AECOM

Kāpiti Coast District Council
10 May 2011

Landcare Research
Manaaki Whenua

Human Carrying Capacity

Stage 1: Working Definition for Kāpiti Coast District Council

Human Carrying Capacity

Stage 1: Working Definition for Kāpiti Coast District Council

Prepared for

Kāpiti Coast District Council

Prepared by

AECOM New Zealand Limited
47 George Street, Newmarket, Auckland 1023, PO Box 4241, Shortland Street, Auckland 1140, New Zealand
T +64 9 379 1200 F +64 9 379 1201 www.aecom.com

In association with

Landcare Research Ltd

10 May 2011

60197592

AECOM in Australia and New Zealand is certified to the latest version of ISO9001 and ISO14001.

Quality Information

Document	Human Carrying Capacity
	60197592
Ref	i:\aeep\60197592 aeep misc021 carrying capacity kapiti coast district\4. tech work area\4.1 reporting\report_kcdc assessment of carrying capacity_stage 1_11april2011_revb_v3.doci:\aeep\60197592 aeep misc021 carrying capacity kapiti coast district\4. tech work area\4.1 reporting\report_kcdc assessment of carrying capacity_stage 1_11april2011_issue2.doc
Date	10 May 2011
Prepared by	Robbie Andrew / Daniel Rutledge / Matthew Paetz
Reviewed by	Suzie Greenhalgh / James Hughes / Peter Hartley

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
A	25-Mar-2011	Draft for client review	Peter Hartley Associate Director	
B	11-Apr-2011	Second draft for client review	Peter Hartley Associate Director	
C	10-May-2011	Final	Peter Hartley Associate Director	

Table of Contents

1.0 Introduction

This interim report is the first under AECOM and Landcare Research's contract with Kāpiti Coast District Council: Human Carrying Capacity (HCC). The purpose of this report is to present a review of the literature on the subject of HCC, to explore the context of the District Plan, and to establish a working definition of the concept as a foundation for the remaining phases of the project.

2.0 Historical Overview

The idea that humans might reach some population limit with respect to available resources has a very long history. Observers in ancient times wrote of disasters besetting humans because of overpopulation, often ascribed to the intervention of the gods (Cohen 1995a). While the Reverend Thomas Malthus' influential essay on population growth and resource limits, first published in 1798, is widely known, earlier thinkers in Europe had already written on the subject, and it may be that society was already 'primed' for the apparently convincing arguments put forth by Malthus in his essay (Seidl & Tisdell 1999).

While the concept of carrying capacity has been widely taught in ecology, ecologists recognise that the logistic equation, first posited by Verhulst (1838) after he had read Malthus' *Essay,* applies only to greatly simplified situations, and most, if not all, real-world situations are far more complex (Price 1999). The interactions of environment, both biotic and abiotic, mean there is almost never a fixed carrying capacity for any population of a species in its home range. For example, both the influence of coevolution of predators and prey, and variations in weather cause populations to fluctuate, sometimes widely. For these reasons, the concept of carrying capacity has long been criticized by ecologists as unclear and imprecise, and is seriously flawed (Price 1999).

When applied to humans, carrying capacity becomes even more complex because of our ability to trade, and therefore postpone limits to population growth by depleting other regions, and our ability to develop technology to eke more out of the environment, protect ourselves from environmental extremes, and develop medicines. The use of fossil fuels is an example of both of these factors: fuels are supplied by a small number of countries and shipped around the world, and they are made available by technology and in turn make further technology possible. By using fossil fuels humanity is making use of an historical, one-off subsidy, one that is non-renewable on relevant time scales. Oil has allowed rapid, reliable transportation across the globe, which has further increased our ability to source resources from a great distance; it has enabled mechanised agriculture, greatly decreasing labour requirements; and it has also led to the development of fertilisers and pesticides, two key ingredients of the green revolution that allowed an extraordinary increase in food production following the second world war.

