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Ocean foods ecosystems for planetary survival in the anthropocene

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The Global Climate-Population Crisis

The world's current population is estimated at 7.3 billion persons. Shockingly, demographers now predict that - contrary to previous projections - global population will not stabilize, and that by 2050 Earth may be home to an estimated 9.7 billion people (FAO, 2016) and upwards to 12.3 billion people by 2100 (Gerland *et al.*, 2014). Current and continued global population growth is due to growth in Asia and Africa. Dona Meadows (n.a.) captured this growth in short by stating that if the world were a village of 1,000 people, there would be: 584 Asians, 124 Africans, 95 Europeans, 84 Latin Americans, 55 residents of the former USSR and its satellites, 52 North Americans, and 6 Australians/New Zealanders. Global population has over time become more concentrated in cities. The world's population was estimated to be 3% urban in 1800, by 2007 it had become 50% urban (United Nations, 2008). About 44% of the world's population lives in cities within 150 km of the ocean. China's coastal urban population is estimated to exceed 400 million people (United Nations Atlas of the Oceans, 2000).

Human population pressure has accelerated needs for food, energy, water, and shelter. These human needs have caused in turn a massive transformation of the Earth's biogeochemical systems (Steffen *et al.*, 2004, Rockstrüm *et al.*, 2009). Kolbert (2014) has called this process the "Sixth Extinction" where half of the Earth's land has been transformed; half of the world's available freshwaters have been tapped; and the current atmosphere contains about 400 ppm of carbon dioxide, a level not seen in 800,000 years (Hönisch *et al.*, 2012). In 2001, the leaders of the world's four scientific networks that monitor ecosystem health issued a white paper titled the "Challenges of a Changing Earth: Declaration of the Global Change Open Science Conference Amsterdam". They stated that the Earth "has moved well outside the range of the natural variability exhibited over the last 500,000 years at least. The nature of changes now occurring simultaneously in the Earth system, their magnitudes and rates of change are unprecedented." (IGBP *et al.*, 2001). Scientists have advanced that Earth systems are in such rapid change due to human influences that the Earth has entered a new geological epoch dominated not by biogeochemistry, but by man, and have

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termed this new era the "Anthropocene" (Zalasiewicz *et al.*, 2008).

The world's oceans play a dominant role in maintaining the health of the Earth's ecosystems. The oceans, especially the coastal oceans within Exclusive Economic Zones (EEZs), serve as invaluable current and future aquatic food sources vital to the world's social economy, and to human health and wellness. Coastal ocean ecosystems are among the most productive and biologically diverse ecosystems on Earth. Eighty percent of the 13,200 known species of marine fish are coastal species. Fish and fish products provide about 16% of the world's intake of animal proteins consumed (about 7% of all proteins) (Badjeck *et al.*, 2013). Fish provides about 3 billion people with almost 20% of their intake of animal protein, and 4.3 billion people with about 15% of their total protein. Fishery products are one of the most highly traded foods and feed commodities globally, with 167.2 million metric tons (MMT) harvested in 2014 and involving an estimated 56.6 million people (FAO, 2016).

However, due to the explosive growth of the world's coastal cities, ocean ecosystems are being destroyed, degraded and overwhelmed by pollution. Coastal nitrogen pollution and rapidly increasing atmospheric carbon dioxide levels have made the ocean about 30% more acidic than during the industrial revolution. If such trends continue it is predicted that by 2100 the ocean's pH will be lower than any time in 300 million years, a frightening scenario to be avoided at all costs (Hönisch *et al.*, 2012). Brown (2009) has called for urgent action that would be "mobilizing to save civilization". Most national decision makers are not prioritizing for the future extraordinary magnitude of, and interrelated planning needs of, the world's coming coastal urban, land/water, food needs, and the implications of massively expanding food production on the Earth's natural resources.

In the midst of these enormous changes occurring and those coming to 2050 and 2100, are there possibilities to avoid catastrophes?

Food in the Anthropocene

The United Nations Food and Agriculture Organization (FAO) predicts that due to population growth that annual meat production will need to rise from 200 MMT to 470 MMT by 2050 (FAO, 2009). Foley (2014) stated that agriculture occupies 39% of all land on Earth, with 46% of Earth "undeveloped lands", and 16% "other". However, about 33% of the world's agricultural land has been lost due to erosion or pollution over the past 40 years; this rate of loss exceeds the replenishment of soils by natural processes (Hooke *et al.*, 2012). On a global basis soil degradation is caused primarily by agriculture/overgrazing (63%), deforestation (37%), and industrialization (4%) (Hooke *et al.*, 2012). Agricultures' future expansion is projected to consume not only all of the world's remaining fertile lands (Bruinsma, 2009), but could also encroach upon, make dysfunctional, or destroy completely all of the world's great remaining bioreserves for Nature (Morton *et al.*, 2008). Vast natural areas of South America and Africa have been and are being transformed for soybeans, livestock, and industrial fuel and oil production, primarily for export markets in Asia, Europe, and North America. For example, Mato Grosso State in Brazil has had widespread destruction of its indigenous pampas/grassland ecosystems due to the expansion of soybean farming, primarily for Asian markets (Morton *et al.*, 2008).

