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Misunderstandings, myths and mantras in aquaculture: its contribution to world food supplies has been systematically over reported

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ABSTRACT

This paper re-evaluates the contributions to global food supplies of 'aquatic animal-source food' from aquaculture and capture fisheries, and 'terrestrial animal-source food' from livestock farming. Three common misunderstandings in the scientific and policy literature are addressed: (1) aquaculture was the fastest growing food production sector over the past three decades, (2) aquaculture has surpassed capture fisheries as the main source of fish for human consumption, and (3) production of aquatic animal-source foods has outstripped that of terrestrial animal-source food. These misunderstandings result partly from misuse of statistics: although possessing a relatively high annual growth rate in percentage terms, production of aquatic animal-source food increased from a much lower basal production level than the production of terrestrial animal-source food. Misunderstanding also arose partly from differences in the ways that aquatic and terrestrial animal-source food production are reported in global statistics. These differences systematically biased the reported gross weight of aquatic animal-source food produced globally upwards relative to that of terrestrial animal-source food. Comparing edible portions of aquatic and terrestrial animal-sources foods revealed the following three main points: first, although having a high annual growth rate in percentage terms, growth in the production of edible aquatic food has lagged far behind that of terrestrial meat by volume; second, capture fisheries still produce more edible

aquatic food than aquaculture, and third, global production of beef exceeds that of farmed aquatic meat. Poultry is the largest animal-source food producing sector and is growing faster than aquaculture by volume.

Keywords: Aquaculture; Aquatic animal-source food; Fisheries; Food security; Livestock; Terrestrial animal-source food

1. Introduction

Correct interpretation of trends in the global supply of aquatic and terrestrial animal-source foods is essential for the formulation and design of appropriate and effective food and nutrition policy. Evidence-based policy making has gained precedence as a key objective in the fields of agriculture and health [1], with measurement increasingly at the centre of debates on development and food security [2]. Yet, evidence-based research and policy often remain disconnected, and some of the strongest and longest-lasting policy narratives on aquaculture and fisheries lack rigorous evidence-based validation [3].

This paper provides much needed clarity on the relative contributions of aquaculture, capture fisheries and terrestrial animal-source food to the global food supply by challenging a cluster of misleading assumptions in the academic and policy literature. These misunderstandings have been reproduced so frequently and so widely that they have assumed the status of myths and mantras. Four common misconceptions are identified and debunked: first, aquaculture is the fastest growing food production sector [4–6]; second, the growth of global aquaculture production is slowing down [7–9]; third, aquaculture has surpassed capture fisheries as the main source of fish for human consumption [5,10–12]; and fourth, production of fish has outstripped terrestrial livestock and poultry production.

This paper contends that these misunderstandings result from two sources;(1) improper interpretation of global statistics on terrestrial and aquatic food production (e.g. the

false equivalence of comparisons between total aquaculture production, including aquatic plants, with production of terrestrial animal-source foods); and (2) differences in the way that aquatic and terrestrial animal-source food production are reported in global statistics. These different reporting standards systematically bias estimates of the contribution of aquatic animal-source foods to global food supply upward relative to terrestrial animal source food, because aquatic animal production is reported in live weight equivalents (including inedible and discarded portions) whereas terrestrial animal production is reported as dressed carcass weight.

2. Methodology

The present study used the terms ‘aquatic animal-source foods’ and ‘terrestrial animal-source foods’ in preference to aquatic or terrestrial ‘meat’ because the term ‘meat’ does not adequately capture all the forms in which food of animal origin is consumed. Depending on cultural context, edible portions may include heads, internal organs, fats and bones. Eggs and dairy were excluded from the definition of terrestrial animal-source foods for the purposes of this paper. Production and annual growth rates of aquatic and terrestrial animal-source foods were compared using the FishStatJ [13] online database on global capture fisheries and aquaculture production, and the FAOSTAT [14] database on livestock production.

All aquatic food production data are reported by FAO as live weight equivalents (whole live weight at harvest) whereas production of terrestrial livestock and poultry are reported as dressed carcass weight (weight after having undergone basic processing).

These different reporting procedures systematically bias the contribution of aquaculture and fisheries to global food supply upward relative to that of terrestrial livestock and poultry production when figures are compared directly.

To make production volumes of aquatic and terrestrial animal-source food more readily comparable, we converted fisheries and aquaculture production data to edible aquatic animal-source food equivalents using the following conversion factors: fish 1.15 (gutted, head-on); crustaceans 2.80 (tail meat, peeled); and molluscs 6.0 (meat without shells) [15]. Data for the three major categories of aquatic animal-source food (finfish, crustaceans, and molluscs) were compared with the three major categories of terrestrial animal-source food (beef, pork and poultry), individually and in total.

Data on total production in million metric tonnes (mmt), annual growth rate (%), and net growth (mmt) (defined as the increase in total production between successive years) were analysed for all major categories of aquatic and terrestrial animal-source food and presented in 5-year intervals because reported annual production and growth rates fluctuated widely from year to year, even though annual total production increased overall.

Seaweeds (algae) were excluded from the analysis for three reasons: First, seaweeds and terrestrial plants are both autotrophs (they produce organic matter by photosynthesis). Fish and livestock are heterotrophs (they assimilate organic matter originating from other organisms but cannot synthesize it). Seaweed farming is therefore comparable to terrestrial crop agriculture, but not to aquatic and terrestrial

animal production. Second, the contribution of seaweeds to total aquatic food supply is relatively minor. More than 60% of global seaweed production is used for non-food purposes [16], including production of carrageenan for industrial use [17,18] and feed for aquaculture (e.g. for farming abalone) [19,20]. The biennial FAO State of Fisheries and Aquaculture reports exclude seaweeds from the calculation of world fisheries and aquaculture production, utilization and apparent consumption for these reasons [16,17]. Third, seaweeds comprise mainly water, with conversion factors from wet to dry weight of about 5 for kelps and 10 for all other species [14,21]. Factoring in conversion from wet to dry weight, global production of farmed seaweeds in 2016 amounted to only 3.8 mmt, compared to 30.1 mmt wet weight [14].