In addition to our ability to trade, and use technology, the majority of humans also have a choice of how to live, and this can have a substantial effect on our carrying capacity. For example, in developed countries up to a third of all purchased food is wasted in the household (e.g. WRAP 2009). This lifestyle choice factor was captured by Ehrlich and Holdren (1971) as 'affluence' in their well known equation relating environmental impact with population, affluence, and technology (I=P×A×T). Cohen summarises the lifestyle choice aspect with some prosaic examples (Cohen 1995b, p. 343):

> *"How many people Earth can support depends in part on how many will wear cotton and how many polyester; on how many will eat meat and how many bean sprouts; on how many will want parks and how many will want parking lots. These choices will change in time and so will the number of people Earth can support."*

Because of these significant differences between the standard ecological concept of carrying capacity and how it applies to humans, more recent scholars distinguish between biophysical human carrying capacity, the maximum population that could be sustained under a given set of technologies, and social (or cultural) carrying capacity, the maximum that could be sustained under a given set of social systems (Daily & Ehrlich 1992). However, for clarity we will retain the term human carrying capacity in this project.

Earth currently 'supports' about 6.9 billion people (US Census Bureau 2011), although there is wide debate about whether this number is potentially sustainable. The way the Earth currently supports this population certainly is not sustainable, given our reliance on many non-renewable resources and over-use of ecosystem services. Moreover, 'support' is probably not an appropriate term given over 900 million are presently undernourished (i.e., protein and energy deficient) (FAO 2010).

At a sub-global level, HCC is even harder to define: communities can rely on resources (and other ecosystem services) from outside the community boundary. Such resources include food, water, electricity, fuels, medicines, and a large range of other goods and services.

3.0 Current Applications

Several existing methods attempt to estimate society's impact on the planet's supporting systems. Here we present a selection of these methods from which we can learn and extract useful features – for potential use in both our definition and assessment framework for the present project. These methods all provide useful insight into the establishment of global limits, which can then (in some cases) be downscaled to a local context. Specific, relevant, local indicators will be investigated further in Stage 2 of this project.

3.1 Ecological Footprint

The Ecological Footprint concept was developed in the early 1990s by William Rees and Mathis Wackernagel (Rees 1992; Wackernagel 1994) to create an aggregated measure of humanity's appropriation of total available carrying capacity. The Footprint includes land areas used by humans to produce food and fibre, urban areas, an equivalent area representing the marine fish harvest, and the area that would be required if all CO_2 emissions were to be absorbed by additional forests. All indicators are converted to an areal unit, the 'global hectare,' and then summed and compared to the Earth's biocapacity, defined as the area actually available to produce renewable resources and absorb CO_2. According to the most recent global estimate, in 2007 the Footprint exceeded the Earth's biocapacity by 50 per cent (WWF 2010).

The Footprint methodology is applied by the Global Footprint Network (GFN) to all countries with populations over 1 million for which data are available. Studies have also been undertaken at finer scales, including districts, cities and organisations (Global Footprint Network 2011). According to GFN, New Zealand's Footprint was 4.9 gha/capita in 2007 compared with its biocapacity of 10.8 gha/capita. However, this does not indicate that New Zealand's activities are sustainable: the Footprint methodology excludes any account of the use of non-renewable resources, in addition to a range of other environmental impacts such as water and air pollution. In addition, the Footprint's approach of aggregating indicators potentially allows individual indicators to be beyond thresholds while the aggregate is not.

3.2 Human Appropriation of Net Primary Production

Human appropriation of net primary production (HANPP) is an aggregate indicator that attempts to measure "the 'scale' of human activities compared to natural processes" (Haberl et al. 2010). As with the Ecological Footprint's Biocapacity concept, HANPP attempts to use a single indicator to measure the proximity of human society's size to some limit. Net Primary Productivity (NPP) is the "net amount of biomass produced each year by plants; it is a major indicator for trophic energy flows in ecosystems" (Haberl et al. 2010). Global HANPP for the year 2000 was recently estimated to be 24% of potential net primary productivity (Haberl et al. 2007), leaving 76% for other species and indicating there is little margin for further increases in appropriation of biomass.

