Ability of the Geo-environment and Oceans to Support the Global Population

C. A. Coles
Faculty of Engineering and Applied Science,
Memorial University of Newfoundland, St. John's, Newfoundland, Canada

ABSTRACT
Current global population growth and resource use are contributing to climate change and environmental degradation and often the world's natural resources are exploited beyond their sustainable limit. Has the world reached its maximum carrying capacity? An examination of agriculture, fisheries, water resources, energy and greenhouse gas emissions, and manner of resource use are considered in trying to answer this question. Globally and strategically planned resources management as envisioned in a circular economy, and control of population growth is recommended to ensure sustainable conditions.

RÉSUMÉ
L'utilisation des ressources et la croissance démographique actuelles contribuent au changement climatique et à la dégradation de l'environnement et souvent les ressources naturelles de la planète sont exploitées au-delà de leur limite admissible. La planète a-t-elle atteint son seuil maximal de tolérance? Il s'agit ici d'un examen de l'agriculture, des pêches, des ressources hydriques, de l'énergie et des émissions de gaz à effet de serre, et de la manière d'exploiter les ressources, pour tenter de répondre à cette question. Afin d'assurer des conditions viables, il est recommandé de mettre en place une gestion des ressources au niveau mondial, planifiée stratégiquement telle que préconisée dans une économie circulaire, aussi bien qu'un contrôle de la croissance démographique.

1 INTRODUCTION

There is a need to understand the capacity of the planet to support continued population growth since it has been viewed as one of the main threats to the future environment (Michelcic et al., 2003). Hand in hand with the recognized need to curtail current population growth is the need, perhaps especially in more developed countries, to address the consumption of natural resources (Michelcic et al., 2003; Pimental and Pimental, 2005). Both the more developed countries and the less developed countries need to make major lifestyle adjustments to address the issues of population growth and materials and energy consumption.

Industrialized countries that have relied heavily on coal and oil for heating and energy have found themselves becoming responsible for global climate change at the same time as they are facing the prospect that oil supply may soon be unable to meet the demand (Marsdon, 2009). It has been suggested that it would be wise to save oil for transportation since about 20% of global oil is consumed in transportation and there are other available options besides oil for heating purposes (Lightfoot, 2006).

Researchers have been working on improving energy efficiency and developing more renewable sources of energy but Huesemann (2008) points out that realistically it has to be expected that even the use of relatively renewable energy will be associated with some environmental drawbacks. He continues to explain how education, incentives and social programs can help curb population growth and how human happiness is dependent on relative rather absolute levels of wealth and accomplishment, once basic needs are met.

A brief review of agriculture, fisheries, water resources, energy use and greenhouse gas emissions, and manner of resource use is undertaken to justify the need to curb population growth and make changes to consumption of natural resources.

2 AGRICULTURE

The ability of agriculture to support the global population will be an important factor in determining the maximum population that the planet can support. Some agricultural experts think that the planet may be able to support up to 12 billion people, others think that the planet has reached the maximum population that is environmentally sustainable and others think that the maximum population that can be reasonably supported by the earth has already been surpassed (Harris and Kennedy, 1999).

Harris and Kennedy (1999) conclude that the world will reach its agricultural *"carrying capacity...[within]…the next few decades".* The arguments they present to support this view are difficult to dispute. This estimate may even be optimistic given that currently 3.7 billion people are malnourished and the grain per capita production has been decreasing since 1984 (Pimental and Pimental, 2005),

Harris and Kennedy (1999) point out that since population growth normally follows a logistic curve (of exponential growth followed by declining growth and then stationary growth), agricultural production may be reasonably expected to follow a logistic growth pattern. They also suggest that further growth increases must come from increased crop yields since it is generally recognized that significant amounts of additional land that can be acquired for agriculture do not exist.

