Sains Malaysiana 40(12)(2011): 1331–1340

Natural Resources Management and Food Security in the Context of Sustainable Development

(Pengurusan Sumber Asli dan Keselamatan Makanan dalam Konteks Pembangunan Mampan)

JOHN HILL & SALEEM MUSTAFA

ABSTRACT

This paper elaborates on the inseparable link between sustainability of natural resources and food security. A strategic framework that envisages conservation, improvement and sustainable uses of natural resources is proposed which meets the essential requirements for food security. Sustainability has traditionally been accepted as encompassing three dimensions, namely environment, economics and society but it is necessary to widen this approach for a more complete understanding of this term. Environmental degradation curtails ecosystem services, leading to impoverishment of vulnerable communities and insecurity. Food, whether derived from land or sea, is a product of complex environmental linkages, and biodiversity has a pivotal role to play in producing it. Technology, production methods and management requirements are different for food derived from land and sea, but essentially all foodstuffs utilize environmental resources whose sustainability is crucial for food security. This analysis necessitates consideration of the basic concepts of sustainable development and food security, the strength of the link between these and differences in the patterns of sustainable management of agriculture, fisheries and aquaculture. The growing role of genetically engineered organisms has been included because of the immense possibilities these offer for maximizing food production despite the environmental and ethical concerns raised.

Keywords: Environment; food security; natural resources; sustainability

ABSTRAK

Kertas ini menghuraikan perkaitan yang tidak boleh dipisahkan di antara kemampanan sumber asli dan juga keselamatan makanan. Satu rangka kerja yang strategik bersama gambaran tentang pemuliharaan, pembaikan dan penggunaan sumber asli secara mampan telah dicadangkan bagi memenuhi keperluan penting untuk keselamatan makanan. Kemampanan, secara tradisinya, telah diterima sebagai unsur yang meliputi tiga jenis dimensi, iaitu persekitaran, ekonomi dan masyarakat, akan tetapi pendekatan berkenaan istilah ini perlu diperluaskan lagi untuk pemahaman yang lebih jelas tentangnya. Pencemaran alam sekitar mampu menyekat kitaran ekosistem dan boleh membawa kepada penderitaan dan turut melemahkan sesuatu komuniti dan menjadikannya tidak selamat. Sedangkan makanan, sama ada ia berasal dari daratan atau laut, merupakan satu hasil daripada perhubungan alam sekitar yang kompleks, dan kepelbagaian biologi memainkan peranan yang penting dalam penghasilannya. Keperluan daripada segi teknologi, kaedah pengeluaran dan pengurusan adalah berbeza bagi makanan yang berasal dari daratan dan laut, akan tetapi semua bahan ini pada dasarnya masih menggunakan sumber alam sekitar yang mana kemampanannya adalah penting bagi keselamatan makanan. Analisis ini memerlukan pertimbangan mengenai asas kepada konsep pembangunan mampan dan keselamatan makanan, kekuatan hubungan yang terbentuk di antara keduanya dan juga dari segi perbezaan corak pengurusan mampan dalam bidang pertanian, perikanan dan akuakultur. Peranan organisma secara genetik yang kian berkembang turut disertakan berikutan dengan kemungkinan yang besar bahawa ia mampu menawarkan hasil pengeluaran makanan yang maksimum di sebalik kebangkitan isu berkaitan dengan etika dan alam sekitar.

Kata kunci: Kemampanan; keselamatan makanan; persekitaran; sumber asli

INTRODUCTION

SUSTAINABLE DEVELOPMENT- IMPERATIVES AND DRIVERS

Sustainable development is a challenging abstract concept. It essentially represents a paradigm shift in understanding the relationship between humanity and the environment. Sustainable Development links ‘environmental’ and ‘socio-economic’ issues, as identified by the World Commission on Environment and Development (WCED 1987) which defined it as maintaining the needs of the present generation without compromising the ability of future generations to meet their needs. This WCED (Brundtland) report also recognises that to meet ‘current needs’ the environment is over-exploited in terms of mining its resources at a rate that is not sustainable. In the last two decades, many definitions and interpretations of sustainable development have emerged in an attempt to provide a more workable statement of the meaning of this abstract concept. Hoff (1998) has stated that 'sustainable development involves the integration of cultural, economic, political and environmental factors', which suggests that sustainable development is a process involving many components. UNESCO (2004) has suggested that sustainable development is a process of change during which societies and citizens learn to deal with tensions between ecological sustainability whilst doing justice to interests at both the local and global levels. This definition emphasises that sustainable development is essentially a progressive human endeavour at the community and individual level. Hopwood et al. (2005) apply a conservation approach – sustainable development means keeping the consumption of natural resources within the limits of their replenishment. This definition however fails to recognise that many natural resources such as minerals and fossil fuels are not able to be replenished within realistic time-frames. Kates et al. (2005) go further – sustainable development involves handing down to successive generations not only man-made assets but also natural assets such as clean, adequate water supplies, arable land and sustainable fauna and flora diversity.

However, there exists much criticism of sustainable development definitions in terms of their applicability to resolving the present crisis of global unsustainability. For example, Lele (1991) has stated that sustainable development is in real danger of becoming a cliché like 'appropriate technology' – a fashionable phrase that everyone pays homage to but nobody cares to define. Similarly, Villanveva (1997) has highlighted the lack of operative definitions and Redclift (1993), Satterthwaite (1996) and Sachs (1999) that there is widespread disagreement on 'what' should be sustained and on 'how' sustainability can be achieved. Similarly, Jabareen (2008), has concluded that there is a lack of a comprehensive theoretical framework for understanding sustainable development and its multi-disciplinary complexities, since the range of published definitions is vague and it remains a confused topic fraught with contradictions. Also, Crawford-Brown (2005) has simplified sustainable development as a triple bottom line concept embracing environmental quality, social justice and economic vitality.

