Innovation & Information Working Paper
Department of Agricultural Economics, CAU Kiel

Fish in the City

by

Stefan Guettler
Danica Lambrecht
Biniam S. Fitwi
Carsten Schulz
Rolf A.E. Mueller

I & I Working Paper No. 01/2011

ISSN 2190-6440

Available at:

http://www.agric-econ.uni-kiel.de/Abteilungen/II/wp.shtml

– Innovation & Information –
Department of Agricultural Economics
Christian-Albrechts-University of Kiel

March 2011

Olshausenstrasse 40, 24118 Kiel, Germany; Phone: +49 0431-880-4419
E-mail: i&i@agric-econ.uni-kiel.de; E-mail Author: stefan.guettler@ae.uni-kiel.de
Internet: www.agric-econ.uni-kiel.de/Abteilungen/II

FISH IN THE CITY

Guettler, S. [a,c]; Lambrecht, D. [a,c]; Fitwi, B.S. [b,c]; Schulz, C. [b,c]; and Mueller, R.A.E. [a,c]

a Department of Agricultural Economics, CAU Kiel
b Department of Animal Breeding and Husbandry, CAU Kiel
c MASY Aquaculture Competence Center, CAU Kiel

Man can create little without first imaging that he can create it
Joseph Weizenbaum

Summary
Aquaculture is the most recent addition to animal husbandry and it is the fastest growing food production industry. Its contribution to world food security in the 21st century is already significant and it is bound to continue to grow because demand for fish for human consumption is rapidly increasing whereas fish supplies from ocean fisheries are likely to decline.

The rapid evolution of aquaculture involved a host of innovations of which many were based on R&D activities by public and private research organizations. Applied R&D tends to be the more effective the better focused it is on specific research problems or opportunities. Among the many possible aquaculture production systems on which aquaculture R&D might focus are recirculation aquaculture systems and in this paper we explore crucial aspects of the potential of urban recirculation aquaculture.

Our exploration begins with a vision of recirculation aquaculture production plants located at the fringes of cities of converging economies. Such production systems are distinctly different from conventional urban aquaculture systems based on urban sewage. We scrutinize our vision from four perspectives: (i) the expected demand for aquaculture fish from urban consumers; (ii) cost competitiveness of fish produced at the fringes of cities as compared to fish produced in the rural hinterland; (iii) the potential for integration of urban recirculation aquaculture production into the modern food supply chains that are now emerging in converging economies, and (iv) the ecological footprint of aquaculture production compared to that of chicken production.

Based on trends in the growth of urban populations world-wide and trends in demand for fish for food we estimate a total urban demand for aquaculture finfish between 11 and 51 million tons in 2025.

We use von Thünen's location theory to provide support for the vision to locate recirculation aquaculture plants not within cities and not in their rural hinterland but on the fringes of cities. Moreover, we argue that tightly controlled recirculation aquaculture production would seem to be particularly well suited for being integrated into modern food supply chains. Finally, we compare the ecological footprint of recirculation aquaculture fish with that of industrially produced chicken and we find that the ecological balance depends on the source of energy used.

We conclude our exploratory study with some thoughts on the implication for aquaculture R&D of the potential for recirculation aquaculture located on the fringes of cities in emerging economy countries.

1 Introduction

Aquaculture is the fastest growing food production industry of our times. We are currently witnessing the domestication in rapid sequence of marine species (Duarte *et al.*, 2007) together with the design of more efficient production systems. It is no exaggeration to compare the significance for mankind of the current evolution of aquaculture with the domestication of our farm animals during the Neolithic revolution some 10,000 years ago.

Fortunately for us, aquaculture is evolving much more quickly than the production systems for terrestrial farm animals have evolved in the distant past. The main reason for aquaculture's more rapid evolution is science and knowledge. Whereas our farm animals were, for most of the time, domesticated by our illiterate forebears, the on-going domestication of aquatic species is based on modern science and the application of a vast store of engineering knowledge. In short, the evolution of aquaculture is boosted by methods of R&D which mankind has acquired only recently.

Aquaculture research is a risky investment that is made with the expectation that its returns exceed its costs. Typical for all investments is the temporal separation of costs and returns: Whereas expenses are incurred immediately with the start of an investment project, its returns accrue only some time later. The time until returns exceed costs can be significant. In applied agricultural research 15 years and more from project initiation to earning of returns are not uncommon (Alston *et al.*, 2000; 2008). Given such long lags between initiation and fruition of applied research projects, research donors and managers interested in the potential returns need to anticipate the economic environment in which the technology derived from the research will have to perform.

Moreover, when fruition periods are long and discount rates are significant, the net returns generated by a new technology must be much larger than the cost of the applied research in order to make the investment worthwhile. For instance, a research expenditure of 10 million Euro requires a net return of at least two time the amount invested (20.8 million Euro) fifteen years later when the social discount rate is 5 percent, and of more than three times (31.7 million Euro) the initial investment when the social discount rate is 8 percent. It is therefore prudent to target applied research at developing technologies for large and growing markets.

Finally, when research leads to new technologies, such technologies rarely diffuse immediately and rapidly through their potential adoption domain. More often a new technology must first find a foothold, an application niche, where it can mature and improve until it can displace incumbent technologies (Gomory, 1983).

In this paper we first sketch with a broad brush a vision for an aquaculture production niche in the first quarter of the 21st century. This vision, which we named "Fish in the City", reflects several important trends in the economic environment in which, in our view, future aquaculture production systems will have to perform. We then examine the core assumptions on which this vision is based. The paper closes with some implications of the vision for applied aquaculture research.

In some readers, the label "Fish in the City" may evoke visions of low-tech urban aquaculture production systems based on waste water and effluents (e.g. Bunting *et al.*, 2005; Little and Bunting, 2005; Edwards, 2005; Phan Van and De Pauw, 2005; Vo and Edwards, 2005). We believe that such systems are beyond the pale and we do not give them any thought.

2 THE VISION

Imagine a rapidly growing coastal city in some emerging-economy country. The city has developed into a modern trading hub from a sleepy trade post with a deep-water port at the estuary of a navigable river where tramp ships used to call from time to time. The city is now home to several million inhabitants of which some still live in miserable slums in the old city. The growing middleclass whose purchasing power is steadily increasing live mostly in apartment blocks that spring up everywhere on the flat, barren outskirts of the city. There is also a small clique of fabulously rich people whose villas are tugged away in the wooded hills along the shore.

The city earns its income mainly from trade with its hinterland and from light industry. The old harbor still exists but ocean going freight ships call at the modern, efficient container terminal. The airport at the outskirts has been upgraded to accommodate midsize passenger jet aircraft and large cargo jets. Road traffic is chaotic, inner city roads are overcrowded, and traffic jams emerge at any time of the day. Road transport to and from the hinterland is an expensive nightmare. Lowly paid policemen harass truck drivers for baksheesh, bridges that have been severely damaged during the rainy season are poorly repaired, herders drive their cattle on the middle of the road, and, come harvest time, farmers spread out their grain crops on the sealed roads for involuntary threshing by passing cars, busses, and trucks.

Because the city has grown rapidly during the past twenty years or so, some of the older light industry plants are located close to the city center. But the new, environmentally conscious middleclass resents industrial plants in the neighborhood of their offices and the city's administration has developed several industrial parks which protrude from the fringes of the city into its rural neighborhood.

In the old days, coastal fishing was a small but profitable industry. Most of the catch was consumed locally and some fish were canned for export. The fishing industry was, however, doomed when fish became less abundant and when prices for diesel increased.

In the one industrial park that borders on both the river and the sea shore is located an inconspicuous industrial plant, which, from the outside, looks like any other light-industry plant in this park: a steel frame, profiled-metal walls painted in light colors; attached to the main building is a smaller building where a temperature control unit and a generator for emergency electricity supply are housed; the single-storied office building borders on an expansive parking lot for light trucks and cars. Only keen observers notice the two pipelines that distinguish the new plant from any other of the many industrial buildings in this park: one pipeline seems to go to the sea and the other to the river.

Anybody who would be let into the new plant would see several huge basins filled with water in which fish of various sizes are kept. To each basin several automata are attached for dispensing feed and feed additives. Among the fish, several sensors are floating in the basins that measure critical water parameters. The fish are all tagged with tiny RFID chips to allow individual identification. Water temperature in the basins is tightly controlled at its optimum for fish growth, the movement of the fish is monitored by small underwater video cameras, the fish are fed automatically, and the water from the basins is constantly recirculated through a battery of filters in the back of the building.

Data captured by the various sensors are fed into the plant's process control system which monitors the plant in real time and which alerts the plant manager of events and developments that it cannot control automatically. From time to time fresh, sanitized seawater is pumped into the plant through the pipeline that connects the plant with the sea and highly diluted and thoroughly treated wastewater is released into the river.

The aquaculture plant delivers its fish freshly slaughtered to several small local food processing companies. Some fish are filleted, frozen, and delivered to local supermarkets, restaurants, and institutional kitchens. Others are processed into precooked meals that are in high demand from young middleclass families. A small share of the plant's fish production is marketed alive at the local farmers' market. This sales channel is kept alive only to maintain an image of freshness and locality for the plant's output.

Feed for the fish is regularly delivered by truck from a local feed mill. Fish hatchlings are procured from several hatch-to-order suppliers of juvenile fish that have sprung up in different parts of the world. Juvenile fish are air freighted in small purpose-designed containers.

Luckily, the manager rarely has had major disease problems in his plant. For the minor problems that occurred he could rely on assistance from a disease identification and treatment network that has sprung up on the internet. There he can post questions together with high-resolution videos of the diseased fish. The fish health experts of the network then provide advice for a small fee.

3 Examining the Vision

A vision of the future cannot be checked against the facts because the facts of the future are not yet in; but the vision should be plausible. We examine our vision from several perspectives:

(1) prospects of urban demand for aquaculture finfish;

(2) technical feasibility fish supply from recirculation aquaculture systems (RAS);

(3) environmental impact of RAS-production;

(4) desirability of locating RAS at the fringes of cities, and

(5) potential for integrating RAS into modern food supply chains.