Cereal grains make up the bulk (about 80%) of the human diet (Pimentel and Pimentel, 2005). When Harris and Kennedy (1999) compared growth in crop yields between more developed countries and less developed countries for three cereal crops (maize, wheat and rice) they found the less developed countries were about 15 years behind. (The terms less developed and more developed are being used only with regards to technological development.) More importantly, however, they observed a steady rise in crop yields in less developed countries whereas in the more developed countries there was a fluctuating or *"saw-toothed"* rise in crop yields and the rate of yield increase was not as great as for the less developed countries. The yield growths in the more developed countries appeared to be representing later stages on the logistic curve. Crop yield fluctuations indicate that the maximum yields are being approached and the fluctuations are due to the higher yields being more sensitive to weather conditions (Harris and Kennedy, 1999).

Annually, 10 million ha are subjected to soil and wind erosion and 10 million ha are lost through salinization due to irrigation (Pimentel and Pimentel, 2005). Since in the agricultural sector, the past production has not always been sustainable, it may not be easy to use past growth to predict future growth since resources may need to be applied to remediate the environmental degradation that has occurred and this could remove resources from the production side.

In poor rural populations in less developed countries crop residues are used for fuel when leaving them would protect the soil from erosion (Pimental, 2006). In this way poverty is contributing to soil erosion and alleviating poverty and providing education would be a way of improving the environment. Another example of poverty contributing to environmental degradation is in the release of mercury vapour from burning of amalgams during gold mining because of the primitive methods employed by the poor in less developed countries. To reduce transboundary migration of mercury in the atmosphere and possibly in ground and surface waters, a UN Global Mercury Project in 6 countries provided education and technological improvements in the form of filters for the mercury vapours and introduced legislation (Veiga, 2009).

Current and past pesticide use is an unsustainable practice which has been particularly destructive in less developed countries (Wilson and Tisdell, 2001). Runoff from agricultural fields in the United States, containing synthetic nitrogen fertilizers and phosphorus, that enters the tributaries of the Mississippi River has also been blamed for the global oceans' second largest anoxic dead zone in the Gulf of Mexico (Mitchell, 2009). Virtually non-existent before World War II, and now numbering about 407, the number of ocean dead zones, caused by agricultural runoff, industrial and sewage discharges, and atmospheric deposition from burning of fossil fuels, have been growing exponentially in the past few decades (Mitchell, 2009).

Not only will greater future cereal yields be more constrained by environmental degradation, but diminishing water resources and increasing greenhouse gas emissions from soil tillage are a concern (Harris and Kennedy, 1999). Already greater than 70% of freshwater resources are diverted to agriculture (Pimentel and Pimemtel, 2005).

More contamination of surface and ground waters, pest resistance and loss of biodiversity are other problems associated with current conventional agricultural methods and it is feared these methods may only be effective in the short term (Badgley et al., 2007). However, organic agriculture employing crop rotation, intercropping, cover crops, biological control of pests, composting and manure application can equally well meet the global food demands while preserving the environment and can be a viable solution in the long term (Badgley et al., 2007). Higher food production per land area is possible on smaller farms, less water and nutrients are required with organic farming, and organic farming requires a steady and more intensive labour force that could improve rural employment (Badgley et al., 2007). In some countries backyard farming is the norm and energy and food transportation costs could be reduced if this practice became more widespread.

Pesticides and fertilizers used in conventional farming are produced from fossil fuels and fossil fuels provide energy for irrigation and agricultural machinery. Conventional farming relies heavily on fossil fuels (Pimental, 2006) whereas organic farming could help reduce this dependence and could conserve energy.

In the US and Europe there is currently about 0.5 ha of farmland per capita available whereas globally the per capita farmland is only 0.23 ha and to maintain this low level of farmland more forests are being cut (Pimentel, 2006) removing a CO_2 sink. Urbanization in more developed countries however has removed some pressures in the rural setting where forest cover has actually been increasing (Bilsborrow, 2006).

In recent years technological development that included fossil fuel usage was able to ward off famine (Hall and Day, 2009) but the measures contributed further to environmental degradation. *"Acid rain, global warming, pollution, loss of biodiversity and the depleting of the Earth's protective ozone layer"* have been some of the environmental damages (Hall and Day, 2009) but these may be dwarfed by the significance of the changes that have occurred in global ocean that contains the *"switch of life"*, makes up *"99 per cent of the living space on the planet", and is the home to "at least half of the mass of life"* (Mitchell, 2009). Though technology and innovation has "increased the carrying capacity of the earth for humans" and the recent recession has reduced the current demand for oil and thus extended term over which oil supplies may be available, there is a limit to which the earth's resources can provide for the global population consumption (Hall and Day, 2009) and experts are warning there could be a significant *"population downturn"* (Mitchell, 2009; Yong et al., 2007).