There is considerable support for an interactive triple bottom line approach for understanding sustainable development. For example, Hoff (1998) has shown that moving towards sustainable development is based on major changes to the present dominant social and community values. The primary dedication to consumerism and personal accumulation of material goods must change to an emphasis on satisfying the basic needs of all and the cultivation of a non-material goods ethic, such as community interaction and sharing and the use of personal skills to enhance the well-being of communities (Durning 1992; Hoff 1994; Wachtel 1980). Communities can move towards sustainable development by considering how their economic enterprises contribute to meeting basic needs such as housing, health, food and energy security, education and travel and how these are balanced with policies to promote the quality of life whilst maintaining an ecological focus. Overall, sustainable community development requires a de-emphasis of competition and individual choice which have no accountability for effects on the natural environment or on the choices of others. Participatory planning is essential for sustainable community development (Hoff 1998).

Sustainable development also implies a paradigm shift in promoting economic growth. The latter has traditionally been directly associated with increased global trade and individual development (Reid 1995; Moffat 1996) but such a unilateral strategy has produced a global downward spiral of poverty and environmental degradation (WCED 1997). Such a failure calls for a different form of 'growth' by changing its character and quality by meeting essential social needs, merging environment and economics in decision making and equalising benefits (WCED 1987). This strategy offers a means to eradicate poverty, meet basic human needs and ensure parity of natural resources for all. Social justice is thus a crucial component of social development.

Sustainable development is critically dependent on the sustainability of the diverse and complex ecosystems which comprise the global ecosphere. These are under unprecedented threat as a consequence of the increasing demands of humanity for land development. Ecologically-based land use is a distant hope but an urgent objective. Honachefsky (2000) and Wackernagel et al. (1997) argue that the basis for sustaining ecosystems is to determine 'ecological footprints' which they define as the total area of ecologically productive land and water used exclusively to produce the required resources consumed and assimilation of the waste generated by a community. Such a definition leads to the concept of 'ecological capacity' at a national and hence per capita level and it transpires that most of the developed nations of the world at present are living beyond their ecological capacity. Thus, to move towards sustainable land usage, there is an urgent need to include the 'ecological factor' into the multitude of plans for such usage, otherwise intrinsic land resources are further and irreversibly plundered.

We believe that an understanding of sustainable development involves more than a triple bottom line approach. It is intuitively obvious that a political dimension is critical to its achievability since governments at all levels have the power, financial means and interactive strategies to support and drive green policies which are eco-focussed and thus promote quality of life. In this context, Christie and Warburton (2001) argue that radical political reform is needed to produce 'democratic re-vitalisation' so that governments and society together produce 'sustainable, accountable and equitable forms of capitalism'. Thus, sustainable development is consistent with a synergic socio-political interaction.

Science, technology, research, development and innovation all enable sustainable development, particularly with respect to environmental sustainability and mitigation of climate change. The emerging sustainable and climate sciences combine to address the contemporary concerns related to environmental degradation compounded by the consequences of climate change. However, the rate of development of technologies to assist sustainable development is insufficient to remedy the immediate threats of climate change. Inevitably, sustainable development is dependent on the use of clean, renewable energy, the operation of clean, green industries and clean, green community and individual life styles. Such a paradigm shift can only be achieved by educating communities on the benefits of smart life styles with emphasis on less consumerism and more environmental concern.

Hence, we believe that there are at least six dimensions associated with the concept of 'sustainable development' which we interpret as being within the confines of 'sustainable natural resource management', (SNRM), as shown schematically in Figure 1. It is apparent that this framework goes beyond the traditional triple bottom line approach of defining sustainable development and we believe that it is only with such a framework that a workable definition of sustainability can be achieved which not only reveals its inherent complexities but also acknowledges the opportunities which a wider understanding of its intricacies offers.

NATURAL RESOURCES / FOOD SECURITY LINKAGE

Environmental resources and food security, are defined by the Food and Agriculture Organisation (FAO) as a condition when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life and are strongly linked. Recognizing this linkage, a major objective of the Strategic Framework (2000-2015) developed by FAO is to support the conservation, enhancement and sustainable utilization of natural resources to provide food security. At present, it is not possible to ensure sufficient food and water for all to sustain livelihoods for present and future generations. The latest assessment of the World Wildlife Fund (WWF) is that overuse of the planet's natural resources has reached alarming proportions and in the last 50 years, human demands on natural resources have doubled. The WWF's 'Living Planet Report' released in 2010, unequivocally states that global consumption of resources is 50% beyond Earth's sustainable ability and if this trend persists, an alternative planet to Earth will be needed by 2030 to sustain humanity!

Rockstrom (2008) has classified four major pressures on the environment, namely: 1) degradation of ecosystem functions and services, 2) hunger and malnutrition in the expanding human population, 3) continued consumerism in developed countries and growing affluence in emerging economies, and 4) climate change.

FAO considers food insecurity as one of the most visible dimensions of poverty and a glaring sign of destitution, and it aims to break this vicious circle by placing food security as a major emphasis of its action agenda. Programmes seeking to increase food production, ensuring stability of food supplies, generating employment and promoting accessible food for all are the main elements of food security.