In addition to being used directly as human food, fish is also used as a source of feed for fish and livestock as fishmeal and fish oil [22]. A considerable amount of unprocessed "trash fish" is also used as feed in aquaculture, about 3 mmt annually in China alone [23]. This fish destined for non-human consumption was excluded from our calculation of total edible aquatic animal-source food production based on FAO Fishery and Aquaculture Statistics yearbook data [24–27]. Fish diverted to non-human consumption is listed in the FAO yearbooks as 'For other purposes', and includes two sub-items: 'Reduction' and 'Miscellaneous purposes'. Conversion factors were calculated using these data and applied to all non-human consumption prior to 2007. It was assumed that all fishmeal and fish oil not obtained from fish processing by-products originated from capture fisheries [17,28,29] and that the proportion of primary fish

production diverted to non-human use was the same for China as for the rest of the world due to non-existence of China specific statistic data.

The FAOSTAT database was used to analyse the following categories of terrestrial animal-source food: 1) beef and buffalo; 2) pig; 3) poultry (chicken, duck, goose, guinea fowl and turkey); and 4) total (Total world animal-source food production included ass, buffalo, camel, cattle, goat, horse, mule, other camelids, other rodents, pig, rabbit, sheep, and chicken, duck, gam, goose, guinea fowl and turkey.

FAO reports total terrestrial animal-source food production from both commercial and farm slaughter in terms of dressed carcass weight, i.e. including bones and excluding offals and slaughter fats [14]. Production of beef and buffalo animal-source food includes veal, and pig includes bacon and ham in fresh equivalent. Poultry includes animal-source food from all domestic birds and refers, wherever possible, to ready-to-cook weight. The concept of dressed carcass weight varies widely from country to country, according to species and breeds of livestock, what they are fed and the environment in which they are raised. It may include edible offals (head, tongue, brains, heart, liver, spleen, stomach or tripe and, in a few countries, other parts such as feet, throat and lungs) as well as inedible offals. Slaughter fats (unrendered fats that fall in the course of dressing carcasses) are recorded as either edible or inedible according to country practice. Inedible parts generally include hides and skins (except in the case of pigs), hoofs, and stomach contents. Even animal parts not considered edible may routinely end up in the human food chain after processing. Differences in the methods used to report aquatic food and livestock production mean that the former has been

consistently overestimated relative to the latter in previous studies.

China's huge contribution to production of both aquaculture and certain terrestrial animal-source foods obscures trends for the rest of the world. Analysis was thus conducted and reported separately for the world, China (mainland, excluding Hong Kong, Macao and Taiwan), and the world excluding China. Because of the uncertainty around the accuracy of global aquaculture production statistics, production data were rounded to whole numbers, and growth rates were reported to one decimal place [30].

3. Results and discussion

3.1 Re-evaluating global aquaculture production

Policy and academic literature on aquaculture routinely asserts that aquaculture has been, is today, and will continue to be the fastest growing food-producing sector in the world. This so-called conventional wisdom is so entrenched that it is frequently the first sentence of papers on aquaculture, justifying the study. Examples of such statements are quoted extensively below to illustrate the pervasiveness of this mantra. Perhaps the most common statement is the definitive: 'Aquaculture is the fastest growing food-producing sector in the world' [4, p2]. Variations on this core statement abound. Aquaculture is referred to variously as the 'fastest-growing food-producing sector in the world' [6, p34], the 'fastest growing animal-source food-producing sector' or 'animal-source food protein sector', 'over half a century', or 'over the last two', 'three' or 'four decades' [5,7,38–42,16,31–37]. Furthermore, 'Aquaculture has continued to show sustained growth, outpacing all other food-producing sectors' [5, p153]; 'Aquaculture is

projected to remain the fastest growing food commodity sector' [43, p269]; and, 'aquaculture will continue growing faster than the animal-source food-producing sectors' [44, p96]. Numerous other studies make similar claims (e.g. [45,46]).

However, more rigorous examination of the composition of global aquaculture production refutes these statements, particularly when edible yields are taken into account. From 2011-2015, the 5-year average annual world production of farmed aquatic food (live weight equivalent) totalled 95 mmt including aquatic plants, or 70 mmt with aquatic plants excluded (Figure 1). This underlines how the inclusion of seaweed production in comparisons with terrestrial animal-source food results in a highly inflated estimate of aquaculture's contribution to the global food system (e.g. [43]). Moreover, after accounting for edible yield, the total quantity of aquatic animal-source food available for human consumption was equivalent to only 46 mmt (dressed weight of crustaceans, finfish and molluscs) (Table 1). This is equivalent to only 66% of total reported aquaculture production including seaweeds, or 48% excluding them.

Converting total aquaculture production to edible aquatic animal-source food underlines the relative importance of the contributions of freshwater and marine aquaculture to global food security. Mariculture (marine aquaculture) accounted for 55% of total reported world aquaculture production in 2015 [9] but was dominated by molluscs and seaweeds. After excluding seaweeds, mariculture contributed only 38% to total aquaculture production, falling to just 20% after converting to edible weight.