World food prices increased only 1.3% between 2000 and 2005 but increases shot up to 15% between 2006 and 2008 (Peters et al., 2008).

3 FISHERIES

Food contribution to humans from the world's fisheries is about 15% of the protein supply per person (Ormerod, 2003) and the global fisheries will play a role in influencing the carrying capacity of the planet. One trend that has occurred in the fisheries for centuries is the "fishing down marine food webs" (Pauly et al., 2005). Large fish that are high on the food chain are fished to extinction and then fishers move on to another species and repeat the process so that increasingly smaller fish at lower trophic levels are fished (Pauly et al., 2006; Mitchell, 2009). This has lead to losses in quantities of fish and in biodiversity of fish species with more accelerated loss of species diversity occurring since the beginning of the industrial age (Worm et al., 2006). Greater biodiversity enhances the ability of a fishery to resist overexploitation and is correlated with a more consistent catch every year and a higher total level of production (Worm et al., 2006).

Since the mid to late 1980's the total global fish catch and the *per capita* fish consumption by humans has been declining (Pauly et al., 2006; Mitchell, 2009, p. 136). This situation is not alleviated by fish-farming when fishmeal and fish oils are used as food for the farmed stock and are removed from human consumption (Ormerod, 2003: Pauly et al., 2006). Without conservation measures experts are cautioning that total fisheries collapse could occur by the middle of this century (Stokstad, 2008; Worm et al., 2006; Pauly et al., 2006).

Currently about 47% of fish stocks are being fished to their sustainable limit and 28% are being fished beyond their sustainable limit (Ormerod, 2003). Pollution and climate change are additional stressors in freshwater and marine environments (Ormerod, 2003). Improved fisheries management and implementing a long term approach such as a "catch shares" system is recommended to help restore the global fisheries (Stokstad, 2008). Also recommended are controlling pollution, maintaining habitats and creating marine reserves (Worm et al., 2006). For freshwater systems habitat restoration often needs to be undertaken in conjunction with conservation practices (Ormerod, 2003).

Unabated climate change could be devastating for the global fisheries. As the pH drops, the carbonate ion concentration goes down and those organisms that require calcium to build shells and skeletons, including corals and some plankton, may not survive (Mitchell, 2009).

4 WATER RESOURCES

In 1995 when the world population was about 5.67 billion, it was estimated that about one third or slightly more than one third of the global population were living under conditions of moderate to severe or severe water stress (Kuylenstierna et al., 1998; Vörösmarty et al., 2000). Moderate to severe water stress implies that economic and social development is limited because of the lack of freshwater resources available (Kuylenstierna et al., 1998). Although future population trends may be difficult to accurately predict, it has been estimated that if no preventative measures are taken, as much as two thirds of the global population or 5.5 billon people could be living under conditions of moderate to severe or severe water stress by 2025 (Kuylenstierna et al., 1998).

Saudi Arabia is responsible for a quarter of the world's production of desalinated seawater which is used to supplement freshwater quantities for potable water by about 50% and for growing some *"high value"* agricultural crops (Al-Sahlawi, 1999). Multistage flash distillation and to a lesser extent reverse osmosis are employed. Otherwise irrigation water is obtained from groundwater aquifers, in some cases as deep as 300 m (Al-Sahlawi, 1999). Most of the expected decrease of desalination costs occurred between 1980 and 1999 and this region has been able to finance desalination though their export of crude oil but they will need to regularly reassess the technology and the international market to make sure that the most economical processes continue to be employed (Al-Sahlawi, 1999). There is also the question as to whether the health of domestic customers can be compromised by drinking de-mineralized water (Al-Sahlawi, 1999). The freshwater shortage is being mitigated by technology that requires much higher energy consumption.