3.3 Planetary Boundaries

Rockström and colleagues (Rockström et al. 2009a, b) present a framework for looking holistically at the level of stress humanity places on the Earth. Their framework consists of a set of boundaries, or limits, beyond which they say there may be abrupt and nonlinear consequences at a global level. They specify numerical values for these boundaries for seven planetary indicators: climate change, ozone depletion, ocean acidification, biodiversity, freshwater use, the global nitrogen and phosphorus cycles, and change in land use. In deriving/choosing numeric values for these boundaries, the authors attempt to account for the uncertainty association with transition zones.

4.0 Sustainability

Sustainability is a "necessary and sufficient condition for a population to be at or below any carrying capacity" (Daily & Ehrlich 1992). However, sustainability is a broad term that is often only vaguely defined. The definition provided by the Brundtland Commission has gained some currency (WCED 1987):

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

The details and consequences of this definition are often overlooked. What are the 'needs of the present'? The definition leaves open the question of how social choices determine the boundaries between 'needs' and 'wants'. What are the needs of the future? We do not know what the needs (or wants) of future generations will be.

The Brundtland Commission's definition was influential in developing a definition of 'sustainable management' for the Resource Management Act. The purpose of the Act is "to promote the sustainable management of natural and physical resource," where 'sustainable management' is defined as:

> *"managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—*
>
> *(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
>
> *(b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
>
> *(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment."*

While these definitions are clearly anthropocentric, all practical definitions of sustainability are necessarily anthropentric being defined according to human values. Deep ecology is a contrasting paradigm that views all species and ecosystems as having equal worth, with no pre-eminence of humanity. However, deep ecology is obviously very difficult to implement in policy.

Importantly, the Brundtland definition is implicitly a statement of 'weak sustainability': that man-made capital be allowed to substitute for natural capital as the latter is depleted, based on the assumption that such man-made replacements will be found. The weak sustainability approach is often depicted as a trade off between the three (or four) pillars (Figure 1), indicating that the goal is balance.

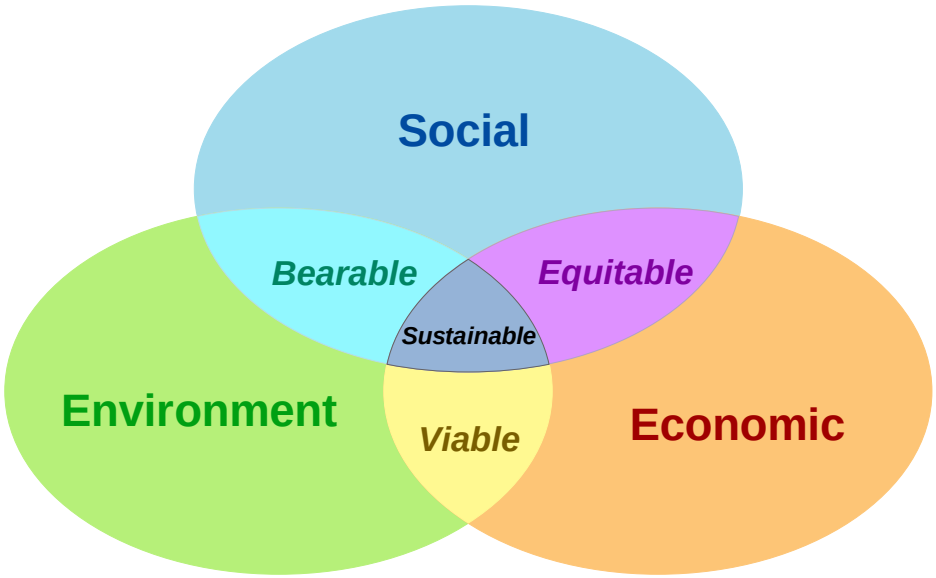

Figure 1 The intersecting-spheres depiction of sustainable development, where sustainability lies at the intersection of all three spheres (source: Johann Dréo, Wikimedia Commons)

In contrast, the 'strong sustainability' approach is commonly represented as having non-negotiable limits set by the environment taking priority over those of society, which in turn take priority over those of the economy (Figure 2). In this paradigm, balance is only considered after ensuring non-negotiable constraints are met. The use of the

strong sustainability paradigm is one of the defining features of the field of Ecological Economics, delineating it clearly from Environmental Economics.