It is widely recognised that food security is the greatest challenge to sustaining humanity in the 21st century in the wake of a global population projected to be in excess of 9 billion by 2050 (UN 2009). Food security currently is not a reality since more than one billion of the present global population of 6.8 billion are under-nourished (Mustafa 2010). It is forecast that global food production will have

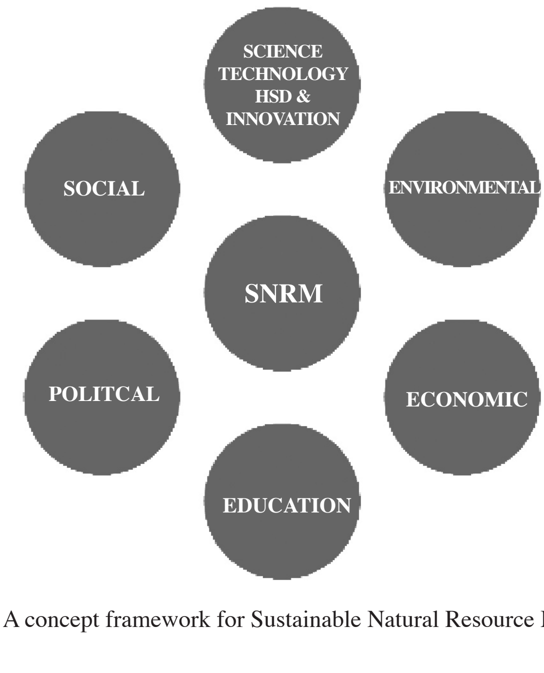

FIGURE 1. A concept framework for Sustainable Natural Resource Management

to increase by at least 40% over the next 2 decades to meet demand. This estimate is conservative and is largely based on grain production with the demand for meat and fish projected to be much greater over the same time frame (FAO 2006). Thus, the challenge is whether a future 9 billion people can be fed equitably and sustainably given that global food production resources are already strained.

It is clear that such a challenge can only begin to be addressed in conjunction with sustainable management of land, energy and water resources together with strategic and effective management of climate change effects. The latter impact detrimentally on the quantity and quality of surface water supplies, food production and ecosystems as a consequence of extreme weather events becoming more severe and more frequent (IPCC 2007). According to IPPC report, agriculture is seriously affected by climate change, not only by more frequent drought and flood cycles but also by rising sea levels which detrimentally affect river deltas and estuaries, and consequently the most productive cultivation regions. Agriculture has also been identified as also a major contributor to greenhouse gas emissions, estimated to be around 12% of global emissions and although scoping studies have been undertaken on agricultural greenhouse gas emissions, little direct action has been taken and much more research and innovation in this area are urgently needed to harmonise with global carbon-based economies. The required increase in food production to meet global demand in the 21st century must therefore be achieved by a parallel reduction in greenhouse gas emissions by at least 50% by 2050 as compared with present levels according to the IPCC (2007).

The so-called green revolution which ensured food security in the 1960s and 1970s saved the world from hunger and malnutrition but left behind serious environmental problems. Excessive use of inorganic fertilizers and pesticides, and extraction of ground water for irrigation on a large scale without putting in place effective means of water recharge, caused degradation of soil quality, depletion of water resources and loss of biodiversity. Environmental resources are unable to sustain food production and remedy the health-related problems caused by consumption of contaminated food. At the time of the initial green revolution, hunger loomed large but the environment and climate change did not receive as much attention as they do now. The strategic decisions at that time addressed the extreme food shortages in developing countries and played a vital humanitarian role under critical circumstances but did not offer a sustainable solution to hunger. The unfolding reality of changing climate and evidence showing unsustainable management of resources needed to produce food for a growing population have radically changed this perception. In this connection, the research carried out by Clapp and Cohen (2009) is pioneering since they have made an attempt to assess the consequences of the governance challenges, the ecological dimensions of the crisis, and the opportunities for developing the long-term goal of building sustainable food systems.

Recent years have witnessed growing interest in exploitation of marine resources for food security. Oceans cover more than 70% of the Earth's surface and have been a source of high quality food for centuries and are attracting increasing attention in the quest for food security. Seafood is a significant source of protein for almost 3 billion people and is the most highly traded food internationally, and yet it is an often overlooked product in global food security (Smith et al. 2010). Despite this importance, seafood is susceptible to numerous threats and is subject to a shifting paradigm in our understanding of future demand (Chamberlain 2010). In the recent decades, seafood demand has steadily increased as a function of increasing population and shifts in economic power between the developed and the developing world. Developing countries produce more seafood and export a substantial proportion to developed countries, thereby using the earnings for purchasing other foods, goods or services (Smith et al. 2010). In maintaining this supply chain which contributes to food security by increasing aid from developed countries for sustainable seafood infrastructure in developing countries will markedly enhance global food security.

The application of modern technology to commercialisation of fishing operations has led to global overfishing such that sustainable fisheries thresholds have been crossed. Many commercial fisheries have collapsed and others are facing threat from warming and acidification of oceans caused by climate change. With oceans being the last frontier on Earth for exploitation of food, the demand for marine resources is intensifying. A rational approach that has so far been elusive involves use of harvesting methods that capture marine fauna selectively and within specified limits, and do not deliver collateral damage or disturb the environmental balance. Maintenance of biodiversity is paramount since this provides the essential links in the chain that produce food. Deletion or depletion that threatens these links disrupts the food production system. Making responsible food choices, finding sustainable seafood solutions and applying environment-friendly seafood farming techniques will increase seafood supply and lessen the pressure on the wild populations, thereby assisting marine biodiversity conservation.

The consequences of over-exploitation of fisheries are of concern for the security of seafood and its socio-economic implications together with the stability of the marine ecosystem as a bastion of food production (Mustafa 2010). The remedy is not to dwell on rhetoric but take realistic action to implement the ecosystem-based fisheries management (EBFM) scheme. Balancing the impact of food production and environmental conservation is a vital factor for enabling food security (Mustafa 2010).

FOOD SUSTAINABILITY DIMENSIONS

Sustainable management of food production is inextricably linked to sustainable agriculture and sustainable fish resources, which in turn are both linked to sustainable natural resource management. A suggested concept framework for sustainable agriculture is shown in Figure 2. It is suggested that sustainable agriculture has 5 major dimensions and these are reviewed with respect to present and future developments towards food sustainability.