A recent study that was undertaken in the United Kingdom to evaluate the removal of emerging contaminants of concern from wastewater with granular activated carbon and ozone or microfiltration and reverse osmosis, concluded that it would be more economical and require less energy to employ secondary biological treatment with extended sludge retention times and nitrification and denitrification. A small amount of micropollutants would not be removed by the extended secondary treatment but the adverse effects of employing the advanced treatment processes (increased energy use and CO_2 emissions) meant the advanced treatments were not environmentally sustainable and outweighed the benefits of removing the pollutants (Jones et al., 2007). Industries will need to be better regulated and controlled with regards to the chemicals they are allowed to produce and discharge and the diversity and number of these chemicals could probably be reduced. For example, Hewlett-Packard formerly used 200 different plastics in their products but they have now reduced this umber to 5 and where formerly they used glue they now use screws to make the items easy to disassemble. Their processes have become more simple and less expensive (McBride, 2009).

The environmental sustainability of advanced wastewater treatments was also assessed by Høibye et al. (2008) who considered sand filtration, ozonation, UV disinfection, membrane bioreactor and UV disinfection combined with advanced oxidation by comparing the beneficial effects of the treatments to their induced environmental impacts which included contribution to global warming, acidification and eutrophication. They showed that sand filtration for removal of heavy metals and half of the micobiological pollutants compared the most favourably of all the technologies and that the membrane bioreactor was not overall sustainable, was the most energy intensive, and had the greatest environmental impacts.

5 ENERGY AND GREENHOUSE GAS EMISSIONS

Energy availability will be another important factor in determining the capacity of the planet to support population growth and energy is tied into agriculture production and transportation of agricultural products. About 40% of energy use is in food production and about 20% of energy use is in transporting commodities including foodstuffs (Lightfoot, 2006). Approximately 32% of the anthropogenic greenhouse gases emitted are attributed to agricultural and livestock production (Peters et al., 2008). However, there are some ways that energy use and greenhouse gas emissions in the agricultural sector can be reduced.

Peters et al. (2008) suggest that two ways of reducing agricultural resource use could be for people to reduce the proportion of animal food they consume and for obese people to reduce their calorific intake. Concern over future energy availability has made many people think about where their food supply is coming from (Suzuki and Boyd, 2008; Peters et al., 2008) and reducing transportation of food over long distances could significantly cut back on global energy consumption. There is debate on the merits of local food, were "local" has political in addition to geographic implications as it encourages decentralization and discourages monopolies (Peters et al., 2008).

When food is produced in a region with an abundant water supply and transported to a dry or desert area then this also results in the transportation of virtual water and might be more justifiable. In these types of situations more in depth study of the costs and benefits should be undertaken.

Two other areas where energy consumption related to agriculture could be addressed are in the production of tobacco and alcoholic products though this author has not seen this mentioned in the literature. The harmfulness of tobacco is becoming quite well understood and a recent seven year study that followed 1.28 million women found increased risk of cancer, especially breast cancer was correlated with low to moderate levels of alcohol consumption in women (Allen et al., 2009). Diverting resources away from production of non-essential items could help relieve energy demands while improving human health.

From a brief review of the literature related to energy it appears that the potential energy resources are available but will just require more focused research and development so that these resources can be developed in time to meet the energy demands in the near future. New electrical power generation in the next 20 years may equal what was developed in the 20^{th} century except that the new developments must be environmentally sustainable (Lior, 2008). This is an extra challenge requiring the rapid and complete development of the science of sustainability (Lior, 2008).

As energy and technological developments occur, the carrying capacity of the earth increases. By employing "Phytofarming" or hydroponics using artificial lighting the world might be able to support a population of many times what is now thought to be reasonable (Asif and Muneer, 2007). However, currently there is a need to harness enough energy to meet the projected population growth in the coming decades while protecting the environment. Asif and Muneer (2007) relate environmental impact (I), with population size (P), population affluence (A) and technology or energy efficiency (T) by the equation.

$$I = PAT \qquad [1]$$

Renewable energies and nuclear energy are being considered to replace fossil fuels and the use of pure hydrogen may follow those developments. Separately solar and wind may not be sufficiently dependable but together they could be used in a complimentary manner, with regions near the equator relying more heavily on solar energy and regions closer to the poles relying more heavily on wind energy (Asif and Muneer, 2007).

