1 Introduction

1.1 Scope of the report

The Ministry for the Environment has worked with other government departments to produce the Sustainable Development of New Zealand Programme of Action (January 2003) that includes the development of headline indicators of sustainability. This report represents a first step to establish a headline indicator of sustainability for New Zealand and its regions based on the ecological footprint concept. After originally being developed at the University of British Columbia's School of Community and Regional Planning in the early 1990s by Wackernagel and Rees (1996), the ecological footprint is increasingly being used as an indicator of sustainability,. The ecological footprint has recently been calculated for 150 countries in the World Wildlife Fund's report *Living Planet Report 2000* (Loh, 2000).

Specifically the research objectives for this report are:

(1) To develop a scientifically defensible and replicatible methodology for the calculation of ecological footprints of New Zealand and its regions based on extending Bicknell et al's (1998) input–output approach.

(2) To calculate the ecological footprint for New Zealand, for the base year 1997/98, using the above methodology. These calculations will pay particular attention to disaggregating the ecological footprint into its component land types (agricultural, forest, degraded, energy) and according to categories of commodities that are consumed.

(3) To compare New Zealand's ecological footprint with those from other countries and to understand the key reasons behind any significant differences.

(4) To calculate the ecological footprint for the 16 regional council areas in New Zealand, for 1997/98, disaggregating according to land types and type of commodities that are consumed. This regional analysis will be used to understand the ecological interdependencies between regions as indicated by the interregional flows of embodied land.

(5) To compare the 16 regional ecological footprints and to understand the key reasons for any significant differences in the numerical magnitude of these footprints. These regional ecological footprints will then be used to assess the sustainability performance of the various regions.

(6) To extend the regional and national ecological footprint calculations to take account of international exports and imports of embodied land. The ecological footprint measures the embodied land required by local consumption within New Zealand but a considerable amount of New Zealand land-based production supports consumption in other countries.

(7) To identify and briefly discuss any theoretical and methodological limitations of the ecological footprint as a headline sustainability indicator, particularly as it relates to the foregoing analysis and calculations.

1.2 Ecological footprint concept and its measurement

1.2.1 What is the ecological footprint?

The ecological footprint is defined by Rees (2000) as the "area of productive land and water ecosystems required to produce the resources that a population consumes and to assimilate the wastes that the population produces, wherever on Earth that land and water may be located". It can be seen as a sustainability indicator in two senses. Firstly, it measures the total ecological cost (in land area) of supplying all of the goods and services to a human population. This recognises that people not only directly require land for agricultural production, roads, buildings and so forth, but land is indirectly embodied in the goods and services that people consume. For example, the indirect (or embodied) land required to produce a kilogram of butter includes not only the land used directly in manufacturing but all land embodied in the inputs that went into producing the butter – dairy farm land, land required to produce the packaging and so forth. In this sense, the ecological footprint can be used to make visible the hidden ecological cost of an activity or population.

A second, and more controversial interpretation of the ecological footprint as a sustainability indicator, invokes the idea of carrying capacity. Carrying capacity in ecology is the maximum population a given land area can support indefinitely. The idea is relatively straightforward when applied to well-defined biological populations (eg. a certain number of hectares are required to support a herd of deer). If the number of deer exceeds the carrying capacity then the population is said to be in overshoot. Resources (mainly food) will become scarce and population die-back will occur. This idea is more controversial when applied to human populations, as in the *Limits to Growth* study which predicted a decline in global human population as it overshot its carrying capacity (Meadows et al, 1972; Meadows et al, 1992). Some proponents of the ecological footprint argue that the total embodied land area required by a population should not overshoot its biocapacity[1] (eg. Loh (2000) argues that the ecological footprint of the Netherlands at 92.9 million ha, considerably overshoots its biocapacity of 37.4 million ha). Less dogmatically, it can be concluded that the Netherlands is in ecological deficit, in the sense it is using more biologically productive land than is available within its borders.

Using this second interpretation, Wackernagel and Rees (1996) argue that the ecological footprints of most developed nations are unsustainable as they exceed available biocapacity. At the global level the ecological footprint for humanity exceeds global biocapacity by 34 percent (Loh, 2000).