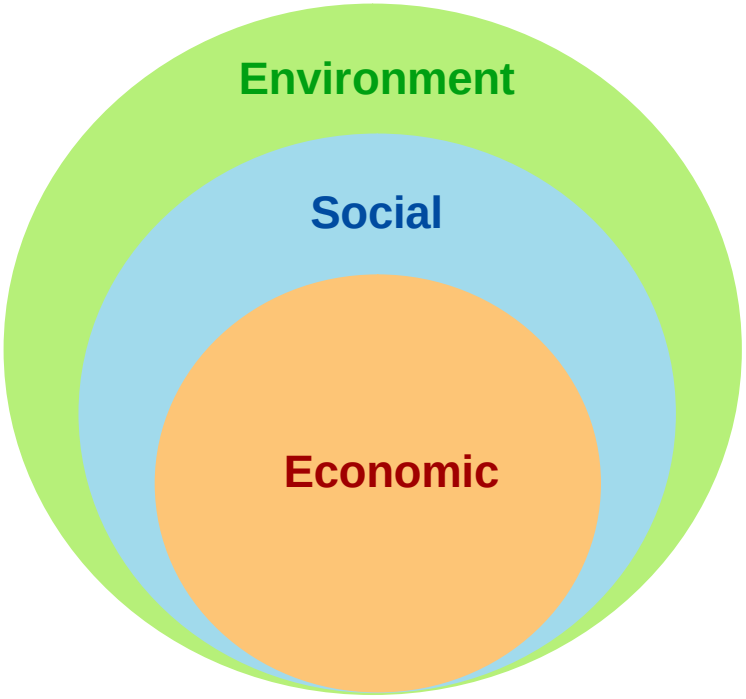

Figure 2 The strong sustainability view, representing the environment as being most critical, and society and the economy constrained within the environment.

While a strong sustainability model is conceptually straightforward at a global level (e.g., the world's real economy is constrained by the global environment), it becomes less so at a local level. For example, if the economy of Kāpiti Coast District were limited only by the District's society and environment, then the District would be self-sufficient. However, the economy (and society) can depend on factors outside of the District. Trade and travel complicate this picture, as do some environmental factors such as weather systems and air purification, and some social factors such as international treaties and protocols.

5.0 Precedence for Application of HCC in Council Plans

A desktop search was undertaken to ascertain whether there is precedence for the application of the Carrying Capacity concept in New Zealand Council Planning documents.

It was found that the term "carrying capacity" was frequently applied in Council documents in terms of infrastructural carrying capacity, for example, roading networks. This usage has some relevance in that it relates to an infrastructural resource (roading) that has a carrying capacity limit in term of the number of vehicles that the roading resource can carry. However this example is not directly analogous in terms of the use of the concept of carrying capacity in this study, which is focussed on human carrying capacity.

The search indicated that some District Plans make reference to carrying capacity in a manner that has some similarity to its use in this study. Two examples are the Proposed (2006) Hauraki Gulf Islands Section of the Auckland City District Plan, and Plan Change 8 (Whitford Rural Area) to the Manukau City District Plan.

In the Proposed Hauraki Gulf Islands Plan, limited references are made to carrying capacity. For example, in reference to the Pakatoa Island Land Unit (Land Unit being an ecologically-based zoning method), the Plan states:

> *"Overall, the island provides for a mix of uses that support the potential for a small residential community combined with a tourist complex activity, while recognising limits to the physical and visual carrying capacity for a small island"*

Little further explicit mention is made of carrying capacity, however the objectives, policies and rules are formulated to control development so that the limits of physical and visual carrying capacity are imposed. It is

also understood that the concept of carrying capacity did provide some theoretical basis to the formation of the Plan, notwithstanding the only minor explicit reference in the final document.

This statement further underlines the varied application of the term “carrying capacity” in planning documents, in this case relating to both physical (biophysical) and visual aspects.