The loss of weight during processing (i.e. the live weight to edible weight conversion

factor) is much lower for finfish than for crustaceans and molluscs (13% compared to 62% and 83%, respectively) (Table 1). Finfish comprised 89% of the total edible aquatic animal-source food derived from aquaculture. Crustaceans and molluscs contributed only 5% each, while 'other aquatic animals' [13] accounted for the remaining 1%. This means that the vast majority of the world's farmed edible aquatic animal-source food still are finfish originating from freshwater production systems. Farmed finfish range from basic food staples to luxury items and make significant contributions to the human diet, particularly in the major producing countries in Asia [47]. In contrast, crustaceans are consumed mainly as a luxury food and, along with molluscs, contribute little to food security at the global scale.

Figure 1 here

Table 1 here

3.2 Re-evaluating aquaculture growth rates

Reports that aquaculture production growth rates are slowing are nearly ubiquitous as those claiming that aquaculture is the world's fastest growing food production sector (e.g. [48]). Causal factors reported include increasing scarcity of locations for optimal production [28,43]; land and space constraints [44,45,49,50], water constraints [28,43,44]; high cost of feeds [28,43,45]; environmental issues, especially eutrophication from aquaculture wastes [45,49–51]; social constraints [51]; public concerns about aquatic production and fish quality [52]; and increasing competition from countries with lower production costs [16,53].

Only belatedly has it been recognized in the literature that a declining annual growth rate does not lead necessarily to insufficient production (e.g. [11]). Concern was expressed nearly two decades ago that a declining growth rate in carp aquaculture in China, would eventually lead to a shortage of fish there [31]. However, the total production of carps in China continued to rise over the past two decades (from 11 mmt in 2000 to 21 mmt in 2015 - a 99 % increase in total production in 15 years [54]). Thus, concern about China having not been able to produce enough relatively cheap fish for national consumption has proven unfounded. Concerns about declining rates of growth have also proven unfounded at the global scale. Projected global production of farmed fish in 2030 under scenarios of baseline, moderate and accelerated supply have been estimated at 93.6 mmt, 101.2 mmt, and 116.2 mmt, nearly all of which would be supplied by aquaculture [16]. The rates of aquaculture growth required to meet these targets were 1.7%, 2.2% and 3.0% respectively. These rates are all well below the 2011-2015 average growth rate of around 6%.

In fact, there has been an inverse relationship between annual aquaculture production (mmt) and annual production growth rate (%) over the past two decades. Total aquaculture production has continued to increase sharply even as the annual percentage growth rate has declined and then stabilized at lower levels (Figures 2 & 3). There was also a similar inverse relationship between the average growth rate (%) and net growth (mmt/year) of global aquaculture. At 2.6 mmt, the net average annual growth of world edible aquaculture production for the period 2011-2015 was the highest ever recorded, with 1.4 mmt for China and 1.2 mmt for the world minus China (Figure 4).

Similar inverse relationships between annual production and growth rate were apparent for both China and the world, because of China's predominance in global aquaculture production (supplying 49 mmt out of 80 mmt, or 62 % of the total in 2016) [17]. The pattern for the world excluding China was different. Here, growth rate (%) remained fairly constant over time, but with a smaller increase in total production (mmt) than China, from a similar level of the baseline of production during the period 1981-1990 (Figures 2 & 3).

Figure 2 here

Figure 3 here

Figure 4 here

Misinterpretation of growth rates has led to misunderstandings about the development of aquaculture production relative to terrestrial animal-source food as growth rate is a less useful statistic than is generally realized. Expressed in percentage terms, growth rates are usually highest when starting from a low base, and decline as the size of base grows. The best example of this is human population growth. This continues to be a major concern even though the growth rate has declined for more than 50 years from a peak of 2.2% in 1962 with a population of 3.1 billion to 1.2% in 2015 with 7.4 billion people, and has been predicted to reach 11.2 billion by 2100 with a growth rate of only 0.1% [55]. This example illustrates the limited value of emphasising growth rates without considering the size of the base value to which they relate.

There are many explanations for declining aquaculture growth rates in the literature but seldom the primary reason, the nature of statistics. Both total and net aquaculture production continued to rise with a declining annual growth rate so the constraints commonly given have not stopping the increasing growth in production in most areas of the world, and especially in Asia, which dominates global aquaculture production.

3.3 Re-evaluating the contributions of aquaculture and capture fisheries to aquatic animal-source food supply

FAO (2016) reported that the supply of fish for direct human consumption originating from aquaculture overtook that from capture fisheries for the first time in 2014. A subsequent revision of historical capture data indicated that aquaculture became the main source of fish for human consumption in 2013 [11]. The same report estimated that aquaculture production would surpass total capture fisheries production (i.e. including fish utilised for non-food uses), in 2021, and that aquaculture was expected to contribute 58% of total food fish consumed in 2026 [10].

The total reported global production of capture fisheries and aquaculture, excluding aquatic plants, was 169 mmt in 2015 [13]. Aquaculture accounted for 45% (76 mmt) of this production, with capture fisheries providing 55% (93 mmt). After excluding fish destined for non-human consumption, global capture fisheries output stood at 72 mmt, providing less than half of the fish destined for direct human consumption. However, after converting aquaculture and capture fisheries production to edible aquatic animal-source food equivalents, capture fisheries still account for more edible aquatic animal-source food than aquaculture. The total quantity of edible animal-source food from capture fisheries and aquaculture in 2015 stood at 104 mmt, of which 54 mmt (52%)

originated from capture, and 50 mmt (48%) from aquaculture. Capture fisheries continued to account for a larger share of edible aquatic animal-source food than aquaculture because aquaculture produced much larger quantities of molluscs than capture fisheries, with a much lower edible yield than fish (a conversion factor of 6.0 for molluscs, compared to only 1.15 for fish [15]).