3.1 Urban demand for aquaculture fish for human consumption

Urban demand for aquaculture fish for human consumption can be split into several components. First, total demand for fish for human consumption results from the product of total world population times the per capita consumption of fish:

$$(1) \quad D_{fish} = \text{Population} \times \text{per capita fish consumption}$$

Assuming that per capita fish consumption in cities is not much different from per capita fish consumption in general, we may calculate urban demand for fish for human consumption from:

$$(2) \quad D^{u}_{fish} = (\text{Population} \times \text{share of urban population}) \times \text{per capita fish consumption}$$

Finally, we need to take into account that aquaculture fish is only one part of total fish consumption, the other being fish from capture. Hence, we obtain:

$$(3) \quad D^{u}_{aquaculture\ fish} = (\text{Population} \times \text{share of urban population}) \times (\text{p. c. fish consumption} \times \text{share of aquaculture fish in total fish consumption})$$

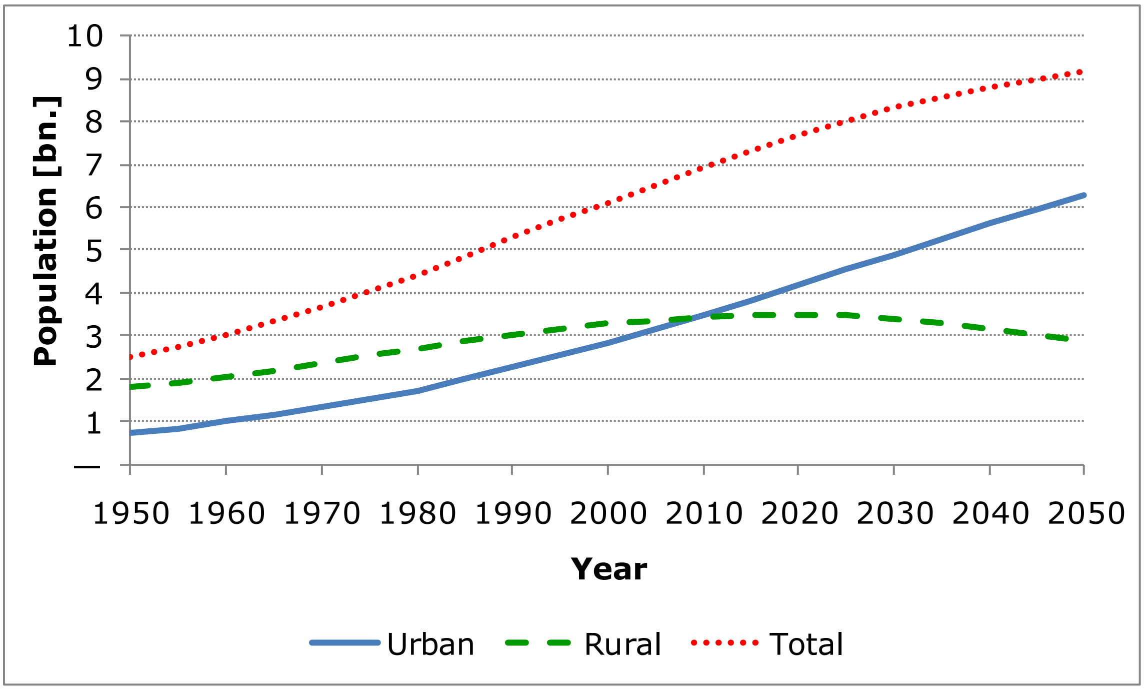
We go through the variables one by one.

3.1.1 Population

World population presently stands at about 6.9 billion people of which half live in only six countries: China, India, the United States of America, Indonesia, Brazil, and Pakistan. World population is expected to continue to grow until about the end of this century. In the next fifteen years another billion will be added to world population, and in the twenty years from 2025 to 2045 another billion more (see Figure 1).

For comparison: when goats and sheep were domesticated in West Asia around 10,000 years before our time, only about 5 million people lived on earth. When rainbow trout were domesticated in Europe in the 1890s world population had reached around 1.5 billion. In the 70 years from 1890 to 1960 when salmon was domesticated world population had doubled to 3 billion.

Figure 1: Development and projection of urban and rural population, 1950 – 2050 [10^9 people]



Data source: UN (2010)

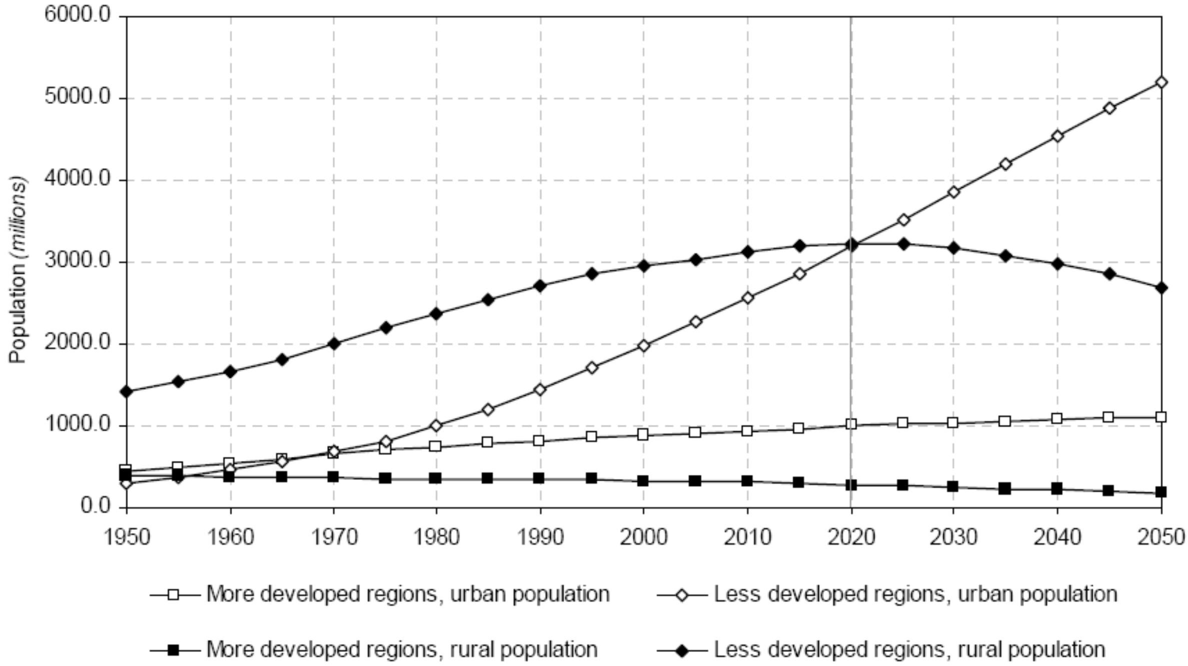
3.1.2 Urban population

For much of human history most people lived in rural villages. This episode is over. Most people now live in cities (see Figure 1). The world has become urban.

The trend from rural to urban will continue as the erstwhile developing countries are urbanizing (Figure 2). By the year 2020 the less developed regions of the world will also be predominantly urban just as the developed regions have been during the last sixty years.

Urban population is estimated to increase from 3.48 billion in the year 2010 to 4.54 billion in the year 2025; this is an increase by 30 percent or equivalent to an annual compound growth rate of 1.8 percent. For comparison, total world population will grow at only about half the rate (0.99 percent p.a.) to 8.01 billion people in the year 2025. By the year 2050 nearly as many people - about 6.3 billion – will live in cities as there had been living on earth at the beginning of this millennium.

Figure 2: Urban and rural populations by development group, 1950 - 2050



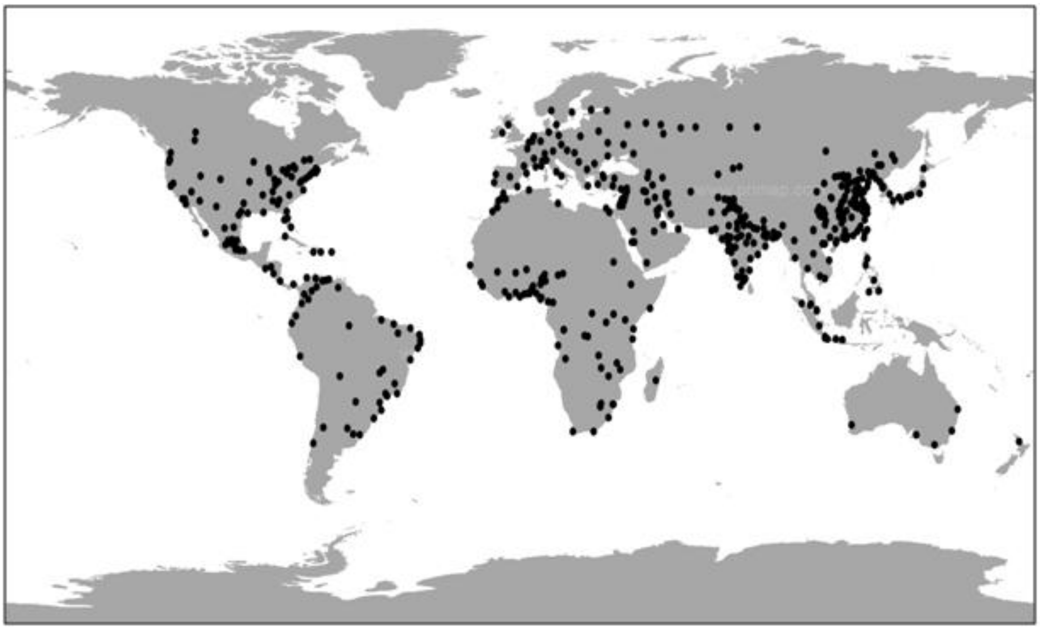
Source: UN (2010)

When urban population grows, large mega-cities will become even larger and large cities will grow to become megacities.

Baghdad was probably the first megacity which reached the 1 million inhabitants mark at around the year 1000. The number of megacities grew only slowly until the year 1800 when there were four – London, Beijing, Edo, and Guangzhou (Modelski, n.D.). In the year 1900 there were 16 megacities and in the next 110 years until the year 2010 their number swelled to 432. This is not the end of city growth and another hundred cities will join the megacity club until the year 2015.