1.2.2 History of the ecological footprint concept

The University of British Columbia's School of Community and Regional Planning developed the ecological footprint in the early 1990s. The concept was popularised by Wackernagel and Rees (1996) in the publication *Our Ecological Footprint: Reducing Human Impact on the Earth*. Wackernagel et al (1999) acknowledge Vitousek et al's (1986) study on the human appropriation of photosynthesis products as the intellectual predecessor to the ecological footprint concept. However its antecedents can be traced back a lot further.

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[1] Biocapacity is a measure of the total biologically productive land available to a specified population.

In the 18th century the Physiocrats argued that the embodied land content of a commodity determined its value. For the Physiocrats, all value was derived from the land (nature), and in this sense agriculture was the only productive sector in the economy with the manufacturing and service sectors considered 'sterile'.

Classical economists, although not subscribing to an embodied land theory of value did emphasise the idea of carrying capacity. Both Thomas Malthus (1766–1834) and David Ricardo (1772–1823) saw population being constrained by the carrying capacity imposed by land availability. Malthus argued that population growth wasn't sustainable in the long run, as it grew according to a geometric progression and it would eventually overshoot food supply from land that grew arithmetically. Ricardo didn't foresee an overshoot, as Malthus did, but instead suggested that population growth would gradually approach its carrying capacity as food production was forced to use less fertile land.

In the modern era, Borgstrom (1967, 1973) developed the concept of 'ghost acreage' which is similar to the idea of the ecological footprint. This idea was further promoted by sociologist Catton (1982) in his book *Overshoot: The Ecological Basis of Revolutionary Change*. Ghost acreage is the additional land a nation needs in order to supply the net amount of food and fuel, from sources outside the nation (ie. the net imports of agricultural products, oceanic fisheries and fossil fuels). The appropriation of ecosystem areas and services has also been a central theme in other approaches (refer to Folke et al, 1997; Brown and Ulgiati, 1998). Brown and Ulgiati (1998) for example measure the ecological footprint of various countries and the globe, using an energy indicator instead of the more widely used land indicator. Folke et al (1997) estimated the 'appropriated ecosystem areas' by cities in the Baltic area based on their resource consumption and waste assimilation.

1.2.3 How is the ecological footprint calculated?

Several methods have been advanced for calculation of ecological footprints (eg. Wackernagel and Rees (1996), Folke et al (1997), Bicknell et al (1998), Wackernagel et al (1999), Loh (2000), van Vuuren and Smeets (2000) and so on). Although each of these methods has its own peculiarities and insights, many have their roots in the work of Wackernagel and Rees (1996).

The Wackernagel and Rees calculation method begins with construction of a 'consumption by land use' matrix. The consumption dimension covers food, housing, transport, consumer goods and services, while the land use dimension encompasses built-up areas (supporting roads, housing and other infrastructure), crop land and pasture (for production of food and other goods), managed forest (for production of wood products), and energy land (for sequestering carbon dioxide emissions resulting from the burning of fossil fuels). This consumption by land use matrix provides a snapshot, for a given population, of the land use types required for production and consumption of goods and services.

Population data, together with consumption information, for each land use category are used to derive an average annual consumption per person. Consumption is calculated by adding imports to domestic production and excluding exports. Referred to as 'apparent' consumption, this differs from true household consumption due to the inclusion of resources processed for export, while at the same time excluding resources embodied in imported finished products. The land area utilised by each consumption category is then determined for each land use category. This requires dividing consumption in each category, by a relevant global average yield, to obtain land area. Global average yields are used so that comparisons can be made between the ecological footprints of different nations and with the globe.

The land appropriated for energy consumption is treated separately primarily due to the size of the contribution it makes. Wackernagel et al (1999) distinguish between five types of energy, namely: gas fossil, liquid fossil, solid fossil, firewood and hydropower.[2] The energy land requirement for fossil fuels is calculated by assessing the amount of planted forest land required to absorb the CO_2 emissions resulting from energy consumption. The role played by the oceans in CO_2 sequestration is also acknowledged. The oceans are assumed to absorb some 35 percent of CO_2 emissions at the global level. Correction for trade is required because energy is utilised in the production of exported goods and services, and conversely embodied in imports. This requires multiplying imports and exports for various trade categories by their energy intensities and determining the difference.[3]

Aggregating the land area appropriated by each land use category generates the ecological footprint. Prior to aggregation each category is multiplied by an equivalence factor to take account of differences in biological productivity (eg. for built up areas, forest land and pasture equivalence factors of 3.16, 1.78 and 0.39 are respectively applied (Loh, 2000)). Wackernagel et al (1997) also argue, in accordance with the Brundtland report (WCED, 1987), that an additional 12 percent of land area is required as a backstop for the preservation of biodiversity.[4] The ecological footprint may also be expressed in per capita terms which permits the comparison between different nations, regions or populations.