China exerted a smaller influence on the overall global production of total edible aquatic animal-source food than on the production of farmed aquatic animal-source food because its capture fisheries production was smaller than its aquaculture output.

3.4 Re-evaluating the relative contributions of edible animal-source foods from aquaculture and terrestrial animal production

It has been widely reported that the world reached a milestone in the evolution of the human diet in 2011 when total farmed fish production exceeded beef production [56–59]. It has also been predicted farmed fish will overtake both poultry and pork to become the world's leading source of animal protein by 2023 [56]. As shown in the following analysis, these claims are misleading because they compare edible beef (dressed carcass weight) with unprocessed aquatic animal-source food, thereby biasing the latter figure upward.

Average annual global (edible) production (mmt) of pigs and poultry for the period 2011-2015 were both higher than all other animal-source foods, at just over 100 mmt each, followed by beef at about 65 mmt. In contrast, edible aquatic animal-source food from aquaculture amounted to 46 mmt (Figure 5a). Edible aquatic animal-source food

derived from aquaculture therefore amounted to only 62% of reported global beef production. In China, production of edible aquatic animal-source food was much higher than that of beef (Figure 5b) but beef production was much greater than production of edible aquatic animal-source food in the world excluding China (Figure 5c), underlining the influence of Chinese aquaculture production on comparisons with the rest of the world.

In quantity terms, global production of poultry increased faster than that of farmed aquatic animal-source foods (Figure 5a). Production of aquatic animal-source foods derived from aquaculture grew at a similar rate to production of pigs, and faster than that of beef. Pigs dominated animal-source food production in China at over 50 mmt, double the quantity of edible aquatic animal-source food from aquaculture (25 mmt) (Figure 5b). Production of farmed edible aquatic animal-source food in China was a little higher than poultry at 18 mmt, with beef trailing at 6 mmt (Figure 5b). Pork was the major animal-source food consumed in China, despite China's dominance in global aquaculture production, as China produced almost 500 m pigs a year, half of all the pigs in the world [60]. In the world excluding China, poultry accounted for the highest production of any animal-source food (Figure 5c). Production of beef and pig was similar while that of farmed aquatic animal-source food trailed behind all three terrestrial animal-source foods, again demonstrating the influence of China on global trends.

Figure 5a, 5b & 5c here

3.5 Re-evaluating total production of aquatic and terrestrial animal-source foods

Two recent high profile papers reported that, globally, "In 2010, the quantity of fish produced was twice that of poultry and three times that of cattle" [3, p178; 43]. This claim appears to be based on a diagram presented in [43], which gave a figure for global fish production totalling 173 mmt including 7-10 mmt of discards of fish from capture fisheries made prior to landing, 12 mmt of post-harvest losses, 17 mmt of fish used to manufacture fish meal and fish oil used in animal and fish feeds, and 6 mmt of ornamental and bait fish. However, as reported by the same authors, only 131 mmt of this fish was available for direct human consumption [43]. Moreover the 173 mmt figure was based on live-weight rather than dressed weight, further distorting the comparison with supply of terrestrial animal-source foods.

Our own analysis indicated steep increases in global production of edible terrestrial and aquatic animal-source foods, with average annual global production of pig and poultry for the period 2011-2015 standing at 115 mmt and 110 mmt, respectively, ahead of aquaculture and capture fisheries with a combined contribution of 98 mmt, with beef around two-thirds of that (68 mmt) (Figure 6a). Poultry showed the steepest increase in global production and will likely soon exceed production of pork, based on current trends**.** Beef showed a much slower increase in global production, particularly in recent years.

China in contrast, showed distinctly different rates of increase and recent levels of production for each commodity, with pig, edible aquatic animal-source food, poultry

and beef in descending order (Figure 6b), as also reported by Tacon and Metian (2013) [15]. In the world excluding China, poultry showed the highest level of production, with total edible aquatic animal-source food, beef and pork making similar but lower contributions (Figure 6c). Poultry production in the world excluding China grew much faster than aquatic and other terrestrial animal-source foods and may ultimately come to dominate global animal-source food production.

Figure 6a, 6b, 6c here

Perhaps the fairest comparison is between total aquatic edible animal-source food (crustaceans, finfish and molluscs from aquaculture and capture fisheries) and total terrestrial animal-source food (beef and buffalo, pig, and poultry). Total terrestrial animal-source food production in 2015 was three times higher than total aquatic animal-source food production. The former, at 324 mmt dwarfed the latter at just over 100 mmt, and was six times greater than that from aquaculture (around 50 mmt). Furthermore, despite a lower average annual growth rate in percentage terms, total terrestrial animal-source food production grew faster than total edible aquatic animal-source food production because it expanded from a much higher level of basal production (Figure 7).

Figure 7 here

3.6 Why have these myths arisen and is the aquaculture sector different to any other?

The way in which data are interpreted reflects a difference in the disciplinary background (bubbles) of the professions. Disciplines in science have grown

progressively narrower with increasing specialization resulting in the limited ability of specialists to see the whole system to which their knowledge relates [61–63], in this case the relative importance of aquatic and terrestrial animal-source foods. Most specialists in aquaculture still have a natural science, productionist and, typically, a fishery science orientation [63,64]. 'Specialized deafness' [62] also explains the ongoing incoherence in 'blue revolution' narratives in which mariculture and aquaculture become subsumed, leading to unrealistic prominence and projections for marine aquaculture [65,66].