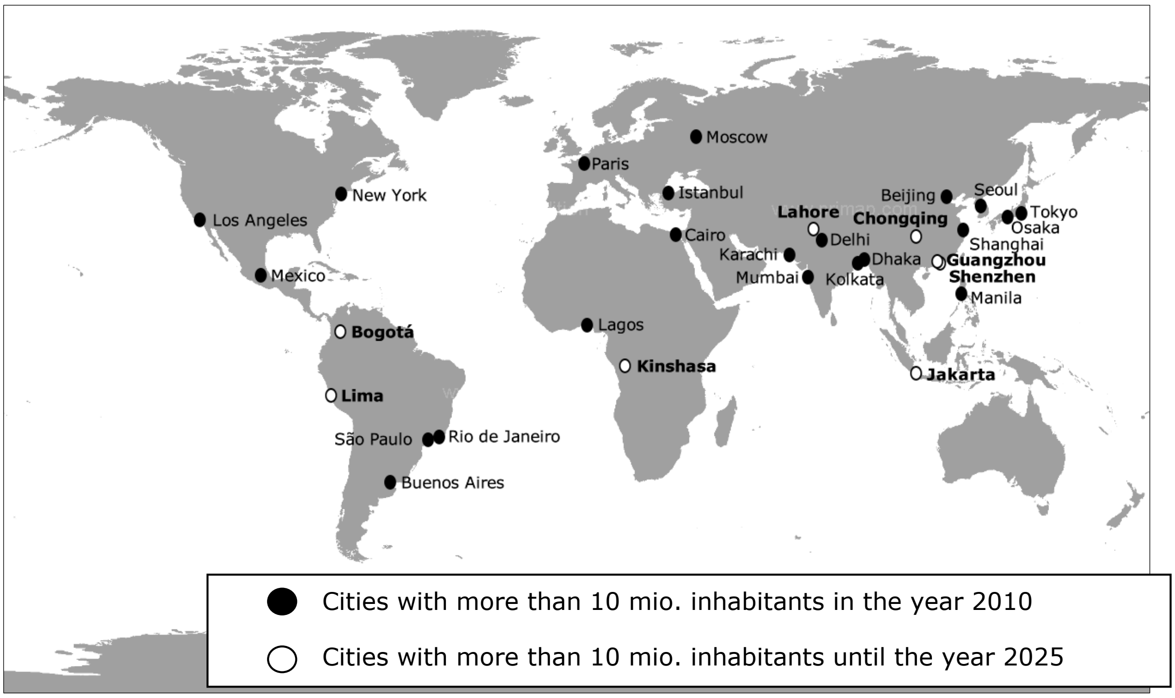
The number of megacity grows where population grows and population growth is most rapid in what used to be called the developing countries in Asia, Africa, and Latin America. Unsurprisingly, most of the megacities will be located in these continents (Figure 3).

Figure 3: Cities with more than 1 million inhabitants in the year 2025



Data source: UN (2010)

Figure 4: Cities with more than 10 million inhabitants in 2010 and 2025



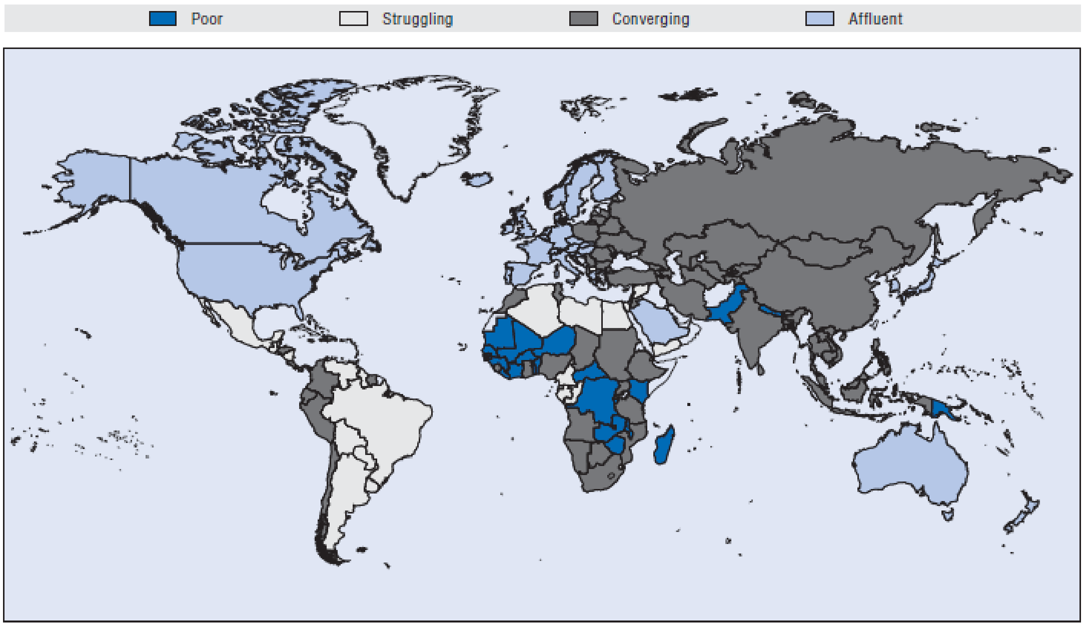
Data source: UN (2010)

In the year 2010, 21 cities in the world will have more than 10 million inhabitants (black dots in Figure 4) and until the year 2025 eight more cities will join this size category (white circles in Figure 4). Three of the seven will be in

Asia, three in Latin America, one in Africa, and none in North America, Europe, or Australia.

Conventional classifications of the countries in the world into industrial and developing countries, into rich countries that provide aid and poor ones that receive aid, or into countries that belong either to the First World in the North or the Third World of the South, have become meaningless. There is just too much overlap between the categories (Rosling, 2006). OECD (2010a) suggests that a "four-speed world" has replaced the worn-out dualisms: Countries are either poor, struggling, converging, or affluent. Figure 5 shows the distribution of the categories around the world. Most of the world will be covered by affluent or converging countries. Poverty will mainly be an African calamity.

Figure 5: OECD´s four-speed world in the 2000s



Source: OECD (2010a)

Most of the new megacities will be located in converging countries: 75 percent of the new 10 million inhabitants megacities will be located there, and 83 percent of the new megacities (Table 1). There will be hardly any change at all in the number of megacities in the affluent countries.

Table 1: Number and location of megacities, 2010 and 2025

Cities with a population of more than ...		Country class			
	Poor	Struggling	Converging	Affluent	All
10 million					
in 2010	1	5	10	5	21
in 2025	3	5	16	5	29
abs. change	2	0	6	0	8
percent of all additions	*25*	-	*75*	-	*100*
1 million					
in 2010	25	59	237	111	432
in 2025	33	65	313	122	533
abs. change	8	6	76	1	91
percent of all additions	*9*	*7*	*83*	*1*	*100*

Data sources: OECD (2010a), UN (2010)

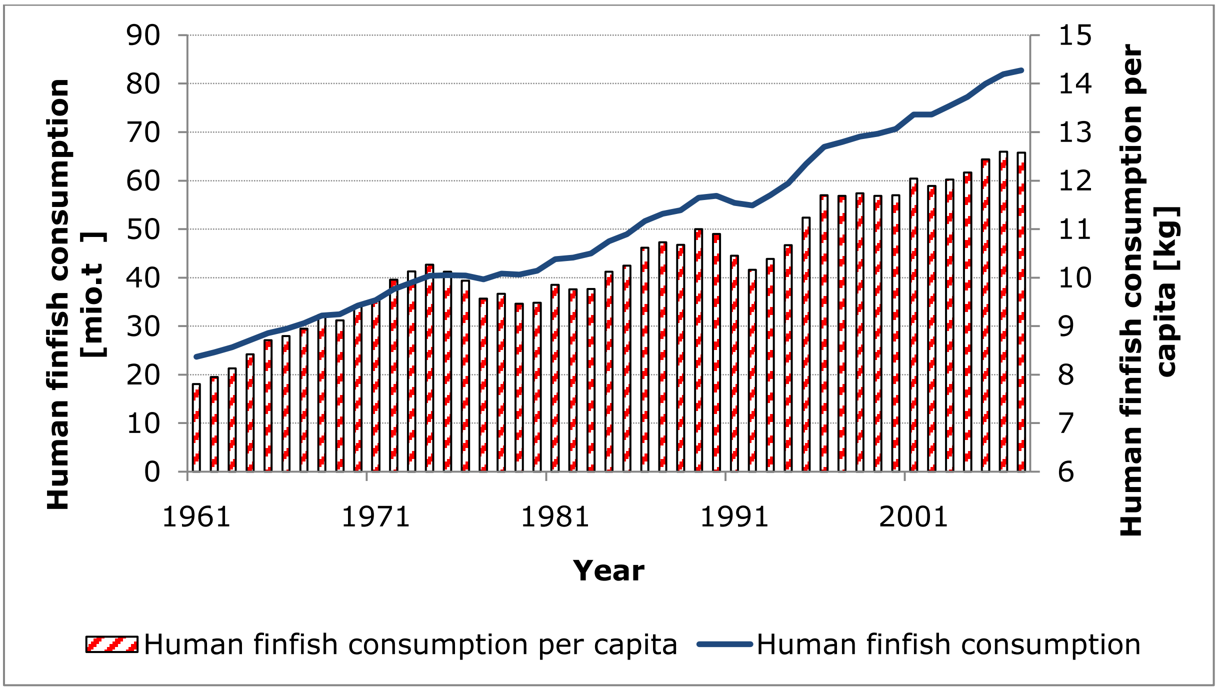
What is the significance of the growth in the number of cities for demand for fish? Assuming that the average size of cities stays the same, total megacity population in the world increases in proportion to the number of cities, that is by about 24 percent in the period from 2010 to 2025, this is equivalent to an annual growth rate of 1.4 percent. If we assume further that consumer preferences for fish do not change by much with the size of a city, a growth rate of demand of 1.4 percent would seem to indicate a growing market.

3.1.3 Global demand for finfish[1]

Global demand for finfish increased steadily during the last decades. This growth is based on two factors, viz. a growing population and an increasing consumption per capita. Total human consumption of finfish more than tripled from 24 million tons in the year 1961 to more than 82 million tons in the year 2007 (Figure 6, left-hand scale), while the total consumption per capita and year increased from 7.8 kg in 1961 to 12.6 kg in 2007. In addition, demand for finfish grew more quickly in the past than population, which "only" doubled during 1965 to 2005 (Figure 7).