Plan Change 8 to the Manukau City District Plan sought to move away from a prescriptive approach (crude minimum lot sizes and performance standards) to a more nuanced and flexible planning approach to rural land use and subdivision, based on environmental qualities. Several general references were made in the Plan Change to the “carrying capacity” of the area, however the review indicated that the term was being used in the sense of landscape character.

Beyond these specific District Plan examples, which only touch on carrying capacity rather than using it as a central planning tenet, it is apparent that there is little evidence of the explicit use of carrying capacity in planning in New Zealand. However we consider that it is likely that some form of the concept of carrying capacity is implicitly utilised in much planning regulation. That is, planning regulation will be based on certain environmental and infrastructural constraints that dictate where, when and how much development occurs. Therefore, whilst prescriptive limits on human population are not necessarily imposed, approximate limits are effectively imposed by virtue of the yield of potential future development that the a District Plan allows.

6.0 Kāpiti Coast District Context

Kāpiti Coast District Council’s Long-Term Council Community Plan (LTCCP) includes some bold and clear statements on sustainability, stating that the programme of activities ‘is focused on delivering services across all wellbeing areas with a strong sustainable development approach’ (KCDC 2009, p. 5). The document expands on this with a set of development principles (KCDC 2009, p. 24):

> *These principles are consistent with the idea of ‘strong sustainability’ which seeks a readjustment of consumption patterns and systems and rejects the notion that resource depletion and degradation can be resolved through technological innovation alone (known as weak sustainability)…. These principles imbue thinking on all Council activities.”*

Given the statement above defining strong sustainability, it is clear that the Kāpiti Coast District is currently not strongly sustainable. The use of non-renewable resources is contrary to the definition, and the District uses, for example, fossil fuels; many products derived from fossil fuels (e.g., plastics, fertilisers, pesticides, cosmetics); and mined minerals such as phosphates, coal, and limestone. While few would advocate immediate and total cessation of use of these non-renewable resources, the use of the term Strong Sustainability in the Plan is clearly as an aspirational goal.

One of the high level Community Outcomes also presented by the LTCCP is that ‘the nature and rate of population growth is appropriate to community goals’ reflecting the community’s desire that population growth be managed to bring benefits rather than problems (KCDC 2009, p. 18).

As required by the Local Government Act, “Significant Issues” (major structural issues, external risks, and uncertainties) are identified in the LTCCP. These are: climate change, peak oil and the cost of energy, global conflict and disruption, narrow economic base, economic downturn, major swings in central government policies, local democratic structures and systems, and population structure (KCDC 2009, pp. 26–27).

The District Plan is currently under review, and KCDC have released a set of seven discussion documents relating to specific sustainability issues: global change, biodiversity, natural hazards, food and rural productivity, landscape, infrastructure, and urban form and transport. Carrying capacity is specifically mentioned in the Global Change discussion document (KCDC 2010, p. 15) which states the following, which clearly establishes context for this current study:

> *A carrying capacity assumes that it is possible to measure the ultimate population for the District based on the land available for particular uses such as food and energy production, housing and open space, taking into account the ecological and hazard constraints for the District. The District Plan review should explore carrying capacity as a concept and assess options against the theoretical carrying capacity for each resource.*

Every community that has the good fortune to have more than sufficient resources to meet basic needs (food, safety, shelter) faces choices as to how to use ‘surplus’ resources. Communities might choose from a wide range

of lifestyles, anywhere from subsistence, through comfortable, all the way to luxury. At any point on that subsistence–luxury spectrum choices can be made that will affect a community's impact on the environment, the economy, and on the society.