Competition for resources means that scientists portray results to maximise attention. 'Science spin' is endemic in biomedical research [67] and inappropriate claims and extrapolations are commonplace. Selective reporting and presentation of more robust or favourable data to the case being made are central to spin. The contention that aquaculture is 'the fastest growing food production sector in the world' reflects not only ignorance of the broader food system but also may also confer advantage in a global race for resources. The follow-up messaging 'but growth is slowing down and food insecurity is a likely outcome' compounds this strategy.

4. Policy implications

The role of fish as an accessible, affordable and bioavailable animal source food within broader diets needs to be couched with the knowledge that plants contribute more protein and dietary energy overall [68,69]. The role of fish may be more critical in terms of supplying micronutrients and avoiding 'hidden hunger' [70,71]. However, increases

in farmed fish production are increasingly reliant on the same set of feed ingredients used for terrestrial livestock production [72] while the need to meet human nutritional needs within the planetary boundaries is becoming ever more pressing given a growing global population with rapidly increasing purchasing power [73].

Most analyses based on Life Cycle Assessment (LCA) suggest that aquatic animal-source foods often have lower global environmental impacts and exert less direct and indirect impacts on land use and biodiversity than terrestrial livestock [74,75]. Some studies have produced optimistic projections for ameliorating the expected impacts of increased consumption of animal-source foods through dietary change towards a higher proportion of farmed seafood (e.g. [76]). However such scenarios are built on data for harvested (live weight equivalent) production rather than edible portions. The choice of live weight equivalents or edible portions as the functional unit for analysis could lead to significant under-estimates of the impacts of aquatic animal-source foods, vis-a-vis terrestrial ones. This is particularly critical as the proportion of fed aquatic species, compared to un-fed filter feeding animals, continues to grow and compete with terrestrial livestock for the same feed ingredients. Additionally the method for allocating impacts to co-products (processing wastes) and cultural variance in what is directly consumed will affect interpretation.

Ultimately, ensuring availability of aquatic food at an affordable price that is competitive with terrestrial substitutes will make an important contribution to sustainable food futures. A better comparative understanding should inform future investment in research aimed at contributing to these goals. For example there has been

a major difference in investment to date in genetic improvement of terrestrial and aquatic animal source foods [77,78]. The rapid improvement in productivity of Atlantic salmon, white shrimp and Nile tilapia strains within a few generations is indicative of the potential of concerted efforts to support genetic improvement [79].

A broader point is that simplistic measures of growth rates and production have limited value in understanding broader benefits. Productivity of terrestrial livestock production is highly dependent on a very few highly inbred strains making these systems vulnerable to shocks as well as their dependence on industrial inputs whereas the diversity of emergent aquaculture systems and natural wild aquatic animal-source foods provides a resilient and versatile dietary component. Can the competitive gap between highly improved terrestrial and aquatic animal-source food be closed? Most aquatic animal-source food remains genetically wild and unimproved so the potential benefits for the application of modern breeding on productivity for aquaculture are much greater than for animal husbandry [79,80]. The scope for technological and institutional innovation remains huge [81].

Greater clarity is required on the relative contributions of aquaculture, capture fisheries and terrestrial animal-source food to global food supplies. Realistic interpretation of data is required for aquatic food to be integrated into food systems thinking and policy rather than being marginalised, as is typically the case [43]. However, as this paper highlights, widely reported imprecise statements surrounding the statistical relationship between annual growth rate and production originating from aquaculture obscure the dynamics of change within the global aquaculture sector. Furthermore, generalized

statements about aquaculture are often misleading and obscure the uneven distribution of global production.

5. Conclusions

This study has challenged four imprecise, misleading and oft-repeated statements that pervade the academic and policy literature on aquaculture. This so-called conventional wisdom has muddied the waters surrounding the relative contributions of aquaculture, capture fisheries, and terrestrial livestock to the global food system, and partially obscured ongoing dynamics of change.

The study attempted to correct for bias inherent in the comparison of unprocessed (live weight equivalent) aquatic animal-source foods, with dressed terrestrial animal-source foods. This was done by converting aquatic animal-source food production to edible aquatic animal-source food. The common statement that aquaculture was the fastest growing food-producing sector was shown to be true only in terms of annual growth rate (%), but not in terms of production (mmt) expressed as both annual production (mmt) and net annual production growth (mmt). There was a distinct inverse relationship between both annual production and net growth, and the average growth rate (%) of global aquaculture over the past three decades, demonstrating that total aquaculture production continued to increase despite a decline in growth rate.

The main misunderstanding highlighted by the study was that while aquaculture was the fastest growing food production sector in terms of annual percentage growth rate, it was dwarfed by terrestrial animal-source food production in terms of both total and net

production (mmt). Although the growth rate of aquatic animal-source food production was higher than that of terrestrial animal-source food, the rate of increase of total production of the latter was greater because of its larger initial production base.

Explanations of the declining growth rate of global aquaculture advanced in the literature seldom acknowledged the primary reason for the overall decline: that growth is occurring from an ever-higher base. Commonly cited constraints to the expansion of aquaculture did not inhibit its growth in most areas of the world, and especially in Asia which dominated global aquaculture production. Aquaculture production continued to increase during the past three decades, and is likely to do so in the future to meet the needs of an increasingly populous and affluent world.

The oft-quoted milestone in fish global supply, that aquaculture overtook capture fisheries as the main source of fish for human consumption for the first time in 2013 [5,10], was shown to be incorrect. When only one year production was considered, global production of edible aquatic food from capture fisheries plus aquaculture was estimated in this study at 104 mmt for 2015; aquaculture at 50 mmt comprised 48% of the total, with capture fisheries at 54 mmt and 52% of the total. Capture fisheries still produced more edible aquatic food than aquaculture in 2015 although the gap was closing.