Only 2.5% of all the water on Earth is freshwater. Of this, about 69% is frozen as snow and ice, and more than 33% is stored groundwater. This means that only 0.3% of all the freshwaters on Earth are readily available as surface water in lakes, swamps, rivers, and streams. Very little of the accessible fresh water left on Earth is available for the expansion of agriculture. Agriculture accounts for about 70% of the freshwater withdrawals in the world and is the main factor behind the increasing global scarcity of freshwater (Alexandratos, 2005, Bruinsma, 2009). Groundwater extraction by agriculture exceeds recharge in 87% of known aquifers (Gleick, 1996). Expansion of irrigated agriculture in East Asia is predicted to increase to over 36% by 2050 (Bruinsma, 2009). Water scarcities preventing large scale expansion of irrigated agriculture are of great future concern in South Asia, North Africa, and parts of the Americas.

National Geographic Magazine completed an 8-month series on how a future world was going to feed itself and included a piece by Foley (2014) on agriculture, and one by Bourne (2014) on aquaculture. Foley (2014) proposed five important steps to increase food production from the terrestrial sphere of the Earth; "step one: freeze agriculture's footprint, step two: grow more on farms, step three: use resources more efficiently, step four: shift diets, step five: reduce waste. These are mostly part of the well-known movement towards "sustainable intensification" of agriculture (Garnett *et al.*, 2013). While all of these steps are well reasoned and certainly admirable, steps two to five - changes to agriculture practices and diets - may be much easier to implement than "freezing" agriculture's footprint. Future food projections to 2050 and beyond by agricultural scientists depend upon continued expansion of arable lands into what are called "unfavorable agroecological and often also unfavorable socioeconomic environments" (Bruinsma, 2009), and, even more alarming, into the Earth's last remaining natural ecosystems and reserves. Providing food for the future from the Earth's terrestrial sphere via the expansion of arable lands for agriculture will result in massive ecosystem destruction (mainly deforestation); this will occur unevenly across the Earth and threaten especially the biodiverse ecosystems of sub-Saharan Africa and South America, "although less so than in the past" (Bruinsma, 2009).

Bruinsma (2009) states that about 90% of the remaining 1.8 billion ha of available arable lands is in sub-Saharan Africa and South America, and "half…is concentrated in just seven countries (Brazil, Democratic Republic of the Congo, Angola, Sudan, Argentina, Colombia, Bolivia)". These countries are also expanding industrial agriculture for non-food exports, e.g. oil palm, biofuels, and soybeans. FAO (2006) stated that oil crops have been responsible for much of the increases in total cultivated lands in the world, often at the expense of forests. Alexandratos (2005) points out that many countries with high population growth rates with the projected greatest food needs are highly dependent on agriculture and states "which combined with their resource constraints, could make solving their food security problems extremely cumbersome if not impossible, at least without external assistance and/or *by finding non-agricultural development opportunities"*.

Nearly all food systems analysts considering that the future of food to 2050-2100 consider "food" as synonymous with "terrestrial foods". Their projections rely upon the expansion of arable lands (= conversion of natural terrestrial ecosystems), expansion of irrigation systems, and "sustainable intensification" of agriculture. Reforming agriculture is required. But in

Table 1. *World Seafood Trade in 2014 (FAO, 2016).*

Exporting Nations	Billions US$	Importing Nations	Billions US$
China	20.98	United States of America	20.32
Norway	10.80	Japan	14.84
Vietnam	8.03	China	8.50
Thailand	6.56	Spain	7.05
United States of America	6.14	France	6.67
Chile	5.85	Germany	6.20
India	5.60	Italy	6.17
Denmark	4.76	Sweden	4.78
Netherlands	4.56	United Kingdom	4.64
Canada	4.50	Korea	4.27
Rest of World	70.35	Rest of World	57.17
World Total	148.15	World Total	140.62

discussions on the future of food on Earth there is little/no recognition that the Earth is 70% ocean and 97% of all water is saltwater, and that "ocean foods" are healthier, more productive, efficient, and less consumptive of natural resources in comparison with terrestrial foods: an overall more rational investment for the future of food and natural ecosystems.

Can Ocean Foods From Sustainable Fisheries and Aquaculture Be "The Answer"?