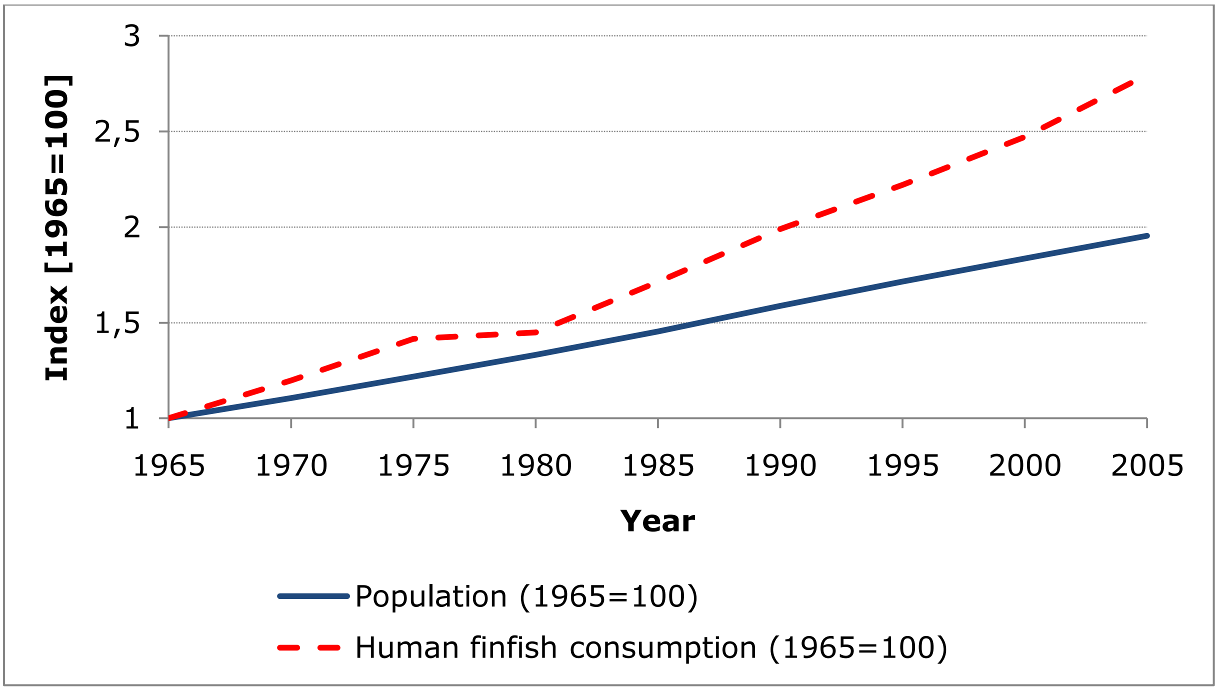
[1] In the following the term "fish" includes finfish, crustaceans and mollusks and excludes aquatic plants, while the term “finfish” only includes finfish and excludes crustaceans, mollusks and aquatic plants. The term “food fish” covers finfish, crustaceans and mollusks for human consumption.

Figure 6: Development of human finfish consumption, 1961 - 2007



Data source: FAO (2010)

Figure 7: Development of world population and human finfish consumption, 1965 – 2005 [1965=100]



Data sources: FAO (2010), UN (2010)

3.1.4 Per capita finfish consumption

Fish consumption, which stood at 16.7 kg per capita (FAO, 2010), is unlikely to have reached its ceiling. Studies that attempt to gauge future fish consumption suggest that fish consumption may grow annually between 0.2 percent and 1.4 percent (Table 2). If finfish consumption will increases by these growth rates a world-average finfish consumption between 12.9 kg/person to 16.1 kg/person can be expected for the year 2025.

Table 2: Projections of world food fish consumption

Author(s)	**Forecast for [yr]**	**Fish consumption [kg/person]**	**Implied annual growth rate of per capita fish consumption***
Delgado *et al.* (2003) (baseline sc.)	2020	17.1	0.18%
Ye (1999)	2030	22.5	1.31%
Wijkstrom (2003)	2050	30.4	1.40%

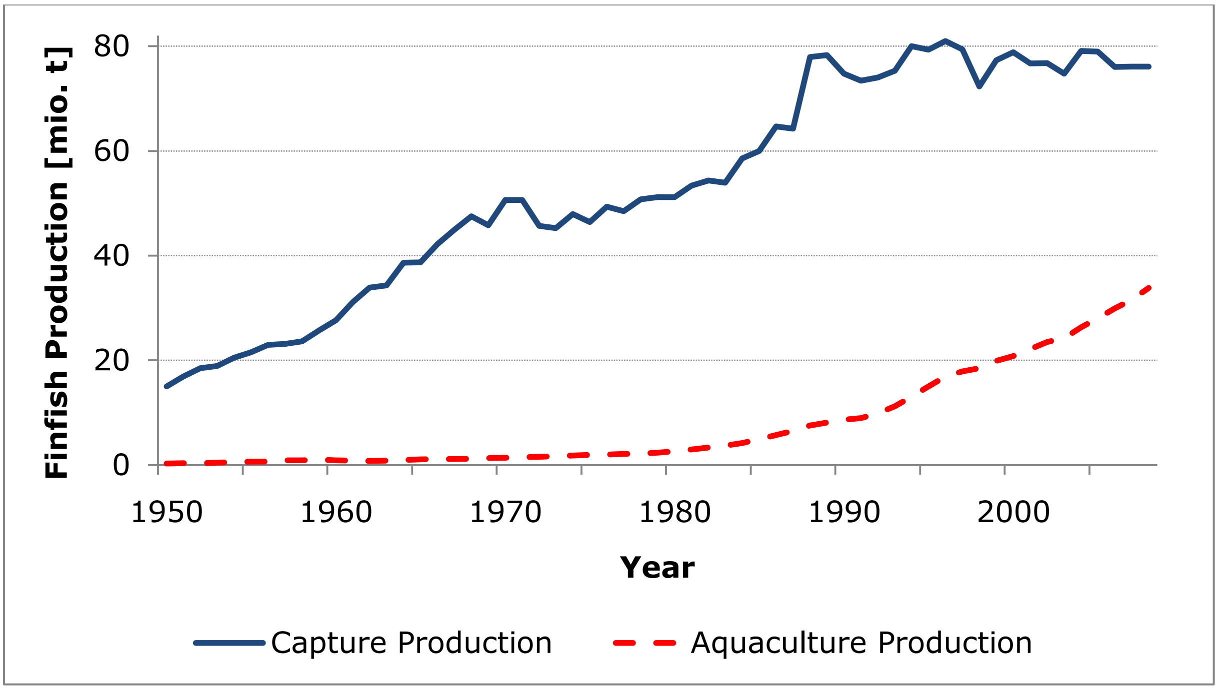
* own calculation based on per capita fish consumption of 16.7 kg in the year 2007

3.1.5 Share of aquaculture fish in total fish consumption

Fish for human consumption is either captured or produced by aquaculture. In the period from 1950 to 2008 capture production increased from about 15 million tons in the year 1950 to 76 million tons in the year 2008. Since the end of the 1980s production from capture fisheries fluctuates between 72 and 81 million tons.

Aquaculture's contribution to total fish production was low and nearly imperceptible in aggregate statistics until the beginning of the 1980s. At this time, Wise (1984, p.123) predicted: "Projections by aquaculture enthusiasts notwithstanding, it is unlikely that aquaculture will increase its contribution to the world food supply very much by the year 2000." Wise (1984) was wrong and the enthusiasts had got it right. Since the beginning of the 1980s aquaculture fish production grew quickly to nearly 34 million tons in the year 2008 (Figure 8). As fisheries production stagnated in the last few years, aquaculture alone accounted for most or all of fish production growth.

Figure 8: Development of finfish production from capture fisheries and aquaculture, 1950–2008 [mio. t]



Data source: FAO (2010)

Developments in the composition of fish production since the late 1980s suggest two trends: (i) production of capture fish is unlikely to exceed 80 million tons per year; (ii) all food fish demand beyond that limit will be met by fish supply from aquaculture.

3.1.6 Estimates of urban demand for fish from aquaculture in the year 2025

We may now quantify equation (3) to obtain estimates for the year 2025 of urban demand for fish from aquaculture.

World population estimates for the year 2025 range from 7.7 to 8.3 billion people (Table 3). Of these, 57.2 percent are expected to live in urban areas. This yields an estimated urban population in the world of 4.4 to 4.7 billion people. At an expected finfish consumption per person from 12.9 to 16.1 kg per year, urban demand for finfish is estimated to range from 56.8 to 76.6 million tons per year. Not all fish will have to come from aquaculture to satisfy urban demand. Assuming that the supply of finfish from capture is split between urban and rural consumers in proportion to the number or rural and urban people, between 40 and 45.8 million tons of capture finfish will be supplied in cities. This leaves an urban demand for aquaculture finfish in the range from 11 to 37 million tons.

This volume would seem to be sufficiently large for a sizeable urban aquaculture industry. Compared with today's estimated urban demand of 17 million tons of finfish from aquaculture, our estimation predicts a change of -6 to +20 million tons of urban aquaculture production until 2025. In the medium estimation this would imply 110,000 new RAS-plants of an average production of 100 tons per year.