Claims that the production of aquatic animal-source foods had outstripped those of terrestrial animal-source food were also shown to be inaccurate. Another milestone in the evolution of the human diet was reported to have been reached in 2011 when global

farmed fish production exceeded that of beef [56–59]. However, our analysis showed that global edible animal-source food from aquaculture in 2015 was only 74 % of global beef production.

The study also indicated that pork and chicken production increased more rapidly than that of farmed fish, and that poultry was the fastest growing animal-source food producing sector considering annual production rather than annual percentage growth rate. Our analysis indicated aquaculture and capture fisheries combined contributed similar levels of edible animal-source food to pigs and poultry, at slightly over 100 mmt each, with beef around half of that. This finding contradicted claims that total fish production from aquaculture and capture fisheries was twice that of chicken and three times that of cattle in 2010 [3,43]. This discrepancy was accounted for by the inclusion of seaweeds and use of live weight equivalents when reporting production of crustaceans, finfish and molluscs, rather than edible aquatic animal-source food as in the present study.

Poultry showed the largest increase in annual global production and, based on continuing trends, will probably soon exceed the combined production of both edible aquatic animal-source food from aquaculture and capture fisheries and pork. However, the recent production of poultry production had exceeded that of the total aquatic animal-source food from aquaculture and capture fisheries for the world excluding China; and the steep increase in production of poultry suggested that it would likely increasingly outpace the production of edible aquatic animal-source food.

Global total edible terrestrial animal-source food (beef and buffalo, pig, and poultry) dwarfed the total global production of edible aquatic animal-source food (crustaceans, finfish and molluscs from aquaculture and capture fisheries combined) in 2015, 324 mmt and just over 100 mmt, respectively. Thus, global terrestrial animal-source food production was more than three times greater than production of edible aquatic animal-source foods, and more than six times greater than the nearly 50 mmt produced by aquaculture. Furthermore, globally, terrestrial animal-source food production increased faster than edible aquatic animal-source food production, expanding with a lower annual growth rate but from a much higher basal production level.

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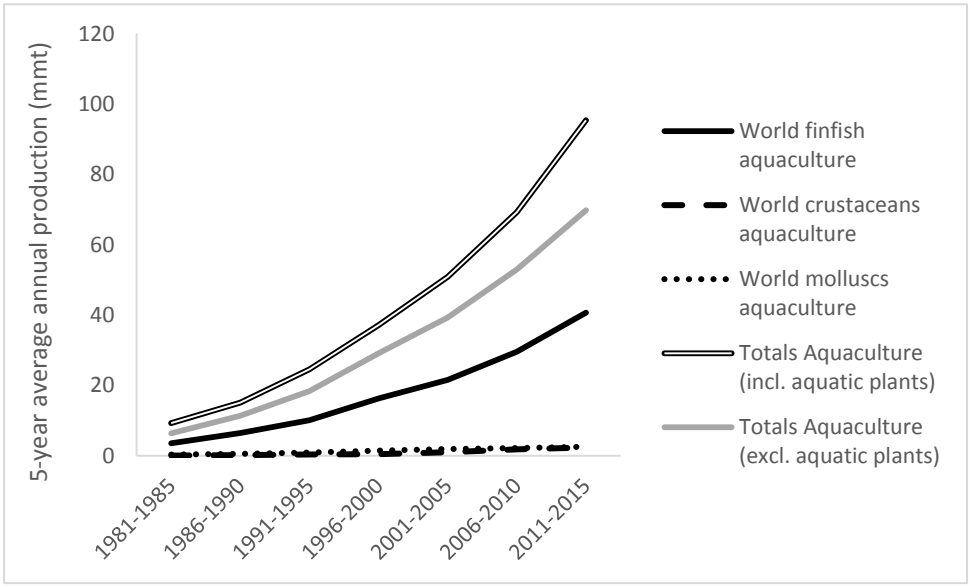
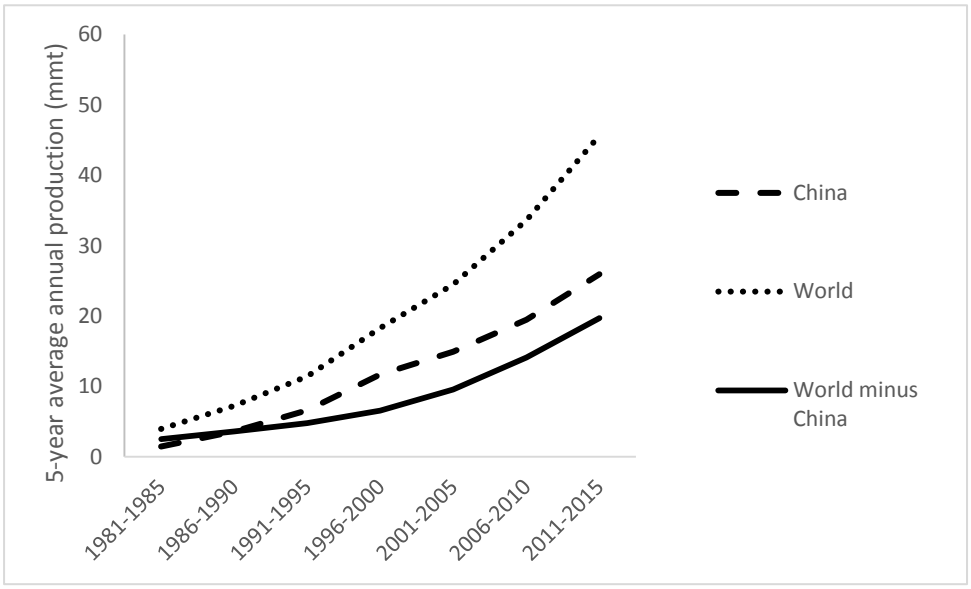
Table 1: Global production of fish, crustaceans and molluscs from aquaculture and capture fisheries (live weight equivalents and edible animal-source food), 2011-2015 average*.

