An Article written by John Reid for Aquaculture Magazine's Dec.14/Jan.15 issue:

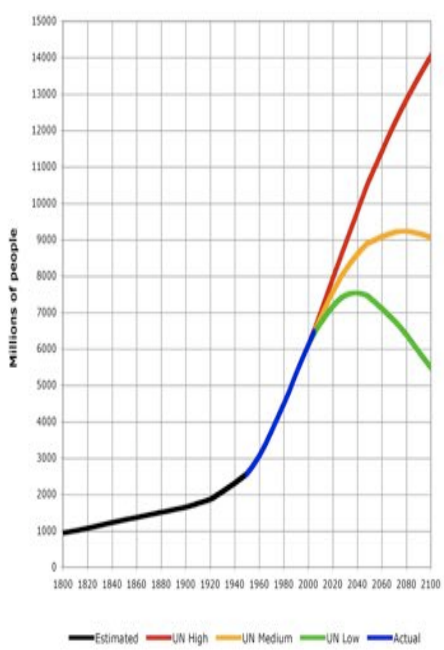
"Grass Fed Fish"

The Aquaculture industry, other than for shellfish, is completely dependent on the animal feed industry that sustains it. This sounds almost silly to say this because it is so obvious, but few fully understand where their feed comes from, and the changes that are accelerating amongst all animal feeds as well as for aquaculture diets. This is kind of like the old adage that most people think that "food comes from the supermarket", forgetting about the role of farms that produce our food. With aquaculture, many people forget that (excluding fish meal) the source of all of our aquaculture feeds is not from our feed suppliers, but our farms, and in particular our soil, water resources, and climate.

There are four key global trends that are colliding to create a great opportunity and challenge for animal protein production and especially within the aquaculture industry. The success of surmounting these trends will depend entirely on our feed sources. These four are: 1. the growing global demand for more meat protein, 2. skyrocketing population growth, 3. soil erosion, and 4. climate change factors like declining water availability, rising temperatures, and ocean acidification. You may be beginning to think this is an article about some doomsday scenario, it is not, but only because I will be so bold as to say, because we will have addressed a major shift in the kinds of fish we grow and the feeds we feed them. This article is not necessary a unique description of our challenges, but possibly a unique solution.

Macro Environment Challenges:

The world's population now stands above seven billion people and all estimates have it growing to about ten and a half billion by 2050. This is a growth increase of 35% or *1.5 million new people per week*. We are adding (and need to feed) the equivalent of one additional New York City metropolitan area *every two months*!



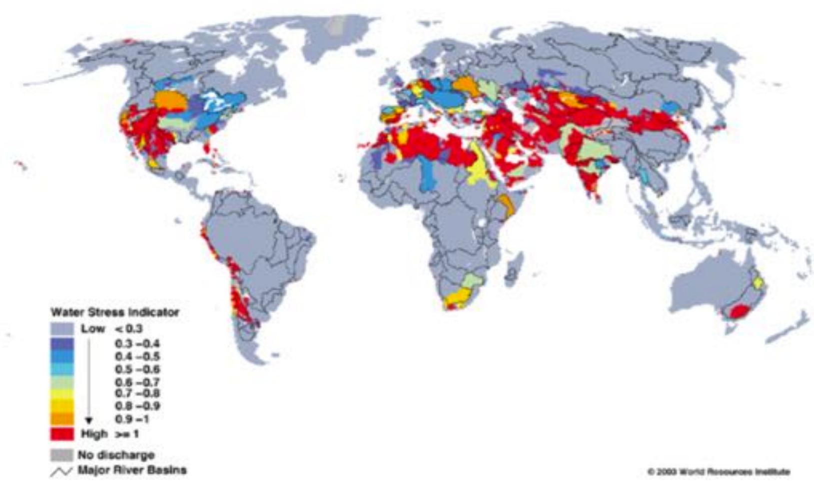
A 35% growth in population means we need to increase the global food supply by at least 35%. This in itself is a daunting challenge to accomplish, but due to changing eating preferences towards higher meat consumption, it is expected that world food production will need to increase by 50% to 100%. This is due to the additional feed needed to produce an increasing percent of animal protein.