Table 3: Estimation of urban demand for aquaculture finfish

	Unit	Estimate 2025		
		Low	Medium	High
World population	10^9 people	7.70	8.01	8.32
Share urban population	%	57.2	57.2	57.2
Urban population	10^9 people	4.40	4.58	4.76
Finfish consumption per person	kg/person	12.9	15.5	16.1
Urban demand for finfish	10^6 tons	56.8	71.0	76.6
Supply from capture fisheries	10^6 tons	80	75	70
Urban share capture finfish	10^6 tons	45.8	42.9	40
Urban demand for aquaculture finfish	10^6 tons	11.0	28.1	36.6

The estimates do not take changes in income into account which are likely to affect demand for fish. Another way to estimate future demand for food is given by an equation suggested by Ohkawa (1956) (quoted by Stevens, 1963): The rate of increase in food consumption (ΔD) is the sum of the rate of population growth (ΔP) plus the product of the rate of per capita income growth (ΔG) and the income elasticity of demand for food (η). For estimating the future demand for finfish we used the income elasticity for fish in place of the income elasticity of demand for food.

$$(4) \quad \Delta D_{fish} = \Delta P + \Delta G \times \eta$$

Population growth rate was computed from UN (2010) world population data, while the per capita income growth rate is calculated on the basis of OECD's (2010b) projection on world GDP development until 2025. Total world GDP is projected to increase between 3 and 3.7 percent p.a., which leads to a GDP growth per capita between 2010 and 2025 by nearly 40 percent. Reviews by Westlund (2005) and Asche and Bjørndal (2001) were used to determine the income elasticity for fish. Depending on the products analyzed and the demand systems used, income elasticities for fish vary widely; values of 0.2, 0.7 and 1.2 are equally plausible.

Our estimates of urban demand for aquaculture finfish derived from equation (4) are presented in Table 5. We expect urban demand for aquaculture finfish to be between 12.6 and 50.6 million tons in 2025. As expected, the estimates in Table 4 exceed those from Table 3 where the impact of rising incomes of demand have not been taken into account.

Table 4: Estimation of urban demand for aquaculture finfish in 2025 by Ohkawa's equation

	Unit	Estimate 2025		
		Low	Medium	High
Total population growth rate 2010-2025	%	12	16	20
Per capita income growth rate 2010-2025	%	20	40	50
Income elasticity of fish		0.2	0.7	1.2
Rate of increase in fish consumption	%	16	44	80
Finfish demand 2010	10^6 tons	88	88	88
Finfish demand 2025	10^6 tons	102.1	126.7	158.4
Finfish consumption per person	kg/person	13.3	15.8	19.0
Urban demand for finfish	10^6 tons	58.4	72.5	90.6
Supply from capture fisheries 2025	10^6 tons	80	75	70
Urban share capture finfish	10^6 tons	45.8	42.9	40
Urban demand for aquaculture finfish	10^6 tons	12.6	29.6	50.6

3.2 Fish supply from urban aquaculture production

3.2.1 Recirculation aquaculture systems (RAS)

Extensive experience with livestock production has shown two things: (i) productivity is higher when the animals are privately owned rather than communally owned or un-owned; (ii) productivity increases with the scope and accuracy of production system control.

Aquaculture production systems whose fish are not private property, such as open-access river aquaculture, are doomed for the same reasons that open sea fishery is doomed. Research investments into such systems would yield only short term payoffs, if any. Moreover, off-shore aquaculture systems are, obviously not relevant for us. Land-based aquaculture production systems with enforceable private property to the fish are of three kinds (FAO, 2008):

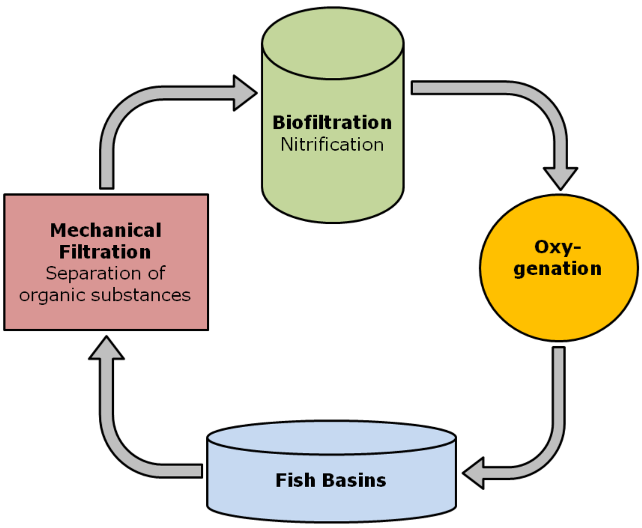
- Ponds, which are embedded in the landscape and whose water supply depends on the natural hydrology of a location;

- Flow-through systems (raceways), which are embedded in the landscape of a location and whose water is supplied from a river and therefore largely independent from the natural hydrology of their location;
- Recirculation aquaculture systems (RAS), which are independent of the natural landscape and hydrology of their location and which therefore can be erected anywhere where water and energy are available.

Ponds and flow-through systems suffer from three weaknesses. First, the choice of their location is constrained by the natural topography and hydrology of a place. Second, production process control is limited. In a pond system the manager may control the stocking rate and the feed provided to the fish. The rest is uncontrolled nature. In a through-flow system the flow of water, but not its quality, is also controlled in addition to the stocking rate and feed supply. All remaining determinants of productivity are, however, left in the unsteady hands of nature. Finally, in both systems effluents are released untreated into the environment (FAO, 2008). This does no harm to the fish but may be a nuisance for somebody else downstream.

The design of recirculation aquaculture systems avoids nearly all of the weakness of ponds and flow-through systems.

Figure 9: Schematic illustration of a closed recirculation aquaculture system



A RAS is a closed fish production facility with a high rearing density (Rennert, 1984). Figure 9 above shows a schematic drawing of a RAS. Fish are kept in fish tanks that are erected above ground. Water is pumped from the fish tanks to a physical filter unit where solids, such as particles of surplus feeds or feces, are removed by gravitation, mechanical filtration, or flotation. Ultraviolet light (UV), or ozone, or both may then be applied to disinfect the water. Undesirable gasses, such as CO_2, may then be removed from the water by a degasser. Water then flows into a biofilter where biological organisms convert ammonia to nitrate. After the water has left the biofilter it is often treated. Water treatment may include oxygenation, heating, salinity, and acid-base equilibrium (pH) regulation. In a RAS water may be heated or cooled to a temperature conducive for fish growth. Some fresh water has to be added from time to time to compensate for water losses, such as losses from evaporation or from treatment.

Because RAS are closed or partially closed systems, there is a clear separation between the outer natural environment and the inner artificial environment of the fish production system. This separation then allows nature's interference with the production process, such as heat, cold, rain, pathogens, to be reduced or eliminated (Bunting and Little, 2005). Some odor from aquaculture plants may, however, spill into the atmosphere. Moreover, the volume of effluent water from RAS is low and effluents are treated to render them fit for release or reuse (FAO, 2008). Finally, RAS technology provides economies of scale and RAS have the highest production per unit area, as well as per unit worker of any aquaculture system (Timmons, 2005).

RAS have, however, two important disadvantages compared to ponds and raceways: (i) high capital costs and (ii) high demands on management skills. The disadvantages of RAS will, however, erode over time whereas those of ponds and raceways will loom even larger in the future than they do now. Capital becomes more plentiful when economies grow and prosper whereas natural resources, including clean water and unspoiled landscapes, become scarcer and more valuable. Management skills become more abundant when growing populations are better educated. Finally, management support tools, such as digital computers, software, networks, smart networked sensors, and autonomous robots will become increasingly cheap in the near future (Economist, 2010) and are certain to ease the burden on management. On balance, we believe that the strengths of RAS greatly outweigh their weaknesses compared to ponds or raceways.

3.2.2 Environmental impact of urban aquaculture

3.2.2.1 Background of Life Cycle Analysis (LCA)

The increase in aquaculture production in the last decades also entails increased use of production inputs such as land, water, feeds, energy, therapeutants and chemicals that lead to exploitation of natural resources and that may raise environmental concerns. Furthermore, the increased production-inputs suggest a similar range of production-outputs, partly coupled with environmental impacts, comprised mainly of airborne and waterborne emissions from the farms. These emissions may result in local ecosystem imbalances, particularly in the recipient water body or contribute to a global scale impacts.

Recently, global emissions, predominantly comprising greenhouse gases (carbon dioxide, methane, nitrous oxides, and fluorocarbon) as a result of energy use and their contribution to global warming and ocean acidification have been addressed. Energy use in aquaculture is linked to its intensification and comprises energy used for fish production as well as indirect utilization of energy for manufacturing of feed, chemicals or material inputs as well as transportation. This indirect energy consumption is highly variable between aquaculture systems (Colt *et al*., 2008; Roque d'orbcastel *et al*., 2009) and management practices. The amount of nutrients and organic load from aquaculture effluent largely depends on the quantity and quality of feed used and on the resulting feeding efficiency. High input of nutrient and organic materials result in substantial increase in primary production, subsequent decomposition and their biochemical oxygen demand (BOD), limiting the carrying capacity of the recipient aquatic system, thus disturbing e.g. oxygen availability.

Some aquaculture production systems have a deservedly poor reputation because of their undesirable environmental impacts (Naylor *et al.*, 2000; Folke *et al.*, 1998). The level and nature of environmental impacts of aquaculture depends, however, crucially on the specific system and its intensity (Folke *et al.*, 1998). RAS production has some desirable feature: Their demands on land and water resources are low and uncontrolled discharges of effluents are minimized because process water is recycled (Schulz *et al.*, 2005; Timmons *et al.*, 2002). Moreover, in contrast to intensive livestock production systems, such as chicken production, RAS-plants produce little or no odor. Finally, because they can be located close to consumer markets, the food-miles of aquaculture fish can be kept low (Muir *et al.*, 2010). On the downside of the environmental impacts of RAS are their high levels of energy use (Ayer and Tyedmers, 2009) due to technical recycling of waste water for re-use.

As a result, there is a growing need and awareness to identify the overall environmental impact of various processes involved in aquaculture production in order to optimize its ecobalance. But, up to now, our knowledge on the holistic environmental relevance of various aquaculture systems or intensities is weak and limited. Thus, in addition to support policy making processes, future development of the aquaculture industry relies on the results of the environmental impact assessment to evaluate prospected expansion under the dominion of sustainability.

In order to fully understand the environmental implications of aquaculture activities, a more detailed, quantitative assessment is required. Such quantitative assessments of the environmental impact of aquaculture require a comprehensive, multi-dimensional accounting tool for assessing the impact of aquaculture on the ecosystem. Life cycle assessment (LCA) is a methodological framework used to quantify a wide range of environmental impacts that occur over the entire life-cycle of a product or process (Monfreda *et al.,* 2004; Kratena, 2004).