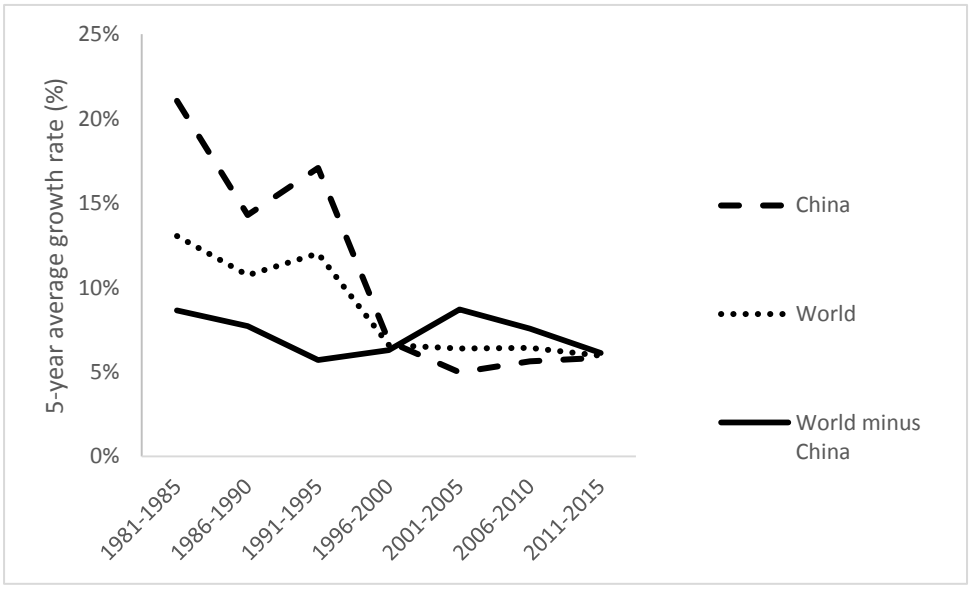
Production type	Production, live weight (mmt)	Share of live weight production (%)	Production, edible animal-source food	Share of edible animal-source food (%)	Edible aquatic animal-source food as a share

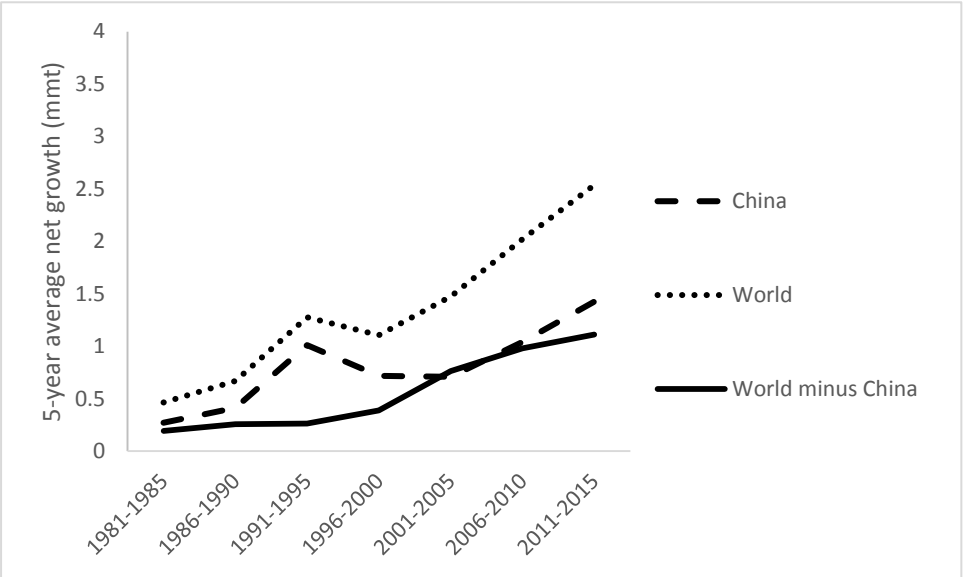
				(mmt)		of live weight (%)
Aquaculture	Fish	47	68	41	89	87
	Crustaceans	7	10	2	5	38
	Molluscs	15	22	3	5	17
	Total	70	100	46	100	67
Capture	Fish	56	81	49	93	87
	Crustaceans	6	9	2	4	38
	Molluscs	7	10	1	2	17
	Total	70	100	52	100	81

