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COMMENT

Commentary: comparing efficiency in aquatic and terrestrial animal production systems

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Aquaculture is receiving increased attention from a variety of stakeholders. This is largely due to its current role in the global food system of supplying more than half of the seafood consumed, and also because the industry continues to steadily expand (UN Food and Agriculture Organization 2018). A recent article in *Environmental Research Letters*, 'Feed conversion efficiency in aquaculture: do we measure it correctly?', by Fry *et al* (2018a) found that measuring feed conversion efficiency of selected aquatic and terrestrial farmed animals using protein and calorie retention resulted in species comparisons (least to most efficient) and overlap among species dissimilar from comparisons based on widely used weight-based feed conversion ratio (FCR) values. The study prompted spirited discussions among researchers, industry representatives, and others. A group assembled to write a standard rebuttal, but during this process, decided it was best to engage the study's original authors to join the discourse. Through this collaboration, we provide the resultant additional context relevant to the study in order to advance conversations and research on the use of efficiency measures in aquatic and terrestrial animal production systems.

After publication of the Fry article, an error was identified regarding edible yield values for terrestrial animals. To calculate protein and calorie retention, the researchers used species-specific values for FCR, feed content (protein and calories), edible yield, and content of final edible product (protein and calories). The authors inadvertently used edible yield data for terrestrial animals that included some inedible parts and therefore overestimated yield for these species. The calculations were performed again, and a corrigendum was published with revised results (Fry *et al* 2018b). The protein and calorie retention values for cattle, pigs, and chickens went down slightly; the revised results, however, do not impact the conclusions of the study that there is variation in protein and calorie retention among the nine aquatic species and these values are comparable to the three terrestrial species.

A motivating factor for conducting the study was to provide clarity regarding the conclusions that can be drawn from species comparisons using weight-based FCRs (i.e. the ratio of feed intake to animals' weight gain). Fish and other farmed aquatic animals have favorable, or low, FCRs in comparison with terrestrial farmed animals because they are ectotherms and are supported by water instead of standing against gravity. FCRs for fed fish and shrimp are similar to chicken, and lower than pigs and cattle. Comparisons of farmed animal species using FCRs, however, have become shorthand in science communication for sustainability and resource use (for example: Bourne 2014), which we believe is not the appropriate use of FCR. Crude comparisons such as this have little bearing on sustainability because the quality of feeds is variable between species. The FCR species ranking is incorrectly presented by some as a measure of efficiency of protein production or protein conversion (for example: see Gjedrem *et al* 2012b as well as Bourne 2014). Fry *et al* (2018a) follow a lengthy pedigree of those (e.g. Åsgård and Austreng 1995, Åsgård *et al* 1999, Tyedmers 2001) who have shown that factors such as protein content of feed and the portion of animal that is edible (i.e. yield) impacts protein retention.

The authors of this commentary believe FCRs are best used for monitoring performance on a farm and comparison between farms producing the same species using a broadly consistent feed. They can be used to evaluate on-farm feed use efficiency and can signal, when increasing, potential negative changes in animal health and/or negative impacts on the production environment, for example resulting in increased eutrophying emissions. Therefore, farmers and certification bodies appropriately use FCRs for assessing performance of individual operations. While impacts ultimately have to be addressed using a broad suite of measures (Ytrestøyl *et al* 2011, Fry *et al* 2018a), improvements start on the farm and FCR is the best indicator to provide real-time feedback of farm practices.

As noted in Fry *et al* (2018a), the analyses focused on intensive production methods and processing methods that are more typical for developed countries, and did not focus on polyculture systems, such as tilapia farms in China, where farmers co-stock bighead carp, which feed off the primary production in the pond. Other farmers co-produce shrimp, tilapia, and carp, where the feed provided benefits each species differently. Shrimp is farmed over a range of intensification regimens in China and shrimp stocked at lower densities and less reliant on compound feed is both lower impact and more likely to enter local markets (Cao *et al* 2011). Processing methods also vary in different regions of the world. In low- and middle-income countries (LMICs), protein consumption levels are lower than high-income countries and in some LMICs aquatic animals contribute a significant proportion of animal protein intake. In these LMICs, parts of animals considered inedible in high-income countries are consumed, including entire fish or nutritious trimmings (Belton *et al* 2017). Similar consumption patterns exist for chickens and other terrestrial animals, too. Consumption patterns in LMICs, such as eating the entire fish, were not considered as part of Fry *et al* (2018a). Across the globe, terrestrial and aquatic animals are eaten in many different forms, and this will influence how they compare using different measures of efficiency. Therefore, additional analyses are required to calculate protein and calorie efficiency for animals based on production systems and consumption patterns.