Before examining this future vision and associated production projections, it is important to note that there is a growing global consensus that the overconsumption of terrestrial proteins is causing a global human health and wellness crisis (Micha *et al.*, 2010). Thilsted *et al.* (2016) have reviewed the broad scientific consensus that the health benefits of aquatic foods outweigh any other terrestrial animal proteins for human health and wellness. Fish have much higher concentrations of essential fatty acids, bioavailable minerals and vitamins than any terrestrial proteins. Lim *et al.* (2012) found that diets low in seafood omega-3 fatty acids accounted for 1.4 million deaths in 2010. Rimm and Mozaffarian (2006) showed that fish consumption reduced mortality from heart disease by 36%.

Fish are one of the world's most widely traded commodities. World fish trade amounted to $129 billion (HLPE, 2014). In 2012, about 200 countries exported fish and fishery products (FAO, 2014). China is the world's largest exporter of fish and fishery products; however, since 2011 China has become the world's third-largest fish importing country, after the USA and Japan *(Table 1)*. If planet Earth is 70% water, and fish are the most important source of proteins for human health and wellness, can increased aquatic protein production through fisheries and aquaculture save humanity from a terrible food-conservation-health crisis?

Fisheries can't do it

Global capture fisheries production (both for foods and industrial products) was around 90 MMT in 2010 (FAO, 2014) and increased to 93.4 MMT by 2014 (81.5 MMT from the ocean and 11.9 MMT from freshwater ecosystems) (FAO, 2016). About 87% of this is used for direct human consumption so that global aquatic food production from capture fisheries is about 81.3 MMT for a global population of 7.3 billion persons (FAO, 2016). Research by Costello *et al.* (2016) has found that the majority of the world's wild fisheries could be restored in about 10 years by implementing known fisheries governance reforms and lessons learned. They report that "applying sound management reforms…could generate annual increases exceeding 16 MMT in catch…". Applying the 87% food utilization rate above, this additional available fish for human consumption would raise annual global fisheries 14 MMT for an annual production of capture fisheries of about 95.3 MMT/year.

FAO (2014) documented that per capita fish consumption increased from 17.6 kg in 2007 to 19.2 kg in 2012. FAO (2016) found that for the first time, global per capita fish consumption reached 20 kg in 2014. They predict per capita consumption to rise even higher as a future world portends to have a more urban and wealthier population. Thilsted *et al.* (2016) found a wide range of per capita fish consumption rates globally, from 60.4 kg/capita/year (Korea) to 5.2 (India). Global fisheries production figures mask a huge disparity in apparent fish consumption (production plus imports less exports and non-food uses) (Thilsted *et al.*, 2016). However, taking the figure of 20 kg/capita/year and 9.7 billion persons (FAO (2016)'s 2050 projection; Gerland *et al.* (2014) predict upwards of 12 billion by 2100), total demand for fish could reach 194 MMT/year by 2050 and 240 MMT/year by 2100. Therefore, fixing all of the world's fisheries as proposed by Costello *et al.* (2016) would provide by 2050 an estimated 49% (95.3/194) of global fish demand. By 2100, the world's completely restored capture fisheries would only provide 40% (95.3/240) of total fish demand. FAO (2009) states that the world's annual total protein meat production will need to increase by 2050 to 470 MMT. If the world were to restore all of its capture fisheries and rely upon that for its total animal protein needs, all capture fisheries would provide by 2050 just 20% of the total global protein demands.

For the future of humanity and to preserve the remaining natural terrestrial ecosystems on Earth that provide us with essential ecosystem goods and services, it is vitally important that we accelerate the development of ecologically and socially sustainable aquaculture.

If aquaculture is the global food soultion: where?

An increasingly large share of fish entering global markets derives from aquaculture. International agencies recognize that the future growth in seafood supplies will come from aquaculture (World Bank, 2013, FAO, 2016). Aquaculture has been the world's fastest growing food production sector for more than four decades (Tveterås *et al.*, 2012). However, there is little recognition in agricultural circles that aquaculture is a much better food investment choice than the expansion of, for example, soybean agriculture or terrestrial plant and animal protein production systems to feed future populations. Nearly all scientific projections from agricultural scientists fill the food needs of future populations on the expansion of arable lands in developing nations, or on "sustainable intensification" (FAO, 2009, Bruinsma, 2009, Garnett *et al.*, 2013). "Think tanks" projecting the future of foods (Stice and Basu, 2015) project

Table 2. *Conversion Efficiencies of Feed and Emissions for Different Animal Protein Production Systems[1].*

Animals	Food Conversion Ratios	% Edible	Production Efficiencies kg dry feed/ kg edible wet mass)	kg CO_2 equiv./ kg edible meat	kg N/MT protein produced (HLPE, 2014)	kgP/MT protein produced (HLPE, 2014)
Beef	5.9	49	10.2	30 (Cederberg et al., 2009)	120	180
Pork	2.5	45	5.6	5.9 (Cederberg et al., 2009)	800	120
Chickens	2.0	59	3.1	2.7 (Cederberg et al., 2009)	300	40
Fish: Tilapia Fish: Catfish Fish: Salmon (Bjørkli, 2002)	1.5 1.5 1.1	60 60 68	2.5 2.5 1.6	Salmon 2.9 (Winther et al., 2009)	360	102
Bivalves	No feed	No feed	No feed	0.25 (suspended mussels) 1.3 (intertidal oysters) (Fry, 2011)	-27 (Hall et al., 2011)	-29 (Hall et al., 2011)

[1]From Costa-Pierce *et al.* (2012) except where cited individually.

terrestrial expansions of soybeans, pea, canola, rice, and what they call "third-generation proteins from novel plant sources…moringa" as solutions.