In the next 35 years this 35% to 100% increase in food production needs to be created on as much as 30% less land than is available for todays population. This is due to declining soil fertility, and soil erosion. In the US, an area the size of the state of Rhode Island is lost every year to soil erosion. Between 1840 and 1917 when the first soil surveys of the US were done there were over eight feet of topsoil depth (or tilth) across the US. The average today is approximately eight inches. By some estimates soil loss in the US is greater now than it was during the ‘dust-bowl’ days of the 1930’s. (We have consumed our fossil soils in similar ways as our fossil fuels). The US has lost nearly 87% of its topsoil resources since the mid 1800’s. The loss of topsoil costs the US $36 billion every year in productivity losses.

Around the world soil is being lost 1000% to 4000% (10 to 40 times) faster than it is being replenished. World wide, cropland is shrinking by more than 10 million hectares a year due to soil erosion (about the size of the state of Indiana every year). This implies that farming techniques used today are not sustainable, and production on much of the US and global soils needs to be changed to less soil intensive techniques. Next to (and irrespective of) Global Warming, soil loss is considered the greatest challenge to sustaining US and global food supplies. It is questionable whether soils the of US and the world can maintain their current output let alone sustain the massive increase in agriculture that will be needed to sustain population growth.

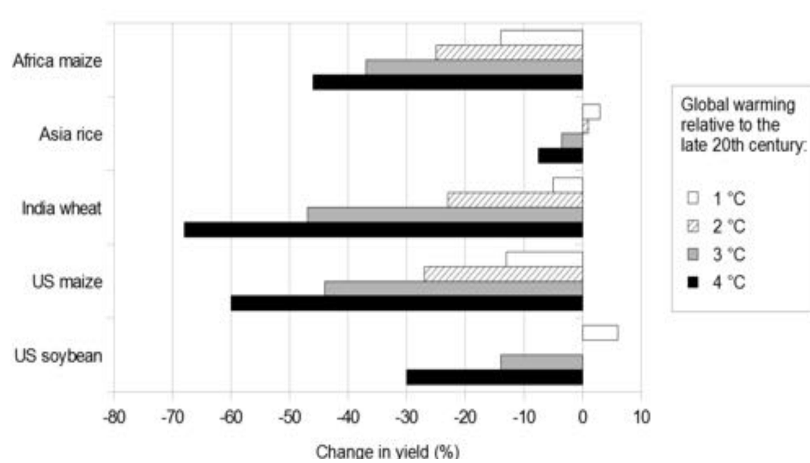
Compounding the dearth of soil tilth is diminishing water availability. Even if more land were pressed into agricultural production (at great cost to forests and biodiversity), there is not the water needed to support additional cultivation using existing practices. 70% of the planet is covered by water, but only 2% is fresh water, and of that 2%, 1.6% is (currently) contained in frozen ice caps, leaving only .4% available for the existing population of 7 Billion people. By 2025, the World Bank predicts that 66% of the world will run short of fresh drinking water and 80% of the world will be fresh water limited by 2050.

Regions currently under water stress.

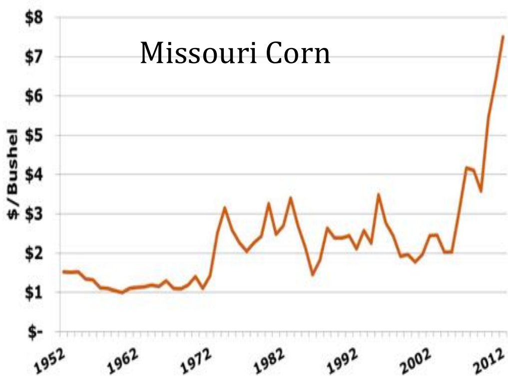


The water shortages for agriculture will be immense. Meeting crop demands in the next ten years, for 2025, when the worlds population will be ‘just’ 8 billion, will require a new volume of water equivalent to the entire flow of the Nile river, *times ten*! There just simply will not be enough water to increase current agricultural output by 100% using current practices. There may not even be enough to supply the base of 35% needed to feed the world as we do today.