3.2.2.2 LCA of trout and chicken production

Comparing different systems producing similar products requires a high degree of accuracy for inventory data. Furthermore, Basset-Mens and van der Werf (2005) state that a large amount of data, which are representative of the systems to be evaluated, needs to be available. The purpose of this section therefore is to compare the overall environmental impact of RAS trout production and chicken farm by LCA. RAS trout production was chosen because of its relatively large production compared to other species, and for reasons of data availability.

A quick comparative life cycle analysis (LCA) of RAS and chicken production using SimaPro 7.2 software, sheds more light on the environmental impacts of RAS as compared to chicken farming. Life cycle impact assessment (LCIA) was performed using CML 2002 method. Life cycle inventory (LCI) of the RAS was based on original data collected from two RAS trout production facilities in Europe and the inventory for chicken from farm is based on the Danish LCA-Food database. We chose chicken production for comparison because chicken is a close substitute to fish for human consumption and because chicken production, like fish production, has a climate footprint of about two-thirds the size of red meat production (Weber and Matthews, 2008). Accordingly, we chose five impact categories representing the common impacts mainly considered in the LCAs of fish and chicken production. The goal of the comparison was to determine the environmental impact of RAS trout farming as compared to chicken production. The functional unit used for comparison is protein content of 1 kg of whole trout fish at farm-gate and comparable protein content of chicken production (1.2 kg of chicken) at farm gate.

The result shows that the trout intensive RAS production has relatively higher environmental impact in all impact categories chosen, except eutrophication (Table 5, Figure 10). This is mainly attributed to the high energy use involved in the production and water recycling. Energy used in the production of these food products is an average energy production of German electricity grid. Alternative energy sources, such as wind and solar energy sources, can greatly reduce the impact on the environment (Figure 11). Using alternative wind energy source, RAS trout production has relatively lower environmental impact as chicken farm in all impact categories chosen, except abiotic depletion.

Table 5: LCA of trout produced in intensive RAS of trout production and chicken produced in farms

Impact category	Unit	Trout, intensive RAS	Chicken, from farm
Abiotic depletion	kg Sb eq	0.3714	0.0049
Acidification	kg SO_2 eq	0.0673	0.0295
Eutrophication	kg PO_4 eq	0.0103	0.0137
Global warming 100a	kg CO_2 eq	52.9130	1.8117
Land competition	kg CFC-11 eq	0.5991	0.9139

Figure 10: Comparative LCA of trout produced in intensive RAS and chicken produced in farms using the average German energy mix

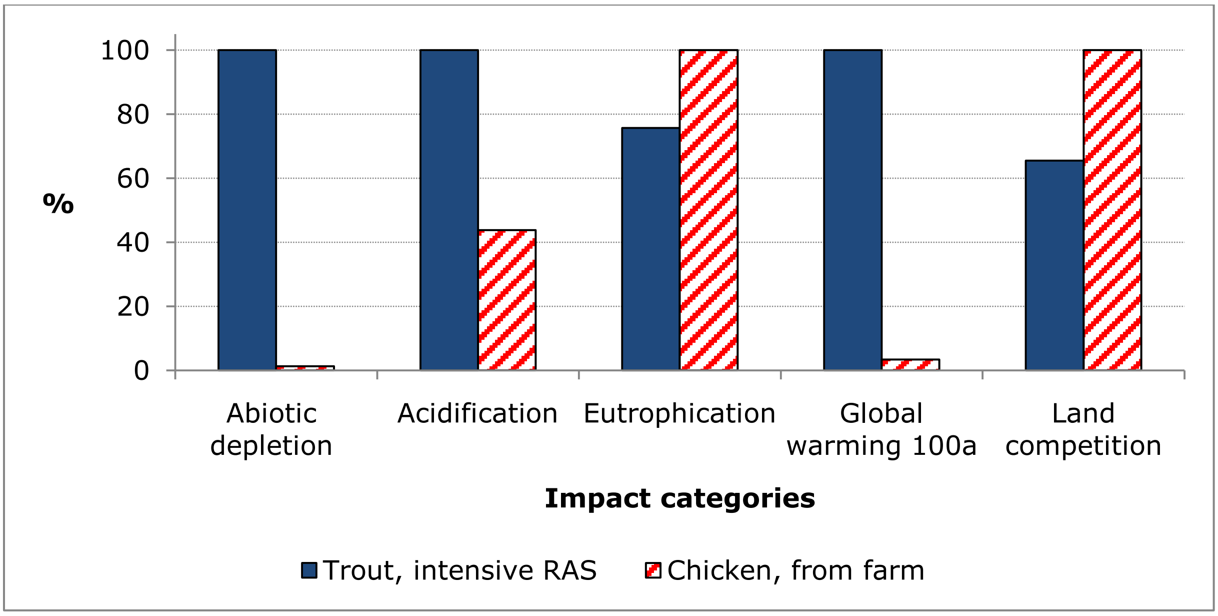
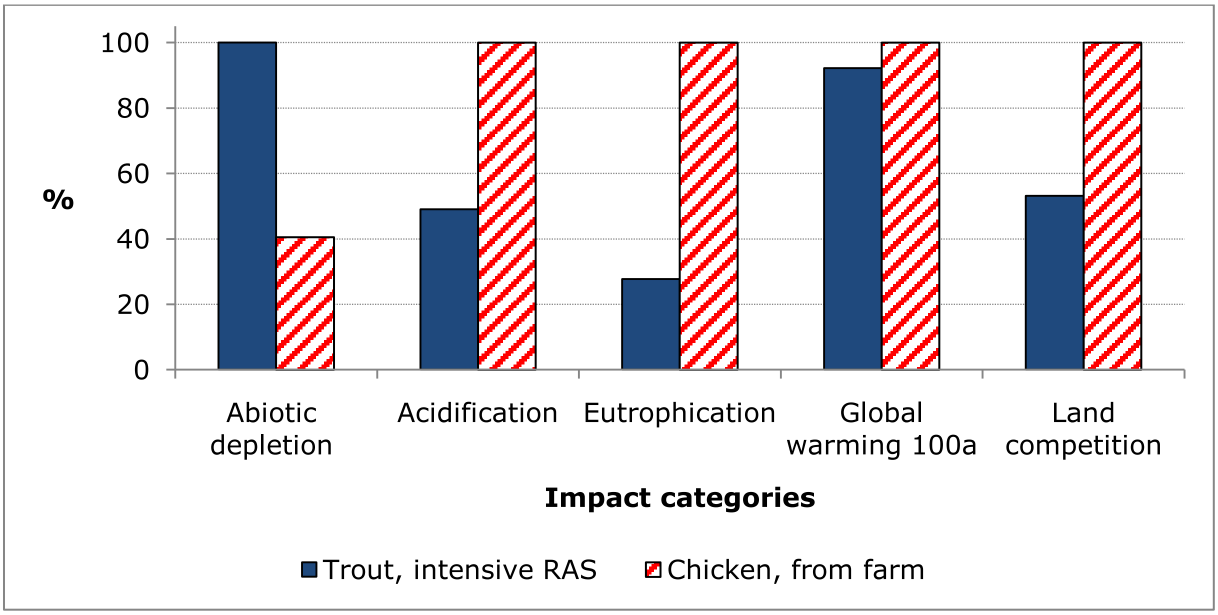


Figure 11: Comparative LCA of trout produced in intensive RAS and chicken produced in farms using alternative energy sources



3.2.3 Von Thünen and the location of production

Because RAS are largely independent of the topology and hydrology of a place they may be located wherever their placement is economically feasible. The question where to place a RAS may be answered with von Thünen's (1842) location theory. Von Thünen (1842) assumed in his model that maximization of land rent by farmers results in the production of different products in concentric rings around a city.

Land rent in farming is given by:

$$(5) \quad r_i(s) = (p_i - k_i - t_i d)\ e_i$$

where *r* is the gross margin of product i when produced at location s, p_i is the market price of product *i*, k_i are per unit production cost, t_i are transport cost per unit, *d* is the distance from the market, and e_i is the yield of product *i*. Producers are assumed to prefer a higher gross margin to a lower one. Moreover, production cost per unit and transport cost per unit are assumed to be constant for a given product *i*. Given a choice among alternative products *i = 1,2, …, n* the model suggests that producers at location s^* will choose the product that is produced at location d^* according to:

$$(6) \quad \max \{i\} \in \{r_1(s^*);\ r_2(s^*),\ \dots\ r_n(s^*)\}$$

When applied to land-based agricultural production this decision rule will, under certain conditions, result in rings around the city of declining land use intensity. We are, however, not concerned with von Thünen's famous rings. Such rings obtain only when the city is located, as von Thünen assumed, in the middle of a "fertile plain", or, more generally, when the hinterland of the city is homogenous all around (Sinclair, 1967).

We illustrate von Thünen's location decision rule in Figure 12 for the simple case of three products: (1) fresh pizza delivered to urban households from a pizza factory; (2) unfrozen fish for processing from RAS-aquaculture, and (3) slaughtered fish for traditional fish markets from pond-aquaculture. In contrast to von Thünen, we assume non-constant transport costs. In particular, we assume low transport costs within the city limit up to d_{cl}; beyond the city limit road density declines and transport cost increase, which is reflected in a steeper drop of the gross margin curves r_i. Moreover, we assume a maximum distance d_3 over which slaughtered fish from ponds may be transported without serious decay. Fish that is shipped into the city from locations beyond d_3 are assumed to be unfit for consumption upon arrival in the city and per unit transport costs for pond-fish jump to infinity at d_3.

Von Thünen's location decision rule divides the city and its surroundings into three zones. The first zone is the pizza zone from d_0 to $d_{1\text{-}2}$. In this zone pizza factories earn the highest gross margin:

$$(7) \quad r_1(s^*) > r_2(s^*) > r_3(s^*) \qquad \forall\ d_0 < s^* < d_{1\text{-}2}$$

Pizza factories can outbid both fish producers for land in this zone and pizza factories will locate here.