It is interesting to note that the dwindling supply of uranium may soon necessitate the development of nuclear reactors that use Th-232 instead of U-235 (Lior, 2008). This is another example of the planet's finite resources.

6 CIRCULAR ECONOMY

Waste does not exist in nature because what is waste from one organism is food for another organism and in this way the planet is continually renewing and cleaning itself. A circular economy is a closed loop system where wastes are converted into resources and 'precycling' or advance planning is employed so that manufactured products at their end of use can be easily disassembled and converted into resources (Greyson, 2007). Instead of making insurance available to cover the growing risk of environmental damage, precycling insurance would put the onus on producers to be proactive and manage materials to prevent them from becoming future wastes (Greyson, 2007). Waste prevention could be less complicated than waste reduction and when wastes are converted into resources then resources become more abundant (Grey, 2007)

China has become dedicated to implementing a circular economy at three levels which include the company level where companies are publicly rated in five categories according to their environmental performance, at the eco-industry level where eco-industrial parks are formed to implement sustainable production through 'energy cascading, sharing of local infrastructure, and exchanging by-products and recycling wastes', and at the eco-municipality or eco-province level where decision makers are learning to combine sustainable production and consumption (Yuan et al., 2006). The creation of a circular economy in China has become primarily an economic tool and secondarily an environmental strategy (Yuan et al., 2006). Though as Grey (2007) admits many aspects of how to promote a circular economy still require research, this interesting approach appears to have great potential in terms of the planet's future development.

7. CONCLUSIONS

According to Pimental and Pimental (2005) the grain per capita production has been decreasing since 1984. Mitchell (2009) mentions that the world reached it maximum fish catch in the mid 1980's. In 1984 the global consumption of fossil fuels began to exceed the global withdrawal (Lightfoot, 2006) and Asif and Muneer (2007) show oil price fluctuations beginning around this time. When the world population was just under 6 million, the economic and social development of about 2 million people was limited due to scarcity of freshwater resources (Kuylenstierna et al., 1998; Vörösmarty et al., 2000). When one resource begins to be inadequate then alternatives may be drawn upon and when the consumption of alternative resources is increased above previous normal levels then there is a greater chance that they may also soon become insufficient (Richard Berthiome, Laval University, May 2009). This can lead to many shortages occurring at the same time or one after another.

Hall and Day (2009) refer to *"peak everything".* However, these peaks have been reached with much waste and inefficiency and with improved energy efficiency and conservation a higher peak population might be acceptable. In a municipality if there are no resources allocated for town planning then unplanned growth occurs. Similarly, on a global scale, if population growth is not planed then unplanned growth will occur and could possibly become unsustainable.

To make better use of the world's limited resources, there needs to be planned global population growth and strategic and equitable resource use. The production of some of the many chemicals that are produced today may need to be curtailed if these chemicals cannot be easily broken down in the environment or removed through simple wastewater treatments. The formation of one or two international bodies to address global population growth and resource use is recommended.

REFERENCES

Allen, N.E., Beral, V., Casabonne, D., Kan, S.W., Reeves, G.K., and Brown, A. 2009. Moderate Alcohol Intake and Cancer Incidence in Women, *Journal of the national Canxcer Institute,* 101(5):296-305.

Al-Sahlawi, M.A. 1999. Seawater desalination in Saudi Arabia: economic review and demand projections, *Desalination,* 123:143-147.

Asif, M. and Muneer, T. 2007. Energy supply, its demand and security issues for developed and emerging economies, *Renewable and Sustainable Energy Reviews,* 11:1388-1413.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Avilés-Vázquez, K., Samulon, A., and Perfecto, I. 2007. Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems,* 22(2):86-108.

Bilsborrow, R.E., 2006. Overpopulation and Sustainability. *Frontiers in Ecology and the Environment,* 4(3):160-161.

Greyson, J., 2007. An economic instrument for zero waste, economic growth and sustainability, *Journal of Cleaner Production,* 15:1382-1390.