Multiplying the negative impacts on food production, beyond the trends of soil loss and water shortages, are the effects of climate change or global warming. There are many impacts of global warming on agriculture that are to numerous to note here, but probably the largest will be the

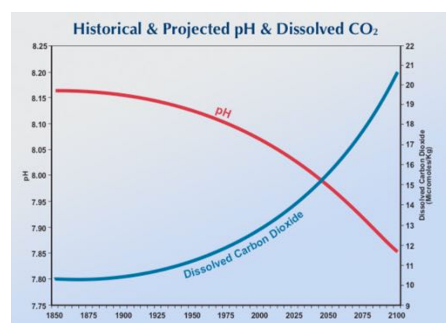


impact of excessive heat. With many crops already growing near their maximum heat tolerance, most crop yields will fall with any further rise in temperatures. Corn fails to form seed heads when average growing temperatures are above 95 °F and soybean above 102 °F. Crop yields are predicted to fall by much as 10% in the US and as much as 50% in Pakistan, or about a 30% global reduction in output due just to heat, not counting lost soil or limited water resources. There are many compounding factors like ethanol production but heat is one of the key factors for price spikes and long term increase in grain prices.



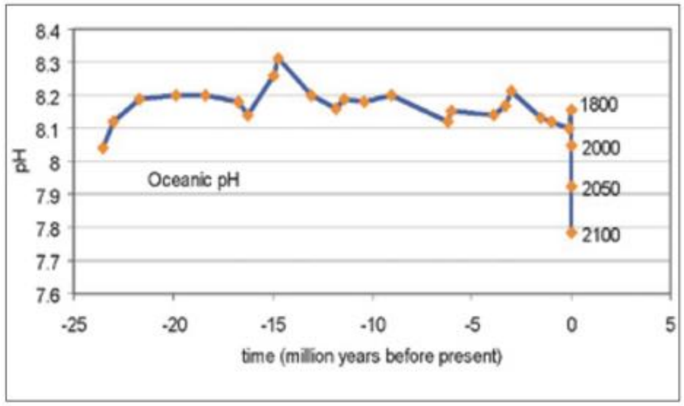
The impact of global warming on food supplies does not stop on land, but continues deep into the oceans. Not counting aquaculture, currently 16% to 20% of the world's protein comes from ocean fisheries. Including the 5% of the worlds protein produced from fisheries products that are fed to animals; the oceans share of global protein production is near 25%. Given that it takes 2 to 15 pounds of grain or fodder to grow a pound of protein on land, the 16% to 25% of global protein that comes from the oceans relieves the amount that terrestrial agriculture must produce by as much as 50%. (Assuming a good food conversion ratio or FCR of 2). Ocean yields in many areas are falling due to overfishing, but global warming will exacerbate declining ocean harvests. Even if ocean harvests remain constant, the 100% new food production needed will not have the ~25% subsidy that is currently provided by the oceans. This means we are likely faced with needing to produce as much as 150% more food to maintain expected market preferences.

Marine or ocean based aquaculture cannot be counted as a true increase in ocean yields because it relies from 50% to 90% on terrestrially produced feeds. Aquaculture can create protein more efficiently but is not a true substitute for lost ocean harvests because even ocean aquaculture is dependent on land based soil and water resources to grow feed. Feeding terrestrial based feeds to an ocean environment is also a form of soil erosion, a concept discussed more below.



Like the terrestrial impacts of global warming, impacts on fisheries yield are also too numerous to note here. Currently the largest impact is projected to come from changes in the pH of seawater, or ocean acidification. The dissolving of CO2 into seawater, forming carbonic acid, causes ocean acidification. Predictions on the decline in ocean fisheries yield due to ocean acidification are still preliminary but range from a 10% to 50% drop in all ocean yields by the end of this century. Calcium based shelled animals, like shrimp, crab and mollusks are the most at risk as acid dissolves their shells. They represent 21% of all ocean harvests and their loss could be from 30% to a complete collapse of all production. In 2008, shellfish aquaculture producers in the US Pacific Northwest experienced an 80% drop in shellfish stocks due to drops in ocean pH. Regional stocks have since recovered to 70% of their previous total, but this one event is indicative of how sensitive ocean species are to pH changes. Based on the decline of calcareous algae's, which are one of the key supports of the entire marine food system, many fish species may also be at risk.