A global consensus of scientists is that aquaculture is much more efficient producer of high value proteins essential for human health and wellness in terms of its resource uses of space, food, energy, and water. Modern aquaculture systems produce less waste and have lower carbon and nitrogen footprints than land-based agriculture protein production systems (Costa-Pierce *et al.*, 2012, Hall *et al.*, 2011, Hasan and Halwart, 2009, Tacon and Metian, 2008, Pelletier, 2008, DeRouchey *et al.*, 2007, Rosenlund *et al.*, 2004). A global review of comparisons of production, water and energy efficiencies of aquaculture versus an array of fisheries and terrestrial agriculture systems show that non-fed aquaculture systems (e.g. shellfish, seaweeds) are among the world's most efficient mass producers of plant and animal proteins, and that various fed aquaculture systems are more efficient (or are comparable to) the most efficient forms of terrestrial animal husbandry. Studies also suggest that aquatic carnivores in the wild have been transformed in aquaculture systems to more efficient omnivores (Costa-

Pierce *et al.*, 2012). Production conversion efficiencies of feed show the superior performance of aquatic animals over terrestrial ones with lower carbon, nitrogen and phosphorus emissions in comparisons with a wide range of conventional terrestrial animal production systems *(Table 2)*. FAO (2016) stated that "fish is six times more efficient at converting feed than cattle and four times more efficient than pork." In addition, aquaculture has a huge potential to expand the protein production of "no feed" animal species. FAO (2016) reported in 2014 that world production of non-fed aquatic animals (mainly silver and bighead carps, molluscs (clams, oysters, mussels, etc.), other filter feeders (sea cucumbers, sea squirts, etc.) was about 23 MMT, or about 31% of world production of all marine aquaculture (mariculture).

Rapid technological and managerial progress combined with numerous scientific and social innovations have occurred in aquaculture over the past 20 years that have demonstrated clearly that environmentally responsible aquaculture production can create new value chains and many opportunities to produce nutritious foods in resource-efficient ways, create jobs, and help maintain healthy freshwaters and oceans (Torrissen, 2011, Future of Fish, 2014, Bourne, 2014). In addition, the "aquaculture toolbox" is a powerful scientific means to restore damaged aquatic and fisheries ecosystems worldwide ("restoration/conservation" aquaculture; Costa-Pierce and Bridger, 2002). Tidal wetland plants, mangrove forests, and seagrasses are grown using marine agronomic practices – restoration aquaculture. Aquaculture hatcheries produce seed that when placed properly in nearshore marine ecosystems establish and maintain oyster reefs. These are important examples of aquaculture creating, enhancing, and maintaining productive aquatic ecosystems, habitats and water quality in a long-term, sustainable manner.

Aquaculture is *the answer* to the looming future global food crisis, not terrestrial agriculture. However, for all of its merits and promise, aquaculture is still in its infancy. Costa-Pierce (2010) stated that "The world has watched, and is watching, a blue revolution … in China". Aquaculture is rare outside of China and a limited number of Asian nations. Asia has accounted for about 89% of world aquaculture production of fish for human consumption over the past two decades (Tables 3 a, b); in 2014, China accounted for 58% (58.8/101.1 MMT) of all global aquaculture production (FAO, 2016). Fifteen countries produced 93% of all farmed food fish in 2012 (FAO, 2014). Aquaculture has grown rapidly in Chile, Norway, Egypt, and Brazil; however, only 9 countries produce more than 1.0 MMT (FAO, 2014). All of Europe, the Americas, and Africa provide less than 5% of global aquaculture production. The share of world aquaculture production for the European Union has dropped over the past 10 years from 4% to less than 2%.

Aquaculture is largely neglected in future considerations as a major protein production system for the world. Many of the world's poorest nations have no aquaculture, and in these places all of the invaluable aquatic proteins produced and traded come from capture fisheries. In many of the world's neediest countries where aquaculture could contribute immensely to human health and wellness, aquaculture development policies and plans do not exist. State Slater *et al.* (2013), "We argue that to successfully develop in any country aquaculture must be policy-led. This policy must be built on an understanding of the socio-economic drivers, resources (human and natural), and the constraints of community members intended to be involved."

