass, survival and apparent biological and economic feed efficiency on a regular basis (based on the frequency of sample weighings for each individual production unit), and in particular at the end of each farm production cycle (Hasan and New 2013);
- Need for farmers to store their feeds under protected, cool and well-ventilated conditions so as to maintain feed quality and nutrient stability, and to use feeds on a first-in first-out basis (FAO, 2001; Hasan and New 2013; O'Keefe and Campabadal 2015);
- Need to prohibit farmers from top-dressing their feeds with non-approved feed ingredients and feed additives, including antibiotics, growth promoters and un-processed marine feed ingredients that may pose a biosecurity or health risk to the cultured species (Tacon 2017);
- Need for the farmer to optimize feed intake and feed efficiency of the cultured species to farm and water quality conditions, including water temperature, dissolved oxygen levels, feeding frequency, feeding method etc following internationally recognized good or best on-farm feed management practices (Boyd 2009; Hasan and New 2013; Molina 2009);

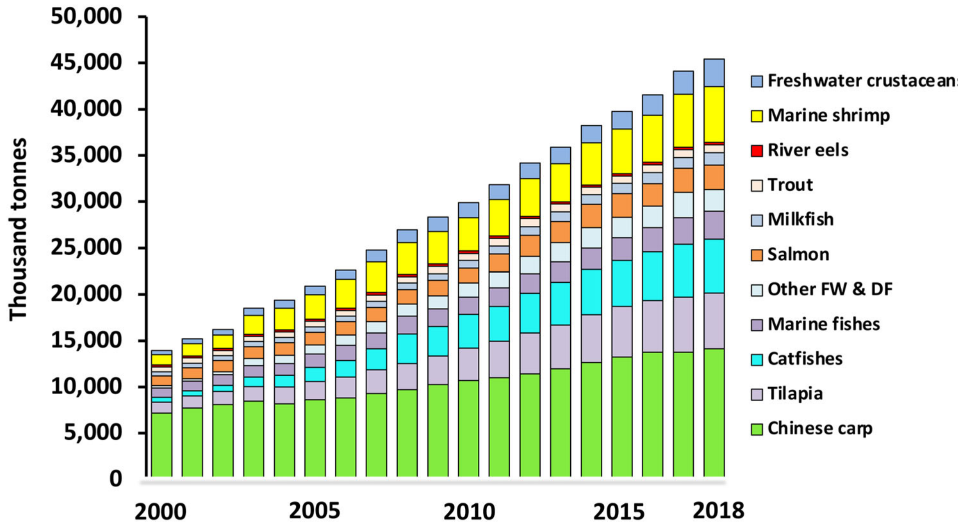


**Figure 1.** Global production of major fed-aquaculture species: 2000 to 2018.
1/Growth expressed as % APR from 2000 to 2018 for total fed-species production was 6.8%/year (13.94 to 45.41 million tonnes), and individually by major species as follows: Chinese-fed carp 3.8%, Tilapia 9.4%, Shrimp 9.6%, Catfishes 14.2%, Marine fishes 6.4%, Freshwater crustaceans 11.4%, Salmon 5.4%, Other miscellaneous freshwater & diadromous fishes 12.4%, Milkfish 5.9%, Trout 3.0% and River eels 1.3%; data calculated from FAO 2020a)

- Need for the farmer to monitor the environmental impact of their feeds by monoitoring waste nutrients levels (including P, N, suspended solids, biological oxygen demand) over the culture cycle, and by minimizing their potential negative environmental impacts through water-recirculation and/or effluent treatment/IMTA prior to discharge (Bartley et al. 2007; Boyd 2009; Ghamkhar and Hicks 2020; Hasan and New 2013);

### *Encouraged*

- Need to encourage farmers to establish a dedicated research and development (R & D) program and facility on-farm for the in-house testing of different feeds and feeding regimes so as reduce feed costs and optimize their feeds and feeding systems;
- Need to increase communication and information between farmers, feed manufacturers, policy makers, consumers, and researchers so as optimize on-farm feed use, farm management, profitability, and the long-term sustainability of the aquaculture sector (Robb and Crampton 2013);

## *Sustainability issues related to fish quality and food safety*

### *Required*

- Need to ensure that feeds used by farmers have no negative effect on the nutritional quaity and safety of aquaculture products (Tacon and Metian 2008b);

**Table 1.** Estimated major fed-aquaculture species production and compound feed usage in 2018 (values given in thousand tonnes; after FAO 2020a & Tacon et al. 2020).

| Top fed species | Tonnes | % on feeds | eFCR | Feed use Tt |
|---|---|---|---|---|
| Chinese fed carp | 14,141 | 58 % | 1.7 | 13,943 |
| Tilapia | 6,031 | 93 % | 1.7 | 9,535 |
| Shrimp | 6,004 | 86 % | 1.6 | 8,261 |
| Catfishes | 5,781 | 81 % | 1.3 | 6,87 |
| Marine fish | 3,006 | 83 % | 1.6 | 3,992 |
| Freshwater crustaceans | 2,961 | 58 % | 1.8 | 3,112 |
| Salmon | 2,637 | 100 % | 1.3 | 3,428 |
| Other freshwater & diadromous fish | 2,358 | 44 % | 1.6 | 1,660 |
| Milkfish | 1,327 | 53 % | 1.7 | 1,196 |
| Trout | 871 | 100 % | 1.3 | 1,132 |
| Eel | 269 | 98 % | 1.5 | 395 |
| Total fed species production Mt | 45,406 | | | 52,741 |

1/Growth expressed as % APR from 2000 to 2018 for total major fed-species production and estimated compound aquafeed usage was 6.8%/year (13.94 to 45.41 million tonnes) and 7.7%/year (13.83 to 52.74 million tonnes), respectively.

- Need to monitor the nutritional composition, quality and safety of aquaculture products destined for direct human consumption, including whole fish/shrimp, gutted fish, shrimp tails, fish fillets, fish balls, fish sausages, fish burgers, nuggets etc depending upon the species and country of origin (Lie 2008; Tacon et al. 2020);

### *Encouraged*

- Need to maximize the use of aquaculture derived trimmings and fish/shrimp off-cuts for direct human consumption when ever possible, including the production of lower-cost (in marketing terms) fast-food and/or ready-made meals for mass consumption (Nikolik 2015; Stevens et al. 2018);