The ecological footprint can also be calculated by using input–output analysis to track the flow of embodied land. This method of analysis which was first developed by Bicknell et al (1998) and refined by Ferng (2001) and others has not to date been widely used. It should, however, be noted that the calculation of embodied resources using input–output analysis was first pioneered in the early 1970s by analysts such as Hite and Laurent (1971), Herendeen (1972) and Wright (1975), and it could be argued that the calculation of ecological footprint (in land terms) in just a special case of the more general method. The input–output method of calculating the ecological footprint attempts to situate the analysis in a rigorous mathematical framework but draws upon many of the ideas and principles of the Wackernagel Rees method.

1.3 Critique of the ecological footprint

Costanza (2000) and Moffatt (2000) argue that the key feature of the ecological footprint is that it provides an effective heuristic and pedagogic tool that captures current human resource use in an easily digestible form. In this way, the ecological footprint frequently promotes discussion on issues directly relevant to sustainable development – in other words, issues such as:

(a) the finite dimensions of human activity

(b) the key resources and ecosystem functions for sustainable development

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[2] Nuclear power is treated as a fossil fuel. It is unclear why nuclear power and fossil fuels are equated, as they have quite different biophysical inputs and have substantially different ecological impacts and risks. Energy generated from other sources is considered to be negligible and is not included (eg. geothermal and wind).

[3] Wackernagel et al (1999) apply energy intensities taken from Hofstetter (1992). Interestingly, van Vuuren and Smeets (2000) note that energy intensity data is only available for developed nations. Furthermore, they consider it to be insufficiently accurate to permit calculation of trade related energy emissions.

[4] Wackernagel et al (1997) note that authors such as Noss (1991), and Noss and Cooperrider (1994) argue that this estimate is probably insufficient to support this backstop.

(c) the role played by trade in distributing ecological resources and pressures

(d) the selection of indicators for monitoring progress toward sustainable development and so forth.

The ecological footprint methodology does, however, have a number of well-known weaknesses and limitations that are described below.

1.3.1 Lack of common definitions and methodologies

There is no accepted methodology for calculating the ecological footprint. The ecological footprint is not, for example, constructed according to widely accepted international conventions such as that used in the United Nations System of National Accounts (UNSNA). This has led to ambiguities in interpreting the results of various ecological footprint studies. For instance, estimates of New Zealand's ecological footprint range between 3.49 and 9.6 ha per capita (Bicknell et al, 1998; Wackernagel et al, 1999; Loh, 2000). Investigation of these studies reveals that differences result largely from the assumptions made concerning biological productivity, the use of equivalence factors, and the calculation of energy land. To avoid misinterpretation in this report, and to allow comparison with earlier ecological footprint estimates, differences in assumptions between three different calculation methods are outlined in Table 1.1.

Table 1.1 Assumptions made by three different ecological footprint calculation methods

Bicknell et al (1998)	Loh (2000)	This report
Applies local yields for pasture, arable and forest land	Applies global average yields for pasture, arable and forest land	Applies local yields for pasture, arable and forest land
Does not apply equivalence factors	Applies equivalence factors when aggregating land types	Does not apply equivalence factors
Applies an international energy-to-land ratio obtained from Wackernagel and Rees (1996)	Applies world average CO_2 absorption factor	Applies CO_2 absorption factor for New Zealand *Pinus radiata* (Hollinger et al, 1993)
Ignores CO_2 absorption by oceans	Assumes oceans absorb 35 percent of CO_2 emissions	Ignores CO_2 absorption by oceans
No allowance for securing biodiversity	Assumes 12 percent of biocapacity is set aside for securing biodiversity (as per WCED, 1987)	No allowance for securing biodiversity
Excludes sea space	Includes sea space, estimated to be 0.1 ha per capita for New Zealand	Excludes sea space
Considers ecological interdependencies between regions as an aggregate (total imports)	Considers ecological interdependencies between regions as an aggregate (total imports)	Makes explicit ecological interdependencies between regions
Based on input–output analysis	Based on work of Wackernagel and Rees (1996)	Based on input–output analysis