In conjunction with the projected global population increase, energy demand is expected to increase by at least 45% over the next two decades (IEA 2008). With respect to food production, the increasing production of biofuels from grain impacts directly on efforts to increase food production and leads to competition between energy and food markets (Mitchell 2008). Also, the production of fertilizers (particularly superphosphate) on which intensive agriculture relies to re-activate nutrient depleted soils is an energy-rich process. Thus, fertilizer prices tend to follow oil prices with consequential increases to the overall food price index (Piesse & Thirtle 2009).

Sustainable agriculture depends on a unilateral reduction in energy consumption across the industry with particular emphasis on the use of renewable energy resources and low energy consumables particularly fertilizers and pesticides. A progressive greening of agriculture is therefore essential.

Water is an essential commodity for agriculture, which is currently estimated to consume about 70% of global supplies (FAO 2007). In conjunction with the global population increase over the next few decades coupled with a parallel increase in demand for food, it is projected that irrigation requirements for agriculture will increase by 70 – 90% based on current consumption rates (Shen et al. 2008). The ever increasing quest to supplement irrigation supplies has already placed river health at risk worldwide with consequential decline in aquatic biodiversity and has also endangered groundwater supplies, which in turn has increased the occurrence of dry-land salinity. There is much evidence to show that irrigation is one of the major factors contributing to environmental degradation (Boddington 2010). Water licences and water trading practices which are currently applied in drought-stricken regions such as in Australia to provide a sustainable water supply for agriculture are only partially successful due to socio-economic, political and environmental constraints. Sustainable agriculture depends on a unilateral reduction in water used for irrigation with greater use of drip-irrigation technologies in conjunction with installation of improved drainage and recycling systems. Improved water trading policies leading to less water extraction from rivers are urgently needed.

It is difficult to estimate the global land area currently under cultivation due to the wide range of factors affecting soil quantity and quality. FAO (2000) has conservatively set this at around 18% with respect to land suitable for wheat, grain and rice cultivation. It is expected that this proportion will at least double over the next few decades to meet the demand for increased food production. However, to make more land available for cultivation is contrary to the fundamental principles of SNRM, since deforestation directly exacerbates the effects of climate change as a result of loss of carbon storage capacity (Cassman & Wood 2005).

It is well known that intensive agriculture leads to soil degradation, both in terms of nutrient loss and reduction of water storage capacity which lead to reduced productivity (Bationo et al. 2007). Further, intensive agriculture leads to degraded surface water resources and hence degraded

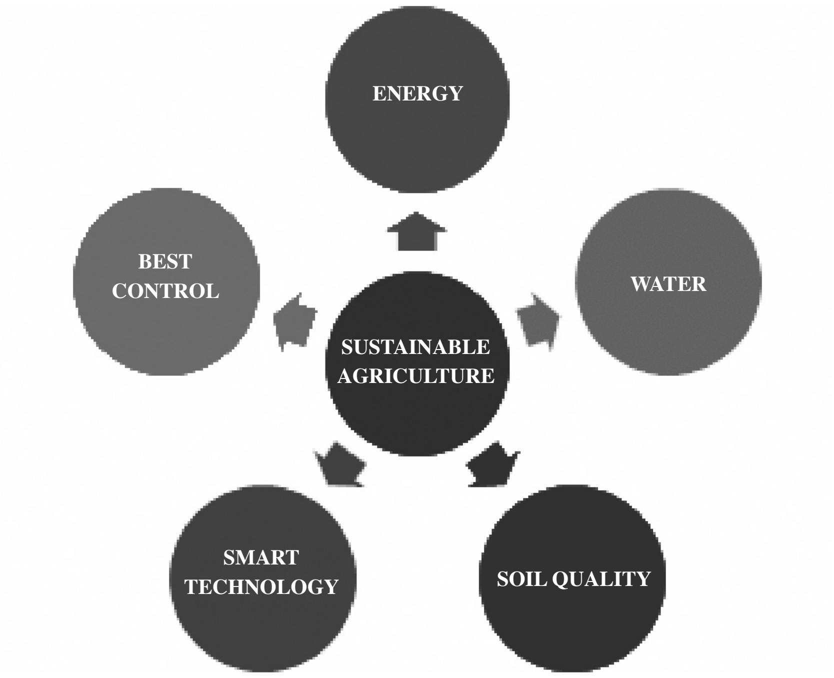

FIGURE 2. A concept framework for sustainable agriculture

aquatic ecosystems through excessive and poorly targeted use of fertilizers and pesticides (Beddington 2010). It has been predicted that a doubling of global food production over the next few decades will lead to 2 to 3 times more eutrophication of marine and freshwater ecosystems driven by increased nutrient levels (Tilman 2001).

Also, soil degradation is exacerbated by climate change since an increase in flood and drought frequency leads to corresponding increases in water-logging and soil erosion, in addition to destruction of emergent crops (FAO 2005).

Sustainable agriculture is dependent on establishing a balance between additional land development for essential food production and simultaneously reducing deforestation to mitigate climate change and also protecting ecosystems and biodiversity.

Science, technology and innovation are essential drivers of sustainable agriculture and food security (Pretty 2005). Development of improved crop varieties (Evenson & Gollin 2003) and marker assisted plant breeding combine to reduce losses due to pests and diseases (Collard & Mackill 2005). Such leading edge genomic technologies allow the development of plant varieties which are tolerant of drought, heat and saline conditions in addition to improved pest and disease resistance (Moller et al. 2009). Further, micro-nutrient enhancement of staple crops such as rice and sweet potato is becoming increasingly effective in reducing malnutrition in developing countries (Nestel et al. 2006).

Along with increasing demand for staple foods, the demand for meat is projected to increase by 85% over the next 2 decades as prosperity of nations increases (World Bank 2008). Just as production of biofuels reduces grain supplies, so does meat production since a third of the global cereal crop is used as animal feed (FAO 2006). Livestock farming also significantly contributes to climate change mainly in terms of methane emissions and this is projected to increase by at least 50% over the next two decades in conjunction with increased livestock farming (FAO 2003). Genetic enhancement of livestock in conjunction with genomic sequencing of animal disease strains will become increasingly prominent in sustainable livestock farming (Flint & Wooliams 2008).