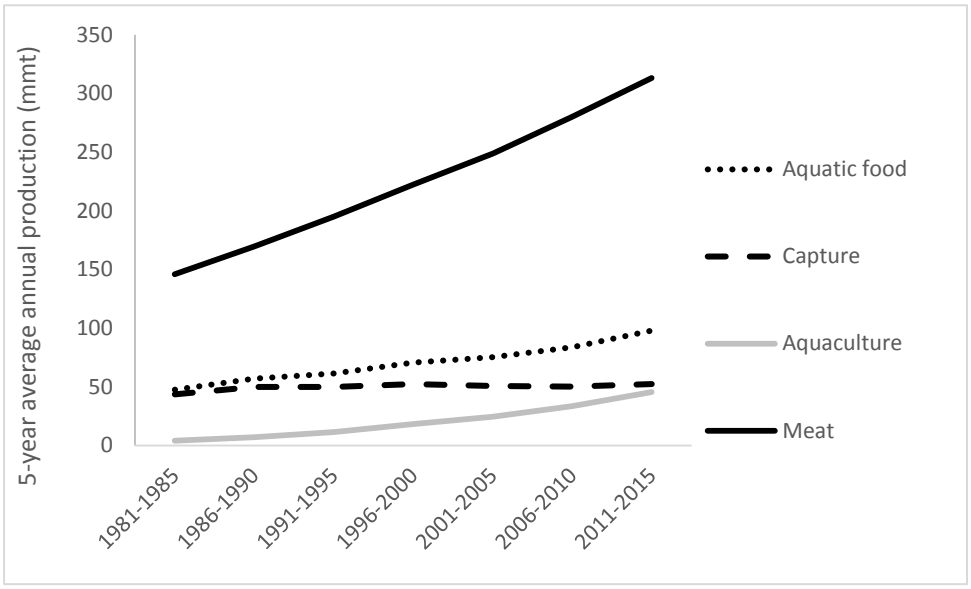
*Note: Percentage contribution rounded to whole numbers so totals not exactly 100%. Calculated based on data from [23], non-human consumption was excluded from the calculation of edible aquatic food production from capture fisheries production.



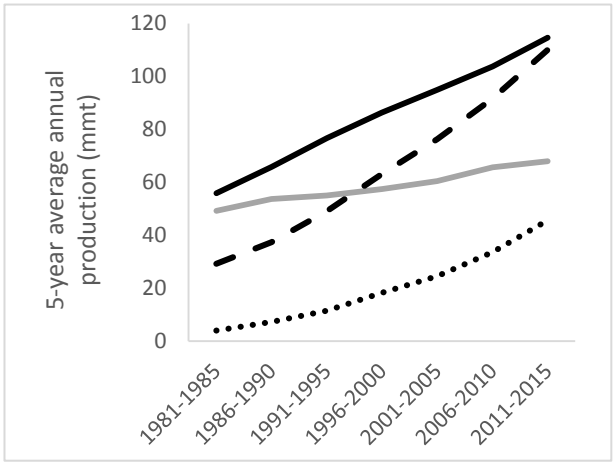

5-year average annual production (mmt)
60
50
40
30
20
10
0
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
China
World
World minus China

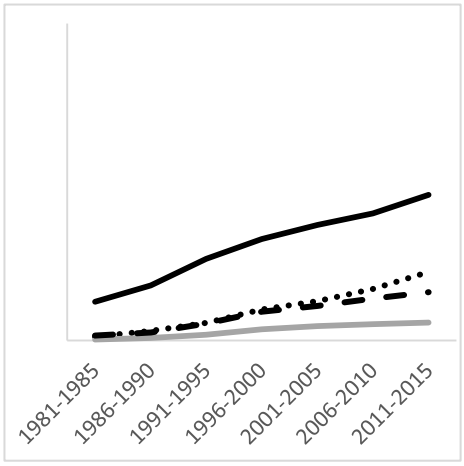

5-year average growth rate (%)
25%
20%
15%
10%
5%
0%
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
China
World
World minus China


5-year average net growth (mmt)
4
3.5
3
2.5
2
1.5
1
0.5
0
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
China
World
World minus China

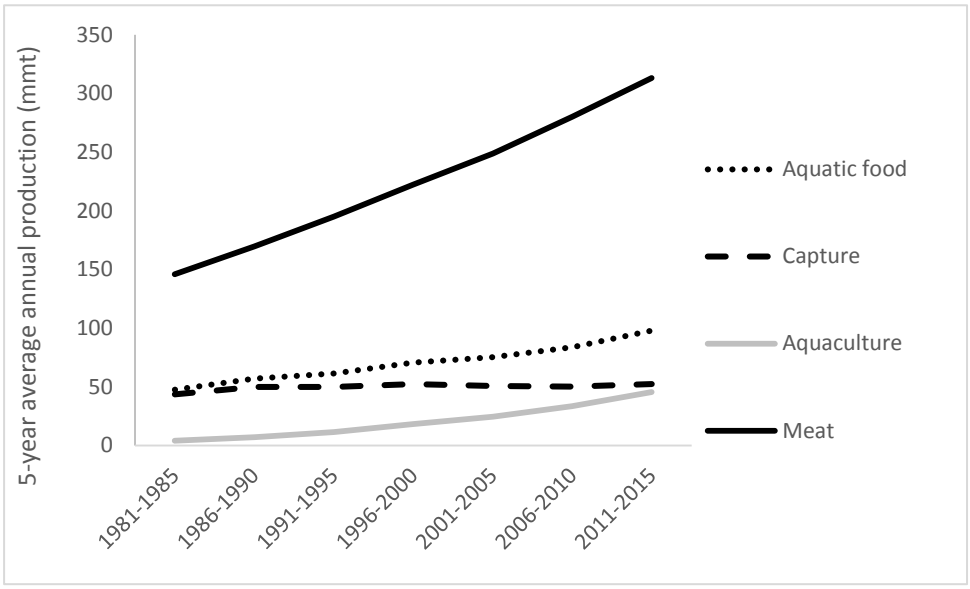

5-year average annual production (mmt)
350
300
250
200
150
100
50
0
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
Aquatic food
Capture
Aquaculture
Meat

(a) **(b)**


5-year average annual production (mmt)
120
100
80
60
40
20
0
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015


1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015


1981-1985
1986-1990
1991-1995


5-year average annual production (mmt)
350
300
250
200
150
100
50
0
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2010
2011-2015
Aquatic food
Capture
Aquaculture
Meat