Hall, C.A.S. and Day, Jr., J.W. 2009. Revisiting the Limits to Growth After Peak Oil, *American Scientist,* 97:230-237.

Harris, J.M. and Kennedy, S. 1999. Carrying capacity in agriculture: global and regional issues, *Ecological Economics,* 29:443-461.

Høibye, L., Clauson-Kaas, J., Wenzel, H., Larsen, H.F., Jacobsen, B.N. and Dalgaard, O. 2008. Sustainbability assessment of advanced wastewater treatment technologies, *Water Science & Technology,* 58:963-968.

Huesemann, M.H. 2008. Ocean fertilization and other climate change mitigation strategies: an overview, *Marine Ecology Progress Series,* 364:243-250.

Jones, O.A.H., Green, P.G., Voulvoulis, N., and Lester, J.N. 20007. Questioning the excessive use of advanced treatment to remove organic micropollutants from wastewater, *Environmental Science & Technology,* 41:5085-5089.

Kuylenstierna, J., Najlis, P., and Björklund, 1998. The comprehensive assessment of the freshwater resources of the world – Policy options for an integrated sustainable water future, *Water International,* 23:17-20.

Lightfoot, H.D., 2006. *Nobody's Fuel,* H. Douglass Lightfoot.

Lior, N. 2008. Energy resources and use: The present situation and possible paths to the future, *Energy,* 33:842-857.

Marsdon, W., "The age of oil is ending", *Montreal Gazette,* January 11, 2009, http://www.montrealgazette.com/Business/ending/1162492/story.html, Accessed March 8, 2009.

McBride, E., 2009. A Special Report on Waste: Tackling Waste, *The Economist,* Feb. 28. http://www.economist.com/specialreports/displaystory.cfm?story_id=13135425, Accessed June 22, 2009.

Mihelcic, J.R., Crittenden, J.C., Small, M.J., Shonnard, D.R., Hokanson, D.R., Zhang, Q., Chen, H., Sorby, S.A., James, V.U., Sutherlanmd, J.W., and Schnoor, J.L. 2003. Sustainability science and engineering: The emergence of a new metadiscipline, *Environmental Science & Technology,* 37:5314-5324.

Mitchell, A., 2009. *Sea Sick The Global Ocean in Crisis,* McClelland & Stewart, Toronto, ON, Canada.

Ormerod, S.J. 2003. Current issues with fish and fisheries: editor's overview and introduction, *Journal of Applied Ecology,* 40;204-213.

Pauly, D., Watson, R., and Alder, J. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security, *Philosophical Transactions: Biological Sciences,* 360(1453):5-12.

Peters, C.J., Bills, N.L., Wilkins, J.L., and Fick, G.W. 2008. Foodshed analysis and its relevance to sustainability, R*enewable Agriculture and Food Systems,* 24(1):1-7.

Pimentel, D., 2006. Overpopulation and Sustainability. *Frontiers in Ecology and the Environment,* 4(3):155-156.

Pimentel, D., and Pimentel, M. 2005. Global environmental resources versus world population growth. *Ecological Economics,* 59:195-198.

Stokstad, E. 2008. Privatization Prevents Collapse of Fish Stocks, Global Analysis shows, *Science,* 321(5896):1619.

Suzuki, D. and Boyd, D. 2008. *David Suzuki's Green Guide*. Greystone Books, Vancouver.

Veiga, M.M., 2009. Artisanal Gold Mining: A Trap of Poverty and Pollution. *Geotechnical News,* 27(1):45-47.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth, *Science,* 289(5477):284-288.

Wilson, C. and Tisdell, C. 2001, Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics,* 39(3):449-462.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., and Watson, R. 2006. Impacts of Biodiversity Loss on Ocvean Ecosystem Services, *Science,* 314(5800):787-790.

Yong, R.N., Mulligan, C.N. and Fukue, M. 2007. *Geoenvironmental Sustainability*, CRC Press, Boca Raton, FL, USA.

Yuan, Z., Bi, J., and Moriguichi, Y. 2006. The Circular Economy, *Journal of Industrial Ecology,* 10:4-8.