Improved mechanisation of agriculture using efficient harvesting machines which reduce soil compaction has increased productivity (Godwin et al. 2008). Precision farming techniques are currently being developed which employ GPS technology to monitor and control the position of machinery and enable measured delivery of seed, fertilizer and pesticides in addition to the detection of soil and plant quality which enables the early detection of diseases (Mondal et al. 2007). Also, the progressive development of drip irrigation is crucial for water conservation in agriculture.

Sustainable agriculture is dependent on the development of precision farming technologies which offer integrated management of seed sowing, plant growth, fertilizer and pesticide application, irrigation and disease monitoring and control.

Crops are subject to a wide variety of pests and diseases which threaten productivity. Pesticides have been used to combat such diseases for at least the last 50 years but productivity losses are still unacceptably high (Oerke 2006). Present methods of pesticide application are insufficiently targeted and unevenly distributed and much of that distributed is lost to runoff which causes environmental degradation since it impacts on aquatic ecosystems. Integrated pest management techniques in conjunction with genomic pest resistance technologies will significantly enhance sustainable agriculture (Cook et al. 2007).

The role of fish in human nutrition and its correlation with world food security has assumed increasing importance. For an uninterrupted supply of seafood, the universally acceptable sustainable fisheries framework must be the basis of global fisheries management as it incorporates conservation, sustainable resource use, governance, economics, and is adaptable to include evolving situations, most importantly, climate change. Such a framework must have monitoring tools to assess the results of EBFM which can provide a reasonable basis for identifying areas that require review and improvement. The results and experience of applying management measures to fisheries exploitation will guide future reforms that ensure the required outcomes. Such a system of management entails environmentally sustainable fisheries while supporting socio-economic objectives. A healthy environment ensures bountiful fish harvests for human prosperity. Such a balanced management strategy meets the sustainable development criteria.

Sustainable fisheries management, shown schematically in Figure 3, calls for regulating fish catch to sustainable levels, restoring populations which have been depleted by overfishing and is inclusive of effective governance, especially with respect to enforcing timely reviewed regulations concerning natural fish stocks. Population restoration can be achieved by habitat improvement, biodiversity conservation, regulation of fishing methods and interventions for enhancing stocks by responsible sea ranching methodologies. Stock enhancement is now considered as an essential tool of sustainable fisheries management.

Going beyond a general understanding that loss of biodiversity is affecting the ocean ecosystem functions, Worm et al. (2008) provided quantitative data to substantiate the link between biodiversity and ecosystem performance. According to their observations, rates of resource collapse increase whereas recovery potential, stability and water quality decrease with decline in diversity but restoration reverses the ecosystem decline. When biodiversity is restored, productivity increases significantly and variability declines substantially. These authors concluded that since these trends are reversible, intervention is necessary to prevent biodiversity loss from reaching a point of irreversible damage to the ecosystem, and this justifies giving serious attention to restoration. EBFM offers a means of balancing resource use consumption with resource conservation (Bartley 2007).

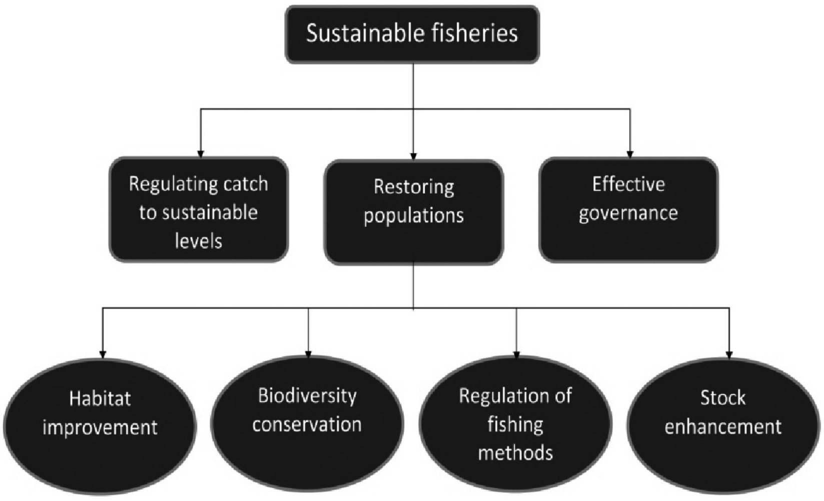

FIGURE 3. Elements of sustainable fisheries management

Total world fish production (capture and aquaculture) amounted to 143.7 million tonnes in 2009 and is expected to reach 145 million tonnes in 2010 (Lem et al. 2010). Of this, aquaculture contributed 54 million tons (or 38% of total fish production). Estimates put aquaculture production in 2010 at 55.5 million tonnes. This represents an increase of more than 20 million tonnes compared to a decade ago. This additional supply is a consequence of the progressive development of aquaculture but despite this, aquaculture has not met the expected target of 50% of total supply set in 2008, suggesting that challenges remain for aquaculture to reach its full potential to support the seafood security goal.

Aquaculture meets at least three objectives: providing seafood and income to communities, reducing fishing pressure on wild populations and maintaining fish population size to sustain commercial, subsistence and recreational fisheries (Bert 2007a; 2007b). Essential requirements for its sustainability are quality water, dependable supplies of high quality seed, nutritionally balanced and cost-effective feeds comprising nutrients from sustainable sources and health management of captive stocks together with the provision of hatchery and grow-out systems (Figure 4).