The Kāpiti Coast District currently relies on a wide range of goods and services (both economic and from the environment) and governance from outside of the District. This follows from the concept of comparative advantage, whereby regions and nations that have a natural (or otherwise) comparative advantage in the production of a good or service can do so more cheaply, and thus greater system efficiency is obtained from making use of these advantages. On the other hand, reliance on others to produce critical goods and services reduces a society's resilience, so a trade-off is required. The following is an incomplete list of areas where Kāpiti Coast is reliant on other regions:

- Fuels, medicines, fertilisers, pesticides
- Foods not produced in the area
- Manufactured goods
- Clean air (via wind), ozone layer protection from UV radiation, climate regulation of the atmosphere
- External regulation, national defence, disaster relief, culture

In the local context, the distinction between local and global issues becomes important. While specifically local issues, such as the availability of potable water in the District, are under the control of the District, the same cannot be said of global issues such as climate change – i.e. there is no set of actions the District can take to prevent climate change. However, the District does have control over its *contribution* to global issues, for example through reducing its greenhouse gas emissions and planting trees to sequester CO_2. Both local and global issues are important in the assessment of sustainability.

7.0 Desiderata for a Definition of HCC and the Assessment Framework

A working definition of Human Carrying Capacity, intended to be suitable for use in a District Plan, will provide a starting point for discussions with Council and is likely to be refined during the course of the project.

From the contextual discussion above, we distil the following list of desirable factors for a working definition of human carrying capacity and for the assessment framework in this project:

- Clear: should be generally understandable with no ambiguity
- Covers the idea of allowing some things to be imported, with some reliance on non-renewables, i.e. some flexibility around the idea of strong sustainability, but such things are explicit and clearly reasoned
- Make explicit the trade-off between population, some indicator of affluence (lifestyle, quality of life), and the way in which that lifestyle is achieved (i.e., technical efficiency). This should reflect the relationship $I=P\times A\times T$.
- Precautionary principle: allowing a margin for uncertainty and resilience against extreme events
- Will be a function of the community's choices, and reflect the range of social values and expectations within the community
- Includes a range of indicators both separately and aggregated
- Should be theoretically measurable and monitorable (but the practicalities will be examined in Phase II of this project)
- The Assessment Framework should be applicable at a range of scales
- The Assessment Framework should allow the conferment of benefit to areas where carrying capacity is maintained (or enhanced), or where certain technologies / methods are employed which are deemed to not detract from the carrying capacity of a particular area. Conversely, the framework could penalise development which is deemed to detract from carrying capacity.

8.0 Proposed Definition of HCC

We propose the following definition of human carrying capacity in this project:

> *The Human Carrying Capacity (HCC) is the measure of a specified area's ability to sustainably support human activity given aggregate lifestyle and development choices and the means used to achieve these, and is expressed in terms of number of people.*

Notes on the definition:

- Because of the number and complexity of factors determining sustainability, it is likely that carrying capacity cannot be calculated directly: there is insufficient knowledge and information to undertake such a calculation and the 'number' shifts constantly, and can be both added to and detracted from by virtue of people's actions. Rather, we expect that at least qualitative changes in carrying capacity may be observed via a set of indicators.
- The degree of sustainability of each indicator will be both determined by the community and specific to the Kāpiti Coast District, such that sustainability is strong for one set of indicators, weak for a second set, and flexible for remaining indicators.
- Sustainability implies the ongoing maintenance (and potentially improvement) of environmental, social, and economic indicators.
- Strong sustainability views the stock of natural capital as irreplaceable, while weak sustainability views natural capital as substitutable with man-made capital.
- We define flexible sustainability as the explicit decision that some indicators will not be weakly sustained, but will rather be traded off against other indicators. This recognises priorities of the community that the requirement of some indicators to be either strongly or weakly sustained is not negotiable, while remaining indicators are desirable but negotiable.
- Indicators will also be clearly identified as locally or globally sustainable. An indicator that is at a locally sustainable level is one that is sustainable without dependence on other areas. This implies specific self-sufficiency. For example, potable water is likely to be locally sustainable for the District as a whole (ignoring growth), although in many places within the District it is not locally sustainable because of reliance on reticulation from other areas. In contrast, an indicator that is globally sustained is one that is sustained in net across a larger area through use of offsets, trade, etc. For example, use of medicines by an area is potentially above any capacity of that area to produce medicines, but well within global capacity.
- Indicators are to be identified and assessed in the second phase of this project, along with methods for determining their sustainability (e.g., thresholds).
- Being dependent on 'aggregate lifestyle and development choices', the Carrying Capacity of KCD can be directly influenced by the actions of individuals and organisations in the District. Indeed, as discussed earlier, actions taken outside of the District can also affect the Carrying Capacity of the District.
- The definition implies that some indicators may be limiting factors in the number of people the district can support. Strong and weak sustainability of individual indicators implies there is a limit (perhaps unknown or highly uncertain) that cannot be breached. If one additional person in the district would breach a single limit for a single strongly or weakly sustained indicator then the carrying capacity would have been surpassed. In contrast, flexibly sustained indicators cannot be limiting factors.
- While the definition allows some factors to be weakly sustainable and others not, the reality is that most inputs into human life support and lifestyle are interdependent. For example, if oil is not included as at least a weakly sustainable factor, then, strictly speaking, all other factors that depend on oil (i.e., that are transported using existing modes) cannot be sustainable.
- Recognising that data and limits are uncertain, the definition in effect requires a 'safety margin' or buffer.
- A particular area may be assigned a 'grade' indicating in some fashion that area's proximity to sustainability, and this grade may used within the framework to signify an increase in allowable development of that particular site, or as an offset against other areas with higher or lower grades. For example, if the water quality of an area is significantly improved then this could allow development to specified limits within another area, as long as minimum water quality standards are met, and all other indicators or limiting factors of concern are considered and assessed as well.