Table 3a. *Top Ten Global Aquaculture Nations and Principal Species in 2014 (FAO, 2016).*

Nations	Total (MMT)	% Inland	Primary and Secondary Species Cultured
China	58.79	44	Carps, Tilapias, Shrimp, Seaweeds (wide diversity)[1]
Indonesia	14.33	20	Marine Shrimp, Carps, Seaweeds
India	4.88	90	Carps, Marine Shrimp
Vietnam	3.41	73	Catfish, Marine Shrimp
Philippines	2.34	13	Marine Shrimp, Seaweeds,Tilapia
Bangladesh	1.96	88	Carps, Freshwater Prawns
South Korea	1.57	1	Seaweeds, Marine Fish, Molluscs
Norway	1.33	<1	Salmon
Chile	1.23	5	Salmon
Egypt	1.14	100	Tilapia
Others (in order of FAO production statistics: Japan (1.20), Myanmar (0.96), Thailand (0.93), Brazil (0.56), Malaysia (0.52), North Korea (0.51), USA (0.43))	5.11	Japan (3%), Myanmar (94%), Thailand (43%), Brazil (85%), Malaysia (21%), North Korea (<1%), USA (41%)	
World	101.09		

[1]China has the largest and most diverse aquaculture farming industry in the world. It is estimated that there are about 140 aquatic species farmed in China (90 fish, 10 shrimp and crabs, 10 shellfish and 10 algae (Likang, 2010).

Table 3b. *Aquaculture Production by Regions and Top Regional Aquaculture Producer Nations (FAO, 2016).*

Regions	Production (MMT)	Leading Producers (MMT)
Asia	65.60	China (45.47)
Americas	3.35	Chile & Latin America (2.75)
Europe	2.93	Norway (1.33)
Africa	1.71	Egypt (1.10)
Oceania	0.19	

Table 4. *Predicted Trends in Land and Water for Terrestrial Food Production to 2050 (Bruinsma, 2009).*

Global Regions	Arable Land 2005[1]	Arable Land 2050[1]	Irrigated Area 2005-2007[2]	Irrigated Area 2050[2]	Irrigation's Pressure on Water Resources (% in 2005-2007)	Irrigation's Pressure on Water Resources (% in 2050)
East Asia	2.35	2.37	85	97	8	8
South Asia	2.06	2.12	81	86	36	39
Latin/South America	1.64	2.55	18	24	1	2
Near East/ North Africa	0.86	0.82	29	36	58	62
Sub-Saharan Africa	2.36	3.00	6	8	2	2
Industrial and Industrializing Nations	6.35	5.87	68	68	4	4

[1]millions km^2; [2]millions ha.

Most global aquaculture production (89% of all production) remains - for all the continuing controversies and much misinformation over shrimp and salmon - freshwater fish (66%) and mollusks (23%) (FAO, 2014) (Table 3a). Freshwater aquaculture has increased its contribution to total farmed food fish production from 50% (1980) to 63% (2012) (FAO, 2014). Growth in freshwater aquaculture has increased while mariculture has not.

In nations where aquaculture has huge potential such as the USA, which, in an FAO study (Kapetsky *et al.*, 2013) was found to have the largest suitable area of its EEZ for mariculture development *(Table 5)*, aquaculture is opposed by "local and national interest groups and local, state, tribal, or national policies" (Knapp and Rubino, 2016). Even food analysts from "think tanks" who should be informed of aquaculture's most recent progress continue to spew out misinformed statements like,

"While fish farmed have the potential to overcome some of the environmental and efficiency deficits of meat, and the ecological devastation of ocean capture, aquaculture systems have their own challenges, particularly when it comes to water usage. Most aquaculture is done in simple pond systems, but without water treatment, these fish populations swim in a putrid cocktail of dead fish, feed, feces, and nutrients that breeds disease and can eradicate entire crops. Traditional systems are also inefficient, consuming large sums of water to produce limited quantities of fish (Stice and Basu, 2015)".

While the future growth in protein supplies has to come from aquaculture (World Bank, 2013, FAO, 2014), a global "blue

Table 5. *Fifteen Nations with the Highest Potential for Mariculture to Feed the World (Kapetsky et al., 2013).*

Nations	Cost Effective Area (km^2)[1]	FAO Overall Scores[2]	Current Status of Mariculture
USA	587,387	7	Developing
Indonesia	340,352	11	Developed
UK	242,888	18	Developing
Japan	218,753	32	Developed
Australia	218,361	11	Developing
France	177,013	26	Developing
Philippines	166,666	43	Developed
Denmark	161,082	32	Developing
India	95,634	44	Developing
Angola	50,916	17	None
Egypt	40,473	33	None
Venezuela	37,859	17	None
Yemen	25,055	28	None
Honduras	16,578	46	None
Total	2,379,017		