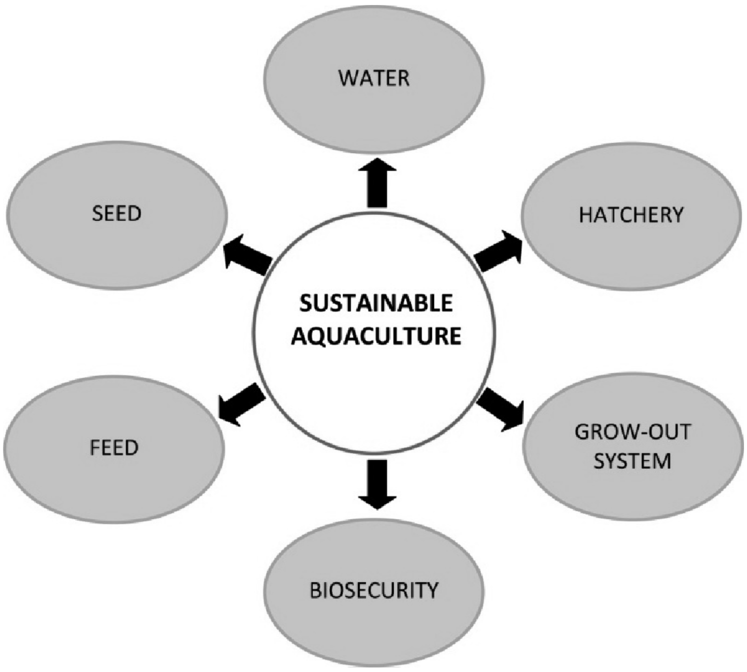

FIGURE 4. Main components of sustainable aquaculture management

Sustaining the contribution of seafood to food security hinges on the ability of institutions, particularly in developing countries, to protect and improve ecosystem health in the face of increasing pressures from international trade (Smith et al. 2010). The changing global environment and fluctuating seafood supply scenarios call for a responsible universal aquaculture policy that protects genetic diversity, respects the environment and improves production without compromising food quality. Such policies employ water recirculation technology, follow a closed cycle approach to captive stocks, operate on integrated and biodynamic principles of multiple animal and plant species cultivation in modular structures which reduce the chances of inbreeding and exclude the use of non-native or alien species. Integrated aquaculture as described by various authors (Shpigel & Neori 2007; Estim 2010; Mustafa 2010; Wahap 2010) emphasizes maximizing the efficiency of limited resources to improve productivity and quality of food in modular systems which are environment-friendly. Mustafa (2010) has elaborated on the ecological problems which are caused by the introduction of exotic species into water bodies.

Acknowledging all these factors, we believe that food security is directly linked to our concept framework for SNRM, most significantly by the application of science and technology together with continued investment in research, development and innovation. It is implied that the 6 dimensions previously discussed as being associated with SNRM are also associated with food security, which in turn is associated with sustainable agriculture and seafood security and both of the latter are affected by climate change, as shown in Figure 5 and discussed above. It is clear that food security cannot be achieved unless all the diverse factors with which it is associated are considered both individually and collectively with due recognition given to their inter-dependence.

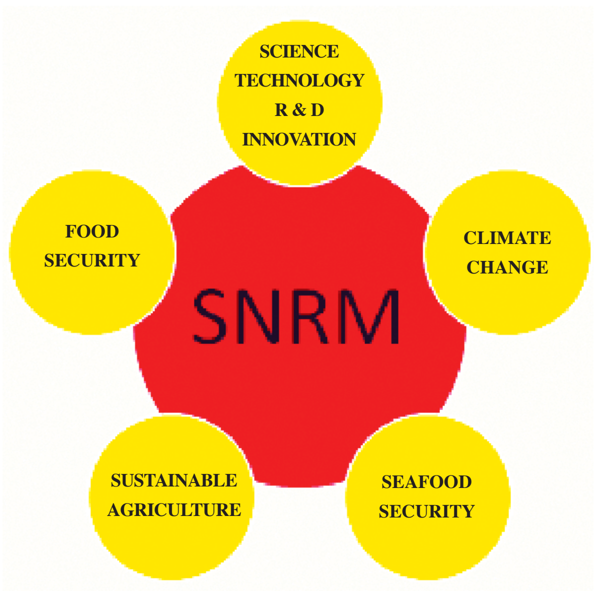

FIGURE 5. Linkage of Food Security to SNRM

FOOD FROM GENETICALLY ENGINEERED ORGANISMS - COMPULSIONS AND CONCERNS

The role of genetically modified organisms (GMOs) that provide food has emerged as a highly contentious issue. GMOs give higher yields with lower chemical inputs. They grow faster, attain harvestable size earlier, do not require pesticide protection and need lower quantities of fertilizers than traditionally produced food crops. Many transgenic plant products, including soybean, corn, canola and cotton seed oil are already available in the market. Transgenic animal products have been developed but are very controversial. Following successful trials of genetically engineered salmon that grow twice as fast as conventional salmon, marketing of these is imminent but this will create further controversy since although the commercial benefits will be enormous, the environmental concerns about manipulation of genetic codes of living organisms and the potential associated human health risks, particularly allergies, will continue to be debated. However, it appears inevitable that increased use of GMOs is required to meet increasing food demand (Raney & Pingali 2007) and it has been argued that food shortages are caused by problems in food distribution and policies and not by production levels (Lappe et al. 1998; Boucher 1999). The reality is that additional food supplies are urgently needed as are appropriate solutions to provide global food security (Lynas 2010) and GMOs are an important component of the food security debate.

The compulsion to accept food products derived from GMOs is driven by declining food supplies resulting from the over-exploitation of natural resources which produce food. Climate change consequences further challenge the conventional methods of food production so genetically engineered plants and animals that can better resist environmental changes will inevitably be used to produce food. This will pose a difficult challenge for biodiversity due to poor regulatory frameworks in most developing countries. Faced with hunger and starvation, priority will not be given to biodiversity. The scenario will drastically change when GMOs threaten natural genotypes, which is expected to occur within this century. Transformation of conventional food production systems which consume energy and release greenhouse gases into low carbon or zero carbon methods is the preferable strategy for moving towards global food security. If as a result of greater investment in research and innovation such methods prove ecologically compatible and commercially viable, they will provide a safer alternative to food based on GMOs and directly as well as indirectly support biodiversity.