9.0 References

Cohen JE 1995a. Population growth and Earth's human carrying capacity. Science 269(5222): 341–346.

Cohen JE 1995b. How many people can the earth support? New York, W. W. Norton & Company.

Daily GC, Ehrlich PR 1992. Population, sustainability and the Earth's carrying capacity. Bioscience 42: 761–771.

Ehrlich P, Holdren JP 1971. Impact of population growth. Science 171: 1212–1217.

FAO 2010. Global hunger declining, but still unacceptably high. Rome, Italy, Food and Agriculture Organization of the United Nations.

Global Footprint Network 2011. Case stories. http://www.footprintnetwork.org/en/index.php/GFN/page/case_stories/

Haberl H, Erb K-H, Krausmann F 2010. Global human appropriation of net primary production (hanpp). http://www.eoearth.org/article/Global_human_appropriation_of_net_primary_production_(HANPP) [accessed March 2011].

Haberl H, Erb KH, Krausmann F, Gaube V, Bondeau A, Plutzar C, Gingrich S, Lucht W, Fischer-Kowalski M 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences of the USA 104: 12942–12947.

KCDC 2009. Kāpiti coast long term council community plan 2009. Paraparaumu, NZ, Kāpiti Coast District Council, http://www.kapiticoast.govt.nz

KCDC 2010. Global Change: Issues and Pressures,

http://www.kapiticoast.govt.nz

Price D 1999. Carrying capacity reconsidered. Population and Environment 21(1): 5–26.

Rees W 1992. Ecological footprints and appropriated carrying capacity: What urban economics leaves out. Environment and Urbanization 4(2): 121–130.

Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA 2009a. Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society 14(2): Article 32.

Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA 2009b. A safe operating space for humanity. Nature 461(7263): 472–475.

Seidl I, Tisdell CA 1999. Carrying capacity reconsidered: From malthus' population theory to cultural carrying capacity. Ecological Economics 31: 395–408.

US Census Bureau 2011. U.S. & world population clocks. http://www.census.gov/main/www/popclock.html [accessed March 2011].

Verhulst P-F 1838. Notice sur la loi que la population poursuit dans son accroissement. Correspondance mathématique et physique 10: 113–121.

Wackernagel M 1994. Ecological footprint and appropriated carrying capacity: A tool for planning toward sustainability. Vancouver, BC, Canada, Doctor of Philosophy, University of British Columbia.

WCED 1987. Our common future. New York, World Commission on Environment and Development, Oxford University Press.

WRAP 2009. Household food and drink waste in the UK. Banbury, Oxon, UK, Waste and Resources Action Programme, http://www.wrap.org.uk [accessed December 2010].

WWF 2010. Living planet report 2010. Gland, Switzerland, WWF–World Wide Fund for Nature, http://www.footprintnetwork.org/