There is however a reasonable prospect that many of these conventions and methodologies for the calculation of ecological footprints will be standardised in the near future. The United Nations (1993) SEEA System of Environmental Accounting provides a good example of how environmental accounting protocols have been established and are now widely accepted in a field which hitherto had few commonly used conventions and methodologies in the 1970s and 1980s.

1.3.2 Why use land as the numeraire?

Why should embodied land be used as the numeraire for a sustainability indicator? Others have argued (Slesser, 1973; Gilliland, 1975; Costanza, 1980; Odum, 1983; Herendeen, 1998) that embodied energy or embodied solar energy is a more appropriate numeraire. Land isn't the only scarce natural resource, so why should it be the only resource entered into the calculation of a sustainability indicator? Arguments alluding to the non-substitutability of land are not compelling, as it could be argued that other natural resources also don't have substitutes (eg. solar energy). By using input–output analysis to calculate the ecological footprint, as is applied in this report, the ecological consequences of human activity on other key resources (eg. energy and water) are easily determined. Energy analysis, for example, has been widely applied in estimating energy embodied in human activities. Examples include work of Bullard and Herendeen (1975), Gilliland (1975), Hannon (1979), Costanza (1980) and Giampietro and Pimentel (1991). The focus of this report is, however, on the appropriation of biologically productive land.

1.3.3 Why include hypothetical energy land?

The hypothetical land required to absorb atmospheric CO_2 emissions, resulting from the burning of fossil fuels, often constitutes more than 50 percent of the ecological footprint. Critics such as Ayres (2000) find this result questionable. It assumes that afforestation is the preferred option for CO_2 sequestering. Serious alternatives already exist such as liquefying CO_2 and pumping it into the ocean depths where it would remain for thousands of years, or into oil and gas fields replacing the fuel extracted, while increasing pressure of the remaining reserves. Planting production forest to sequester CO_2 is arguably only a temporary measure. The forests will grow old, die. be harvested or are used as a fuel source, all of which will eventually result in CO_2 being re-released back into the atmosphere.

Another critical issue with the ecological footprint is that it exclusively focuses on energy related CO_2 emissions, neglecting the ecological consequences caused by other emissions (eg. the depletion of ozone by CFCs, or acidification caused by SO_2 and NO_x). More importantly, the ecological footprint as it is currently formulated overlooks pollution and wastes generated by other unsustainable practices such as the disposal of non-biodegradable consumer wastes (eg. plastics, metals) and persistent toxins (eg. rubbish leachate). These issues are not addressed in this report, although it is recognised that they are important issues that need to be addressed in the further development of the ecological footprint indicator.

1.3.4 Is all land the same?

The use of equivalence factors during the aggregation of ecological footprint components (built area, arable land, forest land etc) is contentious. These equivalence factors recognise that adjustments need to be made to land areas (ha) to take account of variations in biological productivities. For example, fertile flood plains may have a biological productivity several times that of mountainous land, and adjustments need to be made to reflect this difference. It can be argued that this narrow focus on biological productivity, ignores other factors that determine the relative value of different types of land (eg. cultural values, social preferences or relative scarcity, as are often reflected in market prices).

International comparison of ecological footprints requires consideration of differences in biological productivity. Such differences are primarily due to environmental factors (ie. solar flux, soil type, climatic conditions and type of vegetation cover). This issue is addressed in ecological footprint calculations by relating consumption to global average yields rather than local yields.[5] Such an approach is problematical as it produces results that are not comparable with the actual land area occupied by the appropriating population. At a national, or sub-national level, it is often desirable to be able to examine ecological consequences in terms of actual occupied land area – a unit of measurement familiar to the resident communities.

In this report neither global average yields or equivalence factors are used, except when international comparisons are made in Section 3.