[1] Ocean areas of nations EEZs having suitable depths, current speeds and cost-effective economics for the development of cage (fed mariculture) and longline (non- fed mariculture) systems.
[2] FAO's assessment of the mariculture potential of these nations. The range of scores was from 3 (greatest potential) to 60 (least potential).

revolution" is not happening fast enough to meet the global food challenges of 2050 to 2100. Aquaculture is stymied by such misinformation as above; it is not eradicating poverty in the developing world; and it suffers from weak governance due to a "lack of appropriate informed policy" (Slater *et al.*, 2013). Aquaculture is rife with much misinformation, hype, advocacy, over-promotion, and failures due largely to the lack of appropriate governance, experience, and expertise. University centers of aquaculture excellence, innovation, aquaculture extension and training either do not exist, are poorly funded, or have closed their programs, many of which began in the 1970's.

The Expansion of Freshwater Aquaculture

Edwards (2015) stated that freshwater aquaculture in Asia will remain the hub of global growth in aquaculture into the future. He also argued that Asia still has vast untapped areas and available freshwaters for expansion. Asia has the world's largest populations with the highest per capita fish consumption rates fueling large markets for the continued future market expansion of aquaculture there (FAO, 2016). Does Asia have the natural resource base for the expansion of freshwater aquaculture to 2050 and beyond?

Reviewing the available data that project quantities of arable lands, waters, and future expansion of irrigation systems to 2050 in East Asia, I agree with the Edwards (2015) assessment *(Table 4)*. Almost one-third of the arable land in South and East Asia is irrigated, a share which Bruinsma (2009) projects to increase more than 36% by 2050. Expansion of irrigations systems in East Asia could allow the continued development of pond and integrated pond freshwater aquaculture, tied to the expansion of irrigation systems in Viet Nam, Cambodia, and Myanmar where aquaculture is growing rapidly (Edwards, 2009, 2015). Asian societies also have deep social-ecological-historical aquatic farming systems traditions that allow for the rapid uptake of aquaculture (Edwards *et al.*, 2002). Freshwater aquaculture in South Asia however could be constrained by water shortages and extreme population pressure/resource constraints such that sustainable intensification on existing holdings might not be enough to meet projected protein needs. Expansion of land-based freshwater aquaculture outside of Asia to meet projected future protein demands is problematic to 2050 and beyond, especially in South Asia, Africa, and Latin/South America where the large expansion of irrigation systems is not projected (Bruinsma, 2009).

The Case for Seawater Aquaculture (Mariculture)

Only about 4% of human foods come from the ocean (FAO, 2011) and most of that comes from the world's last remaining large scale hunting of wildlife – capture fisheries. If aquaculture is rare worldwide outside of Asia, mariculture is almost non-existent; but it has spectacular potential to feed the future world with the highest quality, nutrient rich plants and animals *(Table 5)*. Kapetsky *et al.* (2013) defined the world into "mariculture nations" and "non-mariculture nations". Mariculture nations were defined as "those listed in the FAO aquaculture production statistics as having mariculture production originating from the marine environment in one or more years for the period 2004-2008" (FAO, 2010). They state "At present, 44% of maritime nations with 0.3 million km of coastline have no mariculture. About half of the "mariculture nations" have outputs of less than 1 MT/km of coastline." They found that "93 countries and territories had mariculture operations during the period 2004-2008, and that there were 72 maritime countries and territories (44% of the total) that were not yet practicing it".

Most of the world's small mariculture production comes not from fed species, but from marine agronomy ("seaweeds") (FAO, 2014); now being termed "sea vegetables" in the popular culinary lexicon (Seaver, 2016). "Seaweed" aquaculture, centered in Asia (FAO, 2016), has enormous global expansion potential. Seaweed aquaculture is now practiced in about 50 countries but remains concentrated in Asia, with China (13.3 MMT), Indonesia (10.1 MMT), Philippines (1.5 MMT) and Korea (1.1 MMT) having 95% of the world's 27.3 MMT production (FAO, 2016). Farming of tropical seaweeds (*Kappaphycus alvarezii* and *Eucheuma* spp.) in Indonesia has grown remarkably from less than 1 MMT in 2005 to 10 MMT in 2014; Indonesia now produces 37% of the world's seaweeds, rising dramatically from 7% in 2005 (FAO, 2016).

Fabulous production potential also exists in the world's temperate zones. Imagine a plant that grows most rapidly in the middle of cold temperate-zone winters with low light intensity and a very short photoperiod, that needs no freshwater, added nutrients or additives, and that produces nutrient-rich, high vitamin and mineral value food, that has clear human health benefits (Seaver, 2016). That is the kelps (*Laminaria, Alaria* spp., etc.). Forster (2011) outlined this huge potential for the marine agronomy of kelp. Production of kelp in China can reach 1940 MT dry weight/km^2 (Chen *et al.*, 2007 cited in Forster, 2011). At this level of production, Forster (2011) states that "it would need less than 1% of the Earth's ocean surface, about 3.1 million km^2, to grow an amount of kelp equal to all the food plants farmed on land".