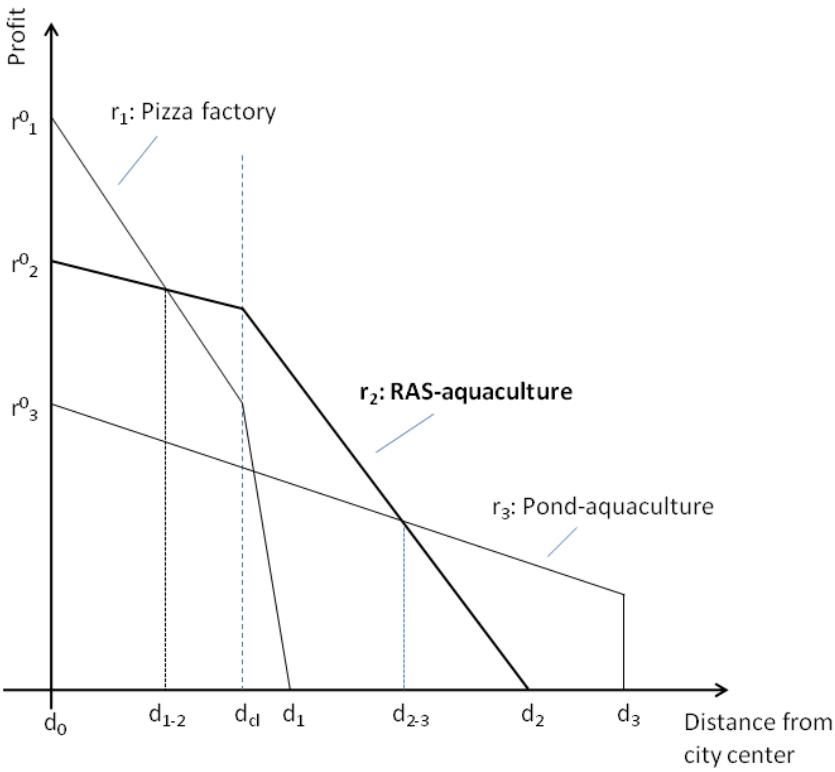
The pizza zone is followed by the RAS-zone in which RAS earn the highest gross margin and can outbid any other producer for land; this zone extends from d_{1-2} to d_{2-3}:

$$(8) \quad r_1(s^*) < r_2(s^*) > r_3(s^*) \qquad \forall\ d_{1-2} < s^* < d_{2-3}$$

RAS-aquaculture would be profitable up to distance d_{2-3} from the city. But RAS-producers would be outbid for scarce land by pond-producers already at a distance of d_{2-3} from the city. Beyond distance d_{2-3} pond-aquaculture earns the highest gross margin; beyond d_3 fish delivered to the market are spoiled and d_3 is the maximum distance from the city of pond-aquaculture:

$$(9) \quad r_1(s^*) < r_2(s^*) < r_3(s^*) \qquad \forall\ d_{2-3} < s^* < d_3$$

Figure 12: Von Thünen model



Von Thünen's theory loses its relevance when transport cost are only a small part of total trading costs and when other variables than transport cost determine location decisions, e.g. available labor force, knowledge spillovers, and the many variables that may cause industries to cluster in a particular location (Porter, 1998). For three reasons we believe that transport cost will remain an important and perhaps the dominant variable determining the location of RAS. First, transport cost, measured in terms of expenditure per distance and mass or volume, are high in many countries other than the high-income countries. In Africa, in particular, transport costs in the year 2007 ranged from 6 – 11 US¢ per tkm on the main transport corridors. In comparison, transport costs in the United States amounted to only 4 US¢ per tkm. In China transport costs were at 5 US¢ per tkm slightly higher than in the United States. In Brazil, in contrast, transport costs were at 3.5 US¢ per tkm lower than in the United States (Teravaninthorn and Raballand, 2009). We do not have any numbers on the transport costs in India but the World Bank (2010) considers India's road to be "congested and of poor quality" which leads to "high transport costs for users".

Second, there is no evidence that road transport services in India and China are rapidly improving. Transport services in Africa are generally of low quality (Teravaninthorn and Raballand, 2009). The second reason for believing in the continued relevance of von Thünen's theory is the increasing importance of the time cost and reliability of transport services. In tightly integrated food supply chains it is not good enough to supply a production input at low cost, the input must also be available at the specified time. Fish that arrives late at a processor or restaurant may be arriving too late.

Finally, concerns about climate change are a reminder that not all costs of transport are included in monetary expenses for transport services. The "carbon footprint" of transport services, in particular, also needs to be considered. At present, few developing or transition countries show much concern about carbon footprint cost. This attitude is, however, likely to change. Demand for a clean environment tends to increase with income and as these countries become richer their assessment of carbon footprint costs is likely to approximate that of the affluent countries (Arrow *et al*., 1995).

3.3 Agglomeration costs and benefits from locating aquaculture in a city

Cities are often perceived as agglomerations of people which encourage crime and the spread of diseases, and critics regard them as cesspits of filth and pollution that spill from profit-oriented factories into an otherwise pristine natural environment. Is it sensible to locate aquaculture at the fringes of cities at a time when the World Development Report (World Bank, 2007, p. 189), which generally reflects fairly well the consensus about politically correct development thinking, suggests that intensive livestock production be driven away from congested urban areas?

Against the view that aquaculture, just like other intensive livestock production, should be kept away from the cities we suggest three arguments. First, RAS-aquaculture produces much less effluents that are released or escape uncontrolled into the environment than conventional intensive livestock production plants. Second, just like a leaf blower does not eliminate foliage, dispersing intensive animal production does not eliminate effluents, they are only less noticeable. Finally, and most importantly, driving intensive animal production away from the cities ignores economic benefits from agglomeration, which are several and which may be huge.

Agglomeration economics has its roots in Marshall (1926), who recognized that firms that are part of agglomerations benefit in three ways from being bunched together. First, when many firms of the same industry co-locate, a local pool of specialized labor emerges from which any one firm in the agglomeration can draw. Second, in an agglomeration the local supply of non-traded goods, such as physical or institutional infrastructure is enhanced, and third, information flows better among firms that are huddled together in a confined location. The effects of population density on innovation have recently been measured by Bettencourt *et al.* (2007) who found that various measures of invention and innovations all increase exponentially with the size of cities.

We believe, but cannot prove, that the information and innovation benefits from locating RAS-plants in urban areas will outweigh the environmental concerns in location decisions of future RAS operators.

3.4 Marketing of fish in cities

3.4.1 Supply chain of urban aquaculture

Following Thorpe and Bennett (2004) an aquaculture fish supply chain can be described in general terms as a set of interdependent producers, agents, processors, distributors and other service providers who work together to supply fish products to consumers.

Figure 13 shows a simplified supply chain for urban recirculation aquaculture systems. The production depends on inputs like feed, seedlings and energy. After the fishes are raised to marketable size, they are harvested, slaughtered and may be processed. These steps may be carried out by the aquaculture farm itself or by specialized firms. Processed fish may be sold along several channels. For urban RAS-producers the best way to deliver fish to consumers probably is through urban supermarkets. Additionally, fish live or processed, may be sold directly to consumers (Little and Bunting, 2005).

Figure 13: Supply Chain of Recirculation Aquaculture Systems in urban areas

3.4.2 Supermarkets as outlets for aquaculture products

In high-income countries supermarkets have become the dominant sales channel for food, including fish. In the United Kingdom, for example, the share of supermarkets in total sales of fish for food increased from 16 percent in 1988 to 66 percent in 2001; in the same period the share of specialized fishmongers in national fish sales dropped from 49 percent to 18 percent (Murray and Fofana, 2002).

We have reason to expect similar developments in the cities of countries where incomes are rising rapidly. Supermarkets already play a significant and increasing role in the supply chains of countries that are catching up, such as Brasil, India, and China (Gulati *et al.*, 2005; Reardon and Gulati, 2008; Pingali, 2006). Annual growth rates of supermarkets vary between 10 and 90 percent, while the share of food sold through supermarkets varies from 5 to 50 percent (Gulati *et al.*, 2005). The rise of supermarkets in these countries is driven by urbanization, income growth, foreign direct investments, increasing consumer interest in one-stop-shopping, and increasing demand for hygiene and food safety (Gulati *et al.*, 2005). In addition, the sale of fresh products is becoming more and more important for supermarkets (Reardon and Berdegué, 2002). Supermarkets in cities of transition countries therefore are bound to be the most important channel for selling fish to consumers.

Marketing fish locally through supermarkets seems to be the obvious way to sell fish from urban RAS-plants which, because of their tightly controlled production, are able to deliver fish of constant quality and on schedule. Moreover, closeness of urban RAS to supermarkets reduces the risk of supply chain disruptions and enhances the ability of fish producers to react flexibly to supermarkets' evolving business models which tend to treat suppliers as renters of shelf space. Finally, as we explained earlier, locating production close to supermarket reduces transport cost and time.

4 Summary and Implications for Aquaculture R&D

At the beginning of the 1980s aquaculture was not expected to contribute significantly to world food security (Wise, 1984). Contrary to this expectation the last decades were marked by strong growth of aquaculture and stagnating fisheries production (FAO, 2011). Today, aquaculture accounts for nearly 50 percent of total food fish supply (FAO, 2011).

We envision a large and growing potential for recirculation aquaculture production systems located at the fringes of cities of converging countries. The technical feasibility of such systems is not in doubt but RAS-production is, at present, rarely profitable. Nevertheless, several trends support our vision: World population growth will be driven by growth of urban population in converging countries. In these countries, by definition, income will grow together with the population and both, population growth and income growth will stimulate demand for fish for food. The growth in demand will have to be met by growth in aquaculture production because fish supply from ocean fisheries is likely to stagnate or to decline. RAS located at the fringes of cities will have several competitive advantages over pond- and flow-through aquaculture systems. Urban RAS will have lower transport costs, will be better integrated into food supply chains that serve urban populations, and its ecological footprint is favorable if energy from low-carbon energy sources is used, such as wind, solar, or nuclear.

The disadvantages of RAS are its high investment and energy costs. The disadvantages can be overcome by R&D, technological evolution, and economies of scale. RAS technology clearly is yet not fully developed and there are many options for improving the efficiency and profitability of RAS. Such improvements will, however, only occur if the technology is actually used and kept alive (Gomory, 1983). Some of the necessary improvement will be generated by specialized public or private R&D agencies and many will emerge from the everyday operations of RAS-plants. As most inventions originate in cities, it seems obvious to implement RAS in or around densely populated cities where the networks among specialists are dense. Implementing RAS in cities could therefore accelerate RAS technology development. Such dispersed applied R&D-efforts may help to make RAS more profitable, less prone to systems interruptions and failures, and easier to manage. In addition, R&D could lead to a reduction of the production costs and thus may lead to large benefits for consumers and producers alike.