1.3.5 What spatial boundaries?

The selection of appropriate spatial boundaries is a critical issue in ecological footprinting. For example, ecological footprints can be calculated at global, national, regional and local (city) scales. Wackernagel and Silverstein (2000) argue for political or cultural boundaries as they represent the level at which environmental policy and decision-making is most often made. By contrast, van den Bergh and Verbruggen (1999) dispute the use of such boundaries on the grounds that they have no environmental meaning, favouring instead hydrological, climate zone, or larger connected ecosystem boundaries. In this report, New Zealand regional council areas are used which reflect both political[6] and environmental boundaries.[7]

Closely associated with the selection of ecological footprint spatial boundaries are the ecological implications of trade. Rees (1992) argues that trade has the effect of physically and psychologically distancing populations from the ecosystems that sustain them. From a regional perspective, information is required not only on footprint size (and on its component shares, for example, agricultural, forest, degraded (built up) and energy land), but also on the origins of contributions made by each imported component and how sustainable it is. For this reason in this report the ecological footprint methodology is extended to include an analysis of the ecological interdependencies of New Zealand regions, in order to consider not only the ecological footprint from the consumption (end-use) perspective, but also the production (source) perspective.

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5 Global (Loh, 2000) average yields may differ substantially from local yields. In New Zealand, for example, the local yield for milk production is 1,759 kg ha^{-1}, compared with a global average yield of 336 kg ha^{-1}. Therefore, applying a global average milk production yield for the calculation of the New Zealand footprint, results in an ecological footprint contribution that is 5.24 times the actual land area used for milk production.

6 Regional councils are the key agencies responsible for environmental governance in New Zealand.

7 The boundaries of regional councils are based on major river catchments.

1.3.6 Dynamics – what about the future?

The ecological footprint provides a snapshot of a population's environmental requirements using current technology under prevailing management practices and social values. Even if the ecological footprint for a particular population is calculated at regular intervals, the results are always out of date – in this respect, the ecological footprint only tells us 'yesterday's news'. Key dynamic components of the sustainability equation such as intergenerational equity, technological change, and the adaptability of social systems are simply overlooked. Moreover, nature is characterised by complex adaptive systems with non-linearities, feedback loops, and thresholds (Holling, 1973; Levin, 1998). By ignoring such dynamics the ecological footprint cannot inform us on the ecological consequences of likely futures or even possible scenarios. This report makes no attempt to address these issues.

1.4 Related New Zealand studies

Input-output analysis was used to calculate the ecological footprints of New Zealand and its regions. That is, the direct and indirect land required to support local consumption was calculated using input–output analysis. Input-output analysis can also be used to calculate not only the embodied (direct + indirect) land content but also embodied inputs for other natural resources. These methods of analysis were first developed in the early 1970s by analysts such as Herendeen (1972), Hite and Laurent (1972) and Wright (1975). These input–output methods were not only applied to resource inputs (into the economy) but also to pollutant outputs (from the economy).

In New Zealand Carter, Peet and Baines (1981) pioneered the use of input–output analysis for calculating the embodied energy content of the output from various sectors in the economy. Initially Peet and his colleagues calculated embodied energy requirements based on the 1971–72 input–output table of the New Zealand economy, but subsequently updated this analysis to cover the 1976–77 and 1981–82 input–output tables (Peet, 1985). In addition, they extended their analysis to cover dynamic input–output scenario models, employment issues, New Zealand's energy Balance of Trade, as well as more recently CO_2 emissions policy issues.

Patterson and McDonald (1996) undertook an input–output analysis of regional data from the Manawatu–Wanganui and Wellington regions to quantify the indirect land, water, air pollutants and water pollutants embodied in economic products. This analysis used data primarily from regional council consents and monitoring databases, and used regionalised versions of the national input–output matrix. This work was extended in the *Eco*link project sponsored both by councils and the Ministry for Environment's Sustainable Management Fund. This project again quantified ecological multipliers (direct and indirect effects) for land energy, greenhouse gases, water takes/discharges and water pollutants for all territorial local authorities in the Northland, Auckland and Waikato Regional Council areas (McDonald and Patterson, 1999a).