A New Generation of Ocean Foods Professionals

Our future world will have stark choices to sustain its projected human population. The time is now to move policies and investments in institutions away from a land-based food future and to embark upon major global investments in "ocean foods ecosystems". In this regard FAO has launched the "Blue Growth Initiative (BGI) in 2013 to emphasize conservation, sustainable management, and healthy aquatic ecosystems for sustainable economies (FAO, 2016). The BGI is "designed around sustainable capture fisheries and aquaculture, livelihoods and food systems, and economic growth from aquatic ecosystem services". It brings the needed support to the implementation of the FAO Code of Conduct for Responsible Fisheries and the FAO Ecosystems Approach to Fisheries and Aquaculture (FAO, 2016).

The world will need all the protein it can produce sustainably from capture fisheries, but that will not be enough. Freshwater aquaculture will expand in Asia but the expansion of mariculture will be the most important priority for the world's protein future.

Most importantly, to meet the food needs of the future, management conflicts due largely to educational deficiencies between fisheries and aquaculture managers will need to end. Aquaculture is routinely managed under agriculture, environment or fisheries agencies that have little knowledge, training or experience in aquaculture with its unique policy needs (Urquhart, 2010). Aquaculture and fisheries are so separate structurally and functionally in many countries' governance systems and academic institutions that institutions and professionals have lost track of their common goal of delivering environmentally friendly, safe, sustainable seafoods to the people they serve. Sensible regulatory alignment is needed to deliver products that sustain livelihoods. More broadly there is a need for institutions to train the next generation of professionals in foods ecosystems. This would create a generation of stewards working in a new paradigm of planning for the supply of ocean and land foods. These professionals would develop and implement more comprehensive "Earth Foods Systems Plans" (Smith *et al.*, 2010, FAO and WHO, 2014).

In the ocean professions, especially to fisheries managers, conservationists, and marine science academic institutions in general, aquaculture is a disruptive social ecological set of pioneering technologies. Professional, regulatory, "decision-maker communities" in the aquatic natural resource areas are dominated by fisheries and conservation professionals. More comprehensive training needed for a sustainable food future would result in the development of a cadre of decision-makers who could conduct the integrated planning for agriculture, aquaculture, fisheries, natural ecosystems, and their allied regional social infrastructures. The target areas of the world where this is most needed are where integrated freshwater aquaculture and mariculture can be developed to prevent the untold destruction of terrestrial ecosystems to create more arable lands for terrestrial food production.

In conclusion:

- Future terrestrial animal protein production has serious resource and environmental constraints to provide an increased 470 MMT by 2050. Projections of arable lands and waters needed to 2050 (and certainly to 2100) for terrestrial food production rely upon the destruction of natural ecosystems and reserves (deforestation, conversions of grasslands, expansion of water irrigation systems, etc.).
- Aquatic protein production systems of fisheries and aquaculture are far superior choices for global investments to 2050 and beyond in comparisons to any other terrestrial animal protein production systems based upon a wide scientific consensus/peer review evaluations of life cycle analyses, input and protein efficiencies, carbon footprints, and nitrogen and phosphorus discharges per unit of protein production. Most importantly, nutrient-rich dense, omega-3 rich, aquatic foods are, from other global scientific reviews, better food choices from human health perspectives than land-based protein foods.
- Thirty-five nations reported to the FAO in 2014 that aquaculture production exceeded fisheries production (FAO, 2016). Future increases in aquatic production cannot come from capture fisheries and must come from an expansion of aquaculture. Complete recovery of all of the world's capture fisheries would provide by 2050 just 20% of the global protein demands (terrestrial and aquatic).
- Inland aquaculture accounted for 65% of the increase in aquaculture production from 2005 to 2014 (FAO, 2016). Most of global aquaculture production until 2050 will continue to be freshwater aquaculture in Asia. Asia still has large untapped areas, freshwaters, and is projected to see a large expansion of irrigation systems for freshwater aquaculture's expansion, especially in East Asia. This is not so in South Asia, which will reach severe limits to the expansion of freshwater aquaculture due to the lack of water and extreme population pressure. Asian societies also have deep social-ecological-historical aquatic farming systems traditions and strong institutions in aquaculture that will allow the rapid uptake of aquaculture in new areas.
- Expansion of freshwater aquaculture into Asia's remaining areas would be a concern if expansion comes as a result of the destruction of natural ecosystems and nature reserves, of which Myanmar is a notable case in point. Developing highly productive, economically attractive, integrated aquaculture-aquaculture farming ecosystems (Little and Edwards, 2003) together with newly expanding irrigation systems could ease the needs for additional arable lands for terrestrial crops.
- In Africa and Latin/South America a large expansion of freshwater aquaculture is unlikely to occur and if it does, it will be unimportant at a global scale. This does not mean South America especially Brazil, Columbia and Venezuela do not have huge potential for freshwater aquaculture;