The net impact of current trends of population growth, soil loss, water shortages, temperature rise, and ocean acidification, (and other factors not noted) add up to a very challenging time to sustain existing production let alone provide the minimum need of 35% to 150% more food for the world.



The US food system is not likely to collapse but the price pressures put on US supply due to domestic and international demand for exports of protein and grain stock will push US food and especially US protein prices to rise much higher than the normal rates experienced over the last 50 years. This is a large opportunity for aquaculture markets to provide a competitive protein source but a huge challenge regarding the food supplies for aquaculture.

Grains as our food base:

The sustainability of aquaculture feed sources is directly related to the sustainability and the very viability of the aquaculture industry itself. There has been a lot of attention paid to replacing fishmeal in diets given the well-discussed limitations of fishmeal supply, overfishing of fishmeal, as well as price limitations. Concurrent with reductions in use, or a complete shift away from fishmeal, has been innovations with protein boosters, like insect diets, algae and other protein sources. But these are all added to a base of grains. Even though we are still developing effective all-grain diets, grains have become the backbone of the aquaculture industry, just like they are for Chicken, Pork and Beef.

However as noted above, it is highly likely that grains cannot carry the load of increased production in a sustainable way. Grains are nutritious for humans on their own, and provide a cornucopia of other uses, but they simply cannot be looked at as the base that will continue to supply the animal feed industry sustainably.

If soil tilth alone is used as an indication of sustainability we have been "deficit-spending", draining the bank account of our soil tilth for a long time. Some could argue this goes back to the reasons humans migrated out of Mesopotamia to northern Europe, but that is another article. If one really does the math, the "global stoichiometry" it simply does not add up to depend on grains for the long-term future of protein production or aquacultures feed supply.

I will be so bold again as to say; it is an inevitability that we must reduce our dependence on grains for all animal feeds, or reduce our dependence on animal protein.

Grass Based Feeds:

Rather than everyone going on vegetarian diets (one proposed solution that would work) an alternate could be grass based feeds. Everything about grass production is nearly the opposite of grain production. Grasses use a fraction of the water and fertilizer of grains, are more heat tolerant than grains, have equivalent, sometimes larger biomass yields and many types are high protein. Because grasses are mowed, and not tilled, they protect and grow soil tilth, not consume it. Grasses can be pelleted and processed in similar ways as grains, with many similar mineral and vitamin mixes added. But most importantly, grasses produced in sustainable ways, sequester carbon in huge quantities.

Some claim that a large percentage of carbon emissions causing global warming has come from our lost soils, not just burning of oil, but soil volatizing back to gaseous carbon that was once sequestered in our deep soils. Even more dramatic is the possibility that converting a large portion of our grain base to grass could recapture this carbon and reduce annual carbon emissions by 25% or more. This is a largely controversial topic, but some have powerful and well grounded arguments that this could be larger factor in slowing climate change than all the wind, solar or even nuclear production installed to date.

All current terrestrial species could grow well on grass-based diets since most evolved to eat grasses in the first place. Aquaculture has the ability to take the best advantage of grass diets, due to their overall lower food conversion ratios, many fish species that are efficient low protein eaters, and other well-known advantages that don't need to be outlined here.

So how do grass based feeds provide the world more protein production, not just the same equivalent yields in a more sustainable way? A large percentage of grass production will need to replace grain fields, and this is not likely to create any net-new production, but it helps reduce soil erosion and the yield killing impacts of global warming. Gains come when grasses are produced on lands that are now currently too poor to grow grains, land set-asides for soil-conservation purposes become moot, allowing a net increase in cultivatable area. Grasses with 60% to 70% lower water requirements can allow irrigated areas to double or triple their effective acreage. When greater net yields are combined with the greater efficiencies of aquaculture achieving the 35% increase in food production seems likely, and gives us a strong shot at supplying the

expanding market for higher protein foods as fish.