Bicknell et al (1998) specifically developed a new methodology for calculating national ecological footprints using input–output analysis which was published in the journal *Ecological Economics*. This methodology was the first published application of input–output analysis methodology for calculating ecological footprints and has since been extended by analysts such as Ferng (2001) and Lenzen and Murray (2001). Bicknell et al (1998) applied their methodology to New Zealand data in order to calculate the New Zealand ecological footprint as a demonstration case.

More recently Patterson and McDonald (2002) have used input–output analysis to calculate various ecological multipliers for the New Zealand tourism industry. These multipliers show that the indirect environmental effects of tourism in New Zealand are very significant and challenge the idea that tourism in New Zealand is 'clean and green'.

New Zealand also has a history of regional input–output analysis which is relevant to our current study. Hubbard and Brown (1981) pioneered regional input–output analysis in New Zealand in their analysis of the income and employment effects of irrigation development in the Lower Waitaki. Moore (1981) constructed a 50 sector input–output model of Northland based on a survey method and used this model to quantify the indirect effects of forestry options for Northland. However, probably the most widely used and known work is that of Butcher (1985) who developed regional employment and income multipliers from regional input–output matrices generated by the GRIT method. The GRIT method is a non-survey based method developed by Jensen et al (1977) for generating reliable regional input–output matrices from national matrices. The GRIT method is also used in this current study to generate regional input–output matrices for the 16 regional council economies. The calculation of ecological multipliers (instead of income and employment multipliers) can be seen as an extension of this type of regional economic analysis.

1.5 Key definitions

1.5.1 Location quotient

Location quotient analysis was used in sections 4–19 of this report. This enabled us to gain some insights into the economic strengths and weaknesses of the various regional economies being analysed.

The location quotient is a statistical measure of the extent to which a particular economic sector is over-represented or under-represented in a regional economy. If the location quotient is greater than one (LQ>1), then that economic sector is over-represented in the regional economy compared with the national economy. If the location quotient is less than one (LQ<1) then that economic sector is underrepresented in the regional economy compared with the national economy. If the location quotient is one (LQ=1), then that economic sector is represented in the regional economy at exactly the same proportion as in the national economy.

It is preferable to measure the location quotient in terms of value-added output ($). However, such data is not available at a regional level in New Zealand. Therefore, in accordance with common international practice, we have used employment as a surrogate measure of value added ($) production. This surrogate measurement assumes that the labour productivity for a given sector in the region is the same as for that given sector nationally.

1.5.2 Ecological footprint indicators

Rees (2002) defines the ecological footprint as the "area of productive land and water ecosystems required to produce the resources that population consumes and to assimilate the wastes that population produces". In our analysis, we use this definition, with the exception that water ecosystems aren't included.

The ecological footprint consists of four different types of land in our analysis:

(1) *Agricultural land*. This is land used for food and fibre production, encompassing: dairy, sheep, beef, other livestock, horticulture, cropping, vegetable production and fruit growing.

(2) *Forest land*. This land is used for the production of commercial forests. It does not include non-commercial forests such as those in National Parks or those in the conservation estate. It also does not include land directly used in the downstream processing of forest products.

(3) *Degraded land*. This represents built up areas that host human settlement. This includes land used for housing, commercial and governmental purposes as well as land covered by the transport network.

(4) *Energy land*. This represents the hypothetical amount of land required to sequester CO_2 emissions resulting from the burning of fossil fuels.

Different sectors in international, national and regional economic systems utilise these four types of land (agricultural, forest, degraded, and energy). There is a complex pattern of flow of these types of land through and between these economic systems. Figure 2.1 provides a schematic summary of these flows and how they relate to the ecological footprint concept. This schematic diagram shows that the ecological footprint is the total (direct and indirect) amount of land consumed by households, when they purchase and consume products. Economic systems, however, do not just produce commodities for households; they also produce commodities for export. Once this is recognised, it is useful to also use the concept of *Ecological Balance of Trade*. The Ecological Balance of Trade is the land embodied in exports minus the land embodied in imports for a national or regional economy. If a national or regional economy has a positive Ecological Balance of Trade, it is a net provider of ecological capital to other economies. New Zealand, for example, has a positive Ecological Balance of Trade which means that we ecologically support other economies more than they support us.