CONCLUSIONS

Sustainable development is an abstract and multi-dimensional concept. It is receiving increasing attention due to the many challenges threatening natural resources by direct human intervention coupled with excessive consumption in conjunction with the constraints imposed on these resources by climate change. Excessive food and energy consumption are responsible for driving the planet to the edge and so sustainable development must involve making wise choices about diet and consumption of non-renewable energy resources. Food security is based on a combination of sustainable agriculture, sustainable fisheries and sustainable aquaculture together with a paradigm shift in the extent to which food resources are exploited. By choice or by compulsion of circumstances, involvement of biotechnology as a tool in food production has all the hallmarks of emerging as the major enabling force in obtaining food security despite current social, ethical and biodiversity concerns.

REFERENCES

Bartley, D.M. 2007. An ecosystem approach to risk assessment of alien species and genotypes in aquaculture. In *Ecological and Genetic Implications of Aquaculture Activities,* edited by Bert, T.M. The Netherlands Springer, Dordrecht, The Netherlands.

Bationo, A., Kilhara, J., Vanlauwe, B., Warwa, B. & Kimetu, J. 2007. Soil organic carbon dynamics, functions and management in West Africa agro-systems, *Agric. Syst.* 19: 17-25.

Beddington, J. 2010. Contributions from science to a new and greener revolution, *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 365: 61-71.

Bert, T.M. 2007a. Environmentally responsible aquaculture – A work in progress. In *Ecological and Genetic Implications of Aquaculture Activities,* edited by Bert, T.M. Dordrecht, The Netherlands: Springer.

Bert, T.M. 2007b. Environmentally responsible aquaculture: realities and possibilities. In *Ecological and Genetic Implications of Aquaculture Activities*, edited by Bert, T.M. Dordrecht, The Netherlands: Springer.

Boucher, D.H. 1999. The paradox of plenty: hunger in a bountiful world. *Food First* 342.

Cassman, K. & Wood, S. 2005. *Cultivated Systems in Ecosystems and human well-being – millennium ecosystem assessment – current state and trends.* Vol. 1. Washington DC: Island Press.

Chamberlain, G.W. 2010. Shifting global wealth drives seafood demand. *The Global Aquaculture Advocate* 9/10: 2.

Christie, J. & Warburton, D., 2001. *From Here to Sustainability.* London: Earthscan.

Clapp, J. & Cohen, M.J. 2009. *The Global Food Crisis: Governance Challenges and Opportunities',* Ontario, Canada: Wilfrid Laurier University Press.

Collard, B.C.Y. & Mackill, D.J. 2008. Marker-Assisted Selection: An approach for precision plant breeding in the 21st century. *Phil. Trans. Royal Society* B, 367: 557-572.

Cook, S.M., Khan, Z.R. & Pickett, J.A. 2007. The use of push-pull strategies in integrated pest management. *Annual Rev. Entomol.* 52: 375-400.

Crawford-Brown, D.J. 2005. *Setting the Environment, The Australian, 24th June* Melbourne.

Durning, A. 1992. *How Much is Enough? - The Consumer Society and the Future of the Earth*, New York: W.W. Norton & Co.

Estim, A. & Mustafa, S. 2010. Aquaponics application in a marine hatchery system, *Aquaponics Journal* 57: 26-34.

Evenson, R.E. & Gollin, D. 2003. Assessing the impact of the Green Revolution: 1960 – 2000. *Science* 300: 758-762.

Flint, A.P.F. & Wooliams, J.A. 2008. Precision animal breeding. *Phil. Trans. Royal Society B* 363: 573-90.

FAO. 2000. *Food and Agriculture Organization Report*, Rome: www.fao.org

FAO. 2003. *Food and Agriculture Organization Report*, Rome.

FAO. 2005. *Food and Agriculture Organization Report,* Rome.

FAO. 2006. *Food and Agriculture Organization Report,* Rome.

FAO. 2007. *Food and Agriculture Organization Report*, Rome.

Godwin, R., Spoor, G., Finney, B., Hann, M. & Davies, B. 2008. *The current status of soil and water management in England .* Warwickshire, UK: Royal Agriculture Society of England.

Hoff, M.D. 1998. Sustainable Community Development. Boca Raton, Florida: Lewis Publishers/CRC Press.

Hoff, M.D. 1994. Environmental foundations of social welfare: Theoretical resources, in 'The global environment crisis: Implications for social welfare and social work', Hoff, M.D., McNutt, J.G., (Eds.), Aldershot, UK: Ashgate Publishing/ Avebury Books.

Honachefsky, W.B. 2000. *'Ecologically-based Municipal Land Use Planning'*, NY: Lewis Publishers.

Hopwood, B. Mellor, M. & O'Brien, G. 2005. Sustainable Development: Mapping different approaches', *Sustainable Development* 13: 38-52.

International Energy Agency (IEA). 2008. World Energy Outlook, Paris.

International Panel on Climate Change (IPCC). 2007. Climate Change 2007. In *Impacts, Adaptation and Vulnerability*, edited by Parry, M.L., Canziani, O.F., Palutikof, J., van der Linden, P.J. and Hanson, C.E. Cambridge, UK: Cambridge University Press.

Jabareen, Y. 2008. A new conceptual framework for sustainable development. *J. Environmental Development and Sustainability* 10(2): 179-192.

Kates, R., Purvis, T. & Leiserwitz, A. 2005. What is Sustainable Development?. *Environment* 47(3): 8-23.

Lappe, F.M., Collins, J., Rosset, P. & Esparza, L. 1998. *World Hunger: Twelve Myths*. New York: Grove Press.