A growing urban population and an increasing demand for fish are factors which will strongly encourage the growth of aquaculture, especially of urban aquaculture. The question is, where and how RAS-aquaculture can find its niche in city economies from where it can grow and evolve. If RAS-aquaculture is unable to gain a foothold in some of the many cities of the future, it will never reach its full potential, because then the investment necessary for its improvement and deployment will not be forthcoming and an opportunity to contribute to world food security will have been wasted.

5 References

Alston, J.M; Chan-Kang, C.; Marra, M.C.; Pardey, P.G. and Wyatt, T.J. (2000): A meta-analysis of rates of return to agricultural R&D: Ex pede herculem? International Food Policy Research Institute, Washington, D.C.

Alston, J.M.; Pardey, P.G. and Ruttan, V.W. (2008): Research lags revisited: concepts and evidence from U.S. agriculture. Staff Paper 08-02, University of Minnesota, December 2008.

Arrow, K.; Bolin, B.; Costanza, R.; Dasgupta, P.; Folke, C.; Holling, C.S.; Jansson, B.O.; Levin, S.; Mäler, K.G.; Perrings, C. and Pimentel, D. (1995): Economic growth, carrying capacity, and the environment. Science 268: 520-521.

Asche, F. and Bjørndal, T. (2001): Demand elasticities for fish and seafood: A review. Unpublished, Centre for Fisheries Economics, Norwegian School of Economics and Business Administration; Bergen, Norway.

Ayer, N.W. and Tyedmers, P.H. (2009): Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada. Journal of Cleaner Production 17(3): 362-373.

Basset-Mens, C. and van der Werf, H.M.G. (2005): Scenario-based environmental assessment of farming systems: the case of pig production in France. Agriculture Ecosystems & Environment 105: 127-44.

Bettencourt, L.M.A.; Lobo, J.; Helbing; D.; Kühnert, C. and West, G.B. (2007): Growth, innovation, scaling, and the pace of life in cities. PNAS 104(17): 7301–7306.

Bunting, S.W. and Little, D.C. (2005): The emergence of urban aquaculture in Europe. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 119-135.

Bunting, S.W.; Kundu, N. and Mukherjee, M. (2005): Peri-urban aquaculture and poor livelihoods in Kolkata, India. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 61-76.

Colt, J.; Summerfelt, S.; Pfeiffer, T.; Fivelstad, S. and Rust, M. (2008): Energy and resource consumption of land-based Atlantic salmon smolt hatcheries in the Pacific Northwest (USA). Aquaculture 280: 94-108.

Delgado, C.L.; Wada, N.; Rosegrant, M.W.; Meijer, S. and Ahmed, M. (2003): Fish to 2020. Washington, Penang, International Food Policy Research Institute; World Fish Center.

Duarte, C.M., Marbá, N. and Holmer, M. (2007): Rapid domestication of marine species. Science 326: 382-383.

Economist (2010). It's a smart world. A special report on smart systems. Economist, November 6th, 2010.

Edwards, P. (2005): Development status of, and prospects for, wastewater fed aquaculture in urban environments. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 45-60.

FAO (2008): Glossary of aquaculture. Food and Agriculture Organization of the United Nations, Rome.

FAO (2010): FAOSTAT. http://faostat.fao.org/

FAO (2011): The state of world fisheries and aquaculture 2010. Food and Agriculture Organization of the United Nations, Rome.

Folke, C.; Kautsky, N.; Berg, H.;Jansson, A.; and Troell, M. (1998): The ecological footprint concept for sustainable seafood production: A review. Ecological Applications 8(1): S63-S71.

Gomory, R.E. (1983): Technology development. Science 220:576–580.

Gulati, A.; Minot, N.; Delgado, C. and Bora, S. (2005): Growth in high-value agriculture in Asia and the emergence of vertical links with farmers. Paper presented at the workshop "Linking Small- Scale Producers to Markets: Old and New Challenges", The World Bank, Washington, D.C., 15 December 2005.

Kratena, K. (2004): 'Ecological value added' in an integrated ecosystem-economy model - an indicator for sustainability. Ecological Economics 48: 189-200.

Little, D.C. and Bunting, S.W. (2005): Opportunities and constraints to urban Aquaculture, with a focus on South and Southeast Asia. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 25-44.

Marshall, A. (1926). Principles of economics. London: Macmillan.

Modelski, G. (n.d.): World cities in history: An overview. https://faculty.washington.edu/modelski/WcitiesH.htm (Nov. 26, 2010).

Monfreda, C.; Wackernagel, M. and Deumling, D. (2004): Establishing national natural capital accounts based on detailed Ecological Footprint and biological capacity assessments. Land Use Policy 21: 231-246.

Muir, J.F.; Little, D.C.; Young, J.A. and Bostock, J.C. (2010): Growing the wealth of aquaculture. In: OECD: Advancing the aquaculture agenda: Workshop proceedings, pp. 39-107.

Murray, A.D. and Fofana, A. (2002): The changing nature of UK fish retailing. Marine Resource Economics 17: 335-339.

Naylor, R.L.; Goldburg, R.J.; Primavera, J.H.; Kautsky, N.; Beveridge, M.C.M.; Clay, J.; Folke, C.; Lubchenco, J.; Mooney, H. and Troell, M. (2000): Effect of aquaculture on world fish supplies. Nature 405: 1017-1024.

OECD (2010a): Perspectives on Global Development 2010: Shifting Wealth. OECD, Paris.

OECD (2010b): Economic Outlook No. 87, Vol. 2010/1. OECD, Paris.

Ohkawa, K. (1956): Economic growth and agriculture. Annals of the Hitotsubachi Academy 7(1): 46-60.

Phan Van, M. and De Pauw, N. (2005): Wastewater-based urban aquaculture systems in Ho Chi Minh City, Vietnam. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 77-102.

Pingali, P. (2006): Westernization of Asian diets and the transformation of food systems: implications for research and policy. Food Policy 32: 281-298.

Porter, M.E. (1998): Clusters and the new economics of competition. Harvard Business Review 76: 77-90.

Reardon, T. and Berdegué, J.A. (2002): The rapid rise of supermarkets in Latin America: Challenges and opportunities for development. Development Policy Review 20(4): 371-388.

Reardon, T. and Gulati, A. (2008): The rise of supermarkets and their development implications. International Experience relevant for India. IFPRI Discussion Paper 00752, February 2008, Washington DC.

Rennert, B. (1984): Geschlossene Kreislaufsysteme zur intensiven Fischproduktion – ein Überblick. Fortschritte der Fischereiwissenschaft 3: 77–86.

Roque d'orbcastel, E.R.; Blancheton, J.P. and Aubin, J. (2009): Towards environmentally sustainable aquaculture: Comparison between two trout farming systems using Life Cycle Assessment. Aquacultural Engineering 40: 113-119.

Rosling, H. (2006): The best statistics you have ever seen. TED presentation February 2006. http://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen.html

Schulz, C.; Herbst, R.; Langensiepen, M. and Ulrichs, C. (2005): Herausforderungen einer umweltgerechten Aquakultur. Humbold Spektrum 1-2005: 42-48.

Sinclair, R. (1967): Von Thünen and urban sprawl. Annals of the Association of American Geographers 57(1): 72-87.

Stevens, R.D. (1963): The influence of urbanization on the income elasticity of demand for retail food in low income countries. American Journal of Agricultural Economics 45(5): 1495-1499.

Teravaninthorn, S. and Raballand, G. (2009): Transport prices and costs in Africa: A review of the main international corridors. AICD Working Paper 14. World Bank, Washington, D.C.

Thorpe, A. and Bennett, E. (2004): Market-driven international fish supply chains: The case of Nile Perch from Africa´s Lake Victoria. International Food and Agribusiness Management Review 7 (4): 40 - 57.

Thünen, Johann Heinrich, von (1842): Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie: oder Untersuchungen über den Einfluß, den die Getreidepreise, der Reichthum des Bodens und die Abgaben auf den Ackerbau ausüben. 2nd edition, Leopold, Rostock.

Timmons, M.B. (2005): Competitive potential for USA urban aquaculture. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 25 - 44.

Timmons, M.B.; Ebeling, J.M.; Wheaton, F.W.; Summerfelt, S.T. and Vinci, B.J. (2002): Recirculating Aquaculture Systems. Ithaca, Cayuga Aqua Ventures.

UN (2010): World urbanization prospects: The 2009 Revision, Highlights. United Nations, New York.

Vo, Q.H. and Edwards, P. (2005): Wastewater reuse through urban aquaculture in Hanoi, Vietnam: status and prospects. In: Costa- Pierce, B.; Desbonnet, A.; Edwards, P. and Baker, D. (eds.): Urban Aquaculture. CABI Publishing, Wallingford, Cambridge, pp. 103-1118.

Weber, C.L. and Matthews, H.S. (2008): Food-miles and the relative climate impacts of food choices in the United States. Environmental Science & Technology 42 (10): 3508-3513.

Westlund, L. (2005): Future prospects for fish and fishery products – 5. Forecasting fish consumption and demand analysis: a literature review. FAO Fisheries Circular No. 972/5, Food and Agriculture Organization of the United Nations, Rome.

Wijkstrom, U.N. (2003): Short and long-term prospects for consumption of fish. Veterinary Research Communications 27: 461-468.

Wise, J.P. (1984): The future of food from the sea. In: Simon, J.L. and Kahn, H. (eds.): The resourceful earth: A response to 'Global 2000'. Basil Blackwell, Oxford, New York, pp. 113-127.

World Bank (2007): World Development Report 2008. Agriculture for development. World Bank, Washington, D.C.

World Bank (2010): India Transport sector.
http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/EXTSARREGTOPTRANSPORT/0,,contentMDK:20703625~menuPK:868822~pagePK:34004173~piPK:34003707~theSitePK:579598,00.html

Ye, Y. (1999): Historical consumption and future demand for fish and fishery products: Exploratory calculations for the years 2015/2010. FAO Fisheries Circular 946, Food and Agriculture Organization of the United Nations, Rome.