Grasses Are Not a Panacea (Yet):

As with any new approach to production, grass based feeds need to undergo a lot of development to be commercially viable on the mass-scale that is needed. The first challenge is that commonly grown grasses are not as energy dense, nor protein rich as most grains. This author has worked with diets that were effectively 40% grasses, and 60% grains to boost protein to a minimal level of 28% that was fed to Tilapia. Growth was about 90% that of the 32% protein diets used as a control. A good start but not a viable solution for most Tilapia growers, and certainly not for other species requiring higher protein diets. Real progress will be made when the ratio can be flipped to 70% grass and just 30% grains or other additives, with equivalent or better growth rates.

This initial formula was based primarily on substituting alfalfa, since that was all that was commercially available at the time. But there are literally thousands of different types of grasses to work with. When these are combined with the new protein boosting compounds coming on the market, based on insects, a wide range of digestive enzymes, and a host of others, perfecting high protein diets in the 35% range seem very likely.

The other side of the coin to raising the protein level of feeds is lowering the protein requirements of fish. Chicken do very well on a 20% protein diet, and is one reason it dominates the market as a low cost protein. High chicken growth on low protein feed was not luck, rather this represents as much as 100 years of development from early modern chicken breeds like the Rhode Island Red to Arbor Acer's (Avigen's) breeding stock. Tilapia, grass carp and many others are good aquaculture options, but they are nearly wild-stock species. The genetic potential for fish species is so much greater than poultry, given their lower overhead as cold-blooded animals and many other reasons. We are just scratching the surface at breeding better strains of the existing species we have, or developing new low-protein eating species.

One other challenge for grass-based diets that must be considered is the recycling of aquaculture wastes back to farmland. The soil-regenerative capacity of grasses is large, but if the manure of aquaculture is thrown into rivers, or the ocean, it is a form of soil erosion. Manure is still the biomass of the soil and too much loss can out-strip the soil growth rate, and we are back again at the negative soil production rates we have currently. Applying aquaculture manure to farmland, to a substantial degree will preclude the use of saltwater production. Not to be a 'soil-fascist', there is of course some room to feed marine species with terrestrially sourced diets, but it must be kept at a minimum because saltwater manure cannot be applied to terrestrial fields. This places interesting constraints on the kind of aquaculture systems that can be used. Of course recirculating aquaculture systems (RAS) comes to mind, but also the use of irrigation reservoirs as ponds, or culture cages in large reservoirs where the manure wastes can be cycled back to farmland, become preferable methods of production.

A large advantage of grass-based feeds as a whole production program combining diets, genetics and production systems, is it is likely to be much more profitable than current aquaculture techniques. All the attributes that make grass-based feeds sustainable, also makes it a less expensive production system. The opportunity exists to lower costs sufficiently to rival chicken as the low cost protein in the world, and the massive sales volumes that would come with that.

A long-term program that must be developed quickly:

Given all of the social and environmental issues noted here that are literally growing exponentially, there is a lot to do. To develop grass based feeds, a multidisciplinary approach is needed between farmers, feed mills, additive producers, livestock and aquaculture producers, universities as well as the government to modify some laws, provide research funding and create some initial market incentives.

Other options other than grass-diets may evolve, but what ever they are they will have to meet the basic tenants discussed here. I will be bold again to say that if these are not met, we will not be able to avoid huge calamities in food production, and all the societal issues that can spin out of food shortages. We categorically cannot continue as we are now for much more than 20 to a maximum of 30 years.

The good news is we have solutions. They will involve a large investment, but can generate huge opportunities. The opportunity is to generate a new low cost protein that can feed the world, upgrade protein levels for many, will be sustainable, and can possibly stop or even reverse global warming. Now this is a recipe worth perusing.

There was a, Green Revolution, and a Blue Revolution – but this is the Teal Revolution, blending fish and fields, Green and Blue for Grass Fed Fish!

Mr. Reid Is the CEO of Watewrfield Farms, Inc. He has over thirty years of experience in the design, finance and operations of food and energy companies. He has built and run multiple aquaculture and hydroponic systems as well as worked with co-generation and bio-fuels around the world.