Efficiency measures that are more comprehensive than FCRs and protein and calorie retention are energy analyses (Åsgård and Austreng 1995, Åsgård *et al* 1999, Tyedmers 2001) and life cycle assessments (LCA) (Henriksson *et al* 2012, Ziegler *et al* 2016, Avadí *et al* 2018). FCRs are a farm-only metric, and the bounds for protein and calorie retention (Fry *et al* 2018a) span the farm and the processing plant. An LCA approach accounts for differences in input resources (such as energy, materials and living resources) necessary to create the feeds and other inputs provided to animals in culture, including broodstock maintenance, juvenile production, all its components, as well as later stages of production including grow-out, processing yields, byproduct utilization, and food waste. It allows comparison of supply chain resource use and environmental impacts across production systems using comparable units such as a defined unit of edible meat, protein, or even nutrient density scores. LCA studies will differ in where they are bounded.

Various farmed animals also contain different micronutrients. A study by Kim *et al* (2015) on a diverse set of nutrients, for example, concluded that: 'finfish tend to have a higher nutritional fitness than poultry despite similarities in their overall nutrient compositions'. Ways to account for these have also been proposed in the LCA framework by using normalized units of comparison (Mungkung and Gheewala 2007, Schau and Fet 2008). Variations in nutrient fitness fluctuate based on feeds, seasons, systems, and animal sizes, making direct comparisons difficult.

Broodstock maintenance is an important, but often overlooked, aspect of animal production systems and represents an important difference between terrestrial and aquatic animals. The energy, space, and feed resources needed to maintain broodstock animals in each system will diverge between species because of enormous differences in fecundity. For example, for every steer sent to slaughter, just over one reproductive age cow must be maintained year-round on relatively high-quality forage (greater than one to account for heifers to be recruited into the cow-calf phase). Consequently, the inputs for beef production would be approximately double that used to calculate FCR and protein/calorie retention values. In contrast, given a typical sow to marketable pig to slaughter ratio is on the order of 1:10–15 and in poultry, the layer hen to broiler ratio approaches 1:100, far less additional feed inputs would be included when considering broodstock. Importantly, given the fecundity of most cultured aquatic species, where the broodstock to market fish ratio is typically one to many hundreds to thousands, little to no additional feed inputs need be practically considered, and will represent a significant source of variation between terrestrial and aquatic animal production systems, something that is excluded from comparisons based on FCR and was not accounted for in the analysis by Fry *et al* (2018a).

Effort invested and resulting success in improving genetic stock of certain species, and potential for improvements among additional species, is also important. The years of commercial selection pressure for production traits among terrestrial animals and Atlantic salmon have resulted in the current efficiency values. Zuidhof *et al* (2014) states that 'From 1957 to 2005, broiler growth increased by over 400%, with a concurrent 50% reduction in FCR…'. In the meantime, only about 10% of farmed fish species are estimated to be genetically improved (Gjedrem 2012a). Atlantic salmon has undergone significant genetic improvements, along with development of feeds and on site technological improvements that have worked concomitantly to reduce both FCRs from above 5:1 to current lows in the range of 1.2:1, and protein content in feed from 55% to 35%, since 1970 (Torrissen *et al* 2011), contributing to Atlantic salmon standing out as efficient in the protein and calorie retention calculations. Beyond genetics, alternative solutions for better edible yield efficiency include altering animal size at harvest and processing improvements. Harvesting smaller sized animals is a means to increase biomass produced in a more food-efficient manner (Tlusty *et al* 2011). As for processing, there are ways to shift more processing by-products to human food and animal feed to improve global food security. This has been relatively unexplored in fish, and improved byproduct utilization (Newton *et al* 2014) can result in more edible yield. A recent study on Scottish salmon processing demonstrated that the edible yield could increase from 60%–77% through better by-product management (Stevens *et al* 2018). Ongoing research is needed to capture improvements in feed efficiency, processing, and byproduct utilization, and there is still room for improving many species of farmed fish.

Ultimately, various measures of efficiency contribute important information and must be properly interpreted. The Fry article demonstrates the importance of considering factors beyond the ratio of feed input weight to animal weight gained when comparing feed efficiency of various aquatic and terrestrial farmed animals. We need measures for on farm performance, including unfed shellfish farms as well as ways to integrate vegetable protein sources into analyses. The entire food value chain also needs to be assessed, and using LCA derived metrics are best suited for a broad scale comparison of food production, and to consider efficiency within the context of changing production methods (Roberts *et al* 2015, Garnett *et al* 2015) to ensure that we minimize negative environmental impacts of food production to ultimately push less against the planetary boundaries (Steffen *et al* 2015).

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