Lele, S.M. 1991. Sustainable Development: A critical review, *World Development* 19: 607 -21.

Lem, A., Ababouch, L. & Karunasagar, I. 2010. Salient issues for fish trade. *FAO Aquaculture Newsletter* 45: 18-21.

Lynas, M. 2010. *Why we greens keep getting it wrong*. The New Statesman, 28 January 10, Retrieved 5 November 2010.

Mitchell, D. 2008. A *note on rising food prices*. World Bank Policy Research Working Paper series, No. 4682, World Bank, NY.

Moffatt, J. 1996. *Sustainable Development: Principles, Analysis and Policies*. London: Parthenon.

Moller, I.S., Gilliham, M., Jha, D., Mayo, G.M., Roy, S.J., Coates, J.C., Haseloff, J. & Tester, M. 2009. Shoot Na+ exclusion and increased salinity tolerance engineered by cell type specific alteration of Na+ transport in Arabidipsis. *Plant Cell* 21: 2163-2178.

Mondal, P. & Tewair, V.K. 2007. Present status of precision farming: A review. *Int. J. Agric. Res.* 2: 1-10.

Mustafa, S. 2005. Sustainable seafood solutions and the role of contemporary aquaculture technologies. *MIMA Bulletin* 12: 17-22.

Mustafa, S. 2010. Alien fins of nature in Sabah. *CCIR News* 2: 16.

Mustafa, S. 2010. *Seafood Security in a Changing Climate*. Koln, Germany: Lambert Academic Publishing.

Nestel, P., Bovis, H.E., Meenakshi, J.V. & Pfeifter, W. 2006. Biofortification of staple food crops. *J. Nutr.* 136: 1064-7.

Oerke, E.C. 2006. Crop losses to pests. *J. Agric. Sci.* 144: 31-43.

Piesse, J. & Thirtle, C. 2009. Three bubbles and a panic: An explanatory review of recent food commodity price events. *Food Policy* 34: 111-129.

Pikitch, E.K. 2004. Ecosystem-based fishery management. *Science* 305: 346-7.

Pretty, J. 2008. Agricultural Sustainability: concepts, principles and evidence, Phil. *Trans. Royal Society B* 363: 447-468.

Redclift, M.R. 1993. *Sustainable Development: concepts, contradictions and conflicts, In Food for the Future: Conditions and Contradictions of Sustainability,* edited by Allan, P. Wiley, NY.

Reid, D. 1995. *Sustainable Development: An Introductory Guide*. London: Earthscan.

Rockstrom, J. 2008. Development in planetary phase of sustainability. *Global Change* 72: 18019.

Sachs, W. 1999. *Planet Dialectics: Exploring in Environment and Development*. Rep. of South Africa: Fernwood Publishing/ Witwatersrand University Press/Zed Books.

Satterthwaite, D. 1996. For Better Living. *Down to Earth* 31: 31-35.

Shen, Y., Oki, T., Utsumi, N., Kanae, S. & Hanasake, N. 2008. Projection of future water resources under SRES scenarios: water withdrawal. *Hydrol. Sci.* 53: 11-33.

Shpigel, M. & Neori, A. 2007. Microalgae, macroalgae, and bivalves as biofilters in land-based mariculture in Israel. In *Ecological and Genetic Implications of Aquaculture Activities,* edited by Bert, T.M. Dordrecht, The Netherlands: Springer.

Smith, M.D., Roheim, C.A., Crowder, L.B., Halpern, B.S., Turnipseed, M., Anderson, J.L. Asche, F., Bourillón, L., Guttormsen, A.G., Khan, A., Liguori, L.A. , McNevin, A., O'Connor, M.I., Squires, D., Tyedmers, P., Brownstein, C., Carden, K, Klinger, D.H., Sagarin, R. & Selkoe, K.A. 2010. *Sustainability and Global Seafood Science* 327: 784-786.

Tilman, D. 2001. Forecasting agriculturally driven global environmental change, *Science* 292: 281-284.

UNESCO. 2004. United Nations decade of education for Sustainable Development: 2005-2014, Draft International Implementation Scheme/UNESCO, Paris.

UN. 2009. World population prospects: The 2008 revision, Population Division of the United National, UN Secreyariat.

Villanveva, C. 1997. Community development and the future of sustainable communities in the Philippines, In *Sustainable Communities in the International Age: Vision from future studies*, edited by Kaoru, Y. Praeger Studies on the 21st Century. CT: Praeger Press.

Wachtel, P. 1989. *The Poverty of Affluence*. Philadelphia: New Society Publishers.

Wackernagel, M., Onisto, L., Callejas-Linares, A. Lopez, I.S., Falfan, J., Suarez-Geerrero, A.I. & Suarez-Guerrero, M.G. 1997. Ecological footprints of Nations: How much nature do they use? How much nature do they have? Commissioned by the Earth Council for the Rio+5 Forum, International Council for Local Environment Initiatives.

Wahap, N., Estim, A., Kian, A.Y.S., Senoo, S. & Mustafa, S. 2010. Producing organic fish and mint in an aquaponic system. *Aquaponics Journal* 58: 28-32.

World Bank. 2008. *Annual World Development Report*. World Bank, NY.

WCED. 1987. World Communication on the Environment and Development *Our Common Future*. The Brundtland Report. Oxford, UK: Oxford University Press.

Worm, B., Barbier, E.B., Beaumont, N., Emmett, J.D., 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. & Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science* 314: 787-790.

John Hill*
Department of Chemistry
La Trobe University
Melbourne, Australia

Saleem Mustafa
Borneo Marine Research Institute
University Malaysia Sabah
88400 Kota Kinabalu Sabah
Malaysia

*Corresponding author; email: j.hill@latrobe.edu.au

Received: 11 November 2010
Accepted: 10 January 2011