Table 6. *Production Estimates of Mariculture Systems.*

Species	MT/km^2	References
Cobia	9,900	Nash (2004)
Salmon	9,900	Nash (2004)
Blue Mussels	4,000	Nash (2004)
Integration of Sea Vegetables, Oysters, Fish with Artificial Upwelling	700,000-800,000	Wilcox (1982)

however, the region is not predicted to not expand its irrigation systems substantially, and, most importantly, is the fact that most of the world's spectacular nature reserves lie there and are under great threat from the predicted expansion of arable lands for agriculture. There are also almost no social-ecological-historical aquatic farming systems traditions or institutions in aquaculture that could allow the rapid expansion of freshwater aquaculture in these regions.

- A large increase in production from nations currently practicing mariculture is possible. Current production ranges from less than 1 MT/km to more than 500 MT/km of shoreline (Kapetsky *et al.*, 2013), and can be much higher *(Table 6)*.
- Expansion of seawater aquaculture (mariculture) is the world's best investment for meeting the food needs of the future. Kapetsky *et al.* (2013) in a global assessment of mariculture potential for just three species of aquatic animals - thousands of plants and animals are available for the development of new ocean food systems - found that 190,000 km^2 was available now having the most suitable environmental and economic conditions for the expansion of mariculture. For this area, and for the three species (cobia, salmon and mussels), and at current rates of technology, developing just 1% of the area would produce 10.1 MMT, developing 5% of the area would produce 50.5 MMT. Technological advancements in mariculture (for example see Goudey *et al.*, 2001) could expand the global area available for mariculture to more than 2 million km^2 *(Table 5)*.
- Mariculture potential is much greater in tropical and warm temperate waters than in cool and cold temperate areas (Kapetsky *et al.*, 2013). Some of the "non-mariculture nations" (no production as of 2013) have among the world's greatest mariculture potential and are among the world's most poverty-stricken today (Angola, Equatorial Guinea, Liberia, Ghana, Honduras, Gabon, Tanzania) and/or are facing enormous challenges due to accelerated climate change (Cape Verde, Nauru, Jamaica, Maldives, Marshall Islands, Kiribati).

Newbold *et al.* (2016) found clear evidence that human land use (agriculture, development, etc.) had crossed a proposed safe limit, a "Planetary Boundary" that is needed to preserve long term terrestrial biodiversity, defined as the maintenance of ecosystem functions from biome to global scales. They estimated that this safe limit for terrestrial biodiversity had been crossed in 48% of global lands. They stated that "land use has reduced the average proportion of natural biodiversity remaining in local ecosystems over 58% of the world's land surface where 71% of the human population lives". Continued consumption and degradation of lands for terrestrial agriculture and urban development will destroy the world's remaining terrestrial and coastal biodiversity and novel ecosystems and threaten human health and wellness into the future unless we plan for and invest in the development of ocean foods ecosystems for planetary survival.

There is an urgent need to develop cooperative, place-based, global centers of excellence in ocean foods ecosystems. The focus of these centers would be multidisciplinary investigations on experimental, but commercial-sized, mariculture systems located in the EEZ of nations that were representative of their ocean region's social-ecological-economic conditions. This was one of the nine recommendations contained in the "Bremerhaven Declaration on the Future of Global Open Ocean Aquaculture" (Rosenthal *et al.*, 2012). Professionals and business leaders would interact not only in oceanography, ocean engineering, and marine biology/ecology, but also in ecosystem governance (Olsen *et al.*, 2009), in the interplay of ecological aquaculture and fisheries (Costa-Pierce, 2010), in ocean conservation/marine parks (Kareiva and Marvier, 2014), and marine spatial planning (Aguilar-Manjarrez *et al.*, 2010). Groups would develop and implement comprehensive "Regional and National Ocean Foods Systems Plans" that would include leaders from land-based foods systems (Gliessman, 2006). There would also be the innovative opportunities to document the positive roles that restoration aquaculture can have in the Earth's ocean biogeochemical cycles, habitats, ecosystems, and societies of coastal ocean nations worldwide, as there are numerous examples of aquaculture facilities revitalizing natural aquatic habitats, ecosystems and fisheries, as opposed to degrading the natural environment, as much of terrestrial agriculture is doing. Without such multidisciplinary centers working on real systems, investment plans for the sustainable expansion of mariculture will suffer from a lack of a rational, scientific basis for planning and policy, and continue to be replaced by heresy, junk science, and advocacy.

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