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The essential parameters of a resource-based carrying capacity assessment model: An Australian case study

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ABSTRACT

Carrying capacity assessments model a population's potential self-sufficiency. A crucial first step in the development of such modelling is to examine the basic resource-based parameters defining the population's production and consumption habits. These parameters include basic human needs such as food, water, shelter and energy together with climatic, environmental and behavioural characteristics. Each of these parameters imparts land-usage requirements in different ways and varied degrees so their incorporation into carrying capacity modelling also differs. Given that the availability and values of production parameters may differ between locations, no two carrying capacity models are likely to be exactly alike. However, the essential parameters themselves can remain consistent so one example, the Carrying Capacity Dashboard, is offered as a case study to highlight one way in which these parameters are utilised. While examples exist of findings made from carrying capacity assessment modelling, to date, guidelines for replication of such studies in other regions and scales have largely been overlooked. This paper addresses such shortcomings by describing a process for the inclusion and calibration of the most important resource-based parameters in a way that could be repeated elsewhere.

1. Introduction

Carrying capacity assessment, as a modelling tool for localised human resource self-sufficiency, has generally been overshadowed by its global variant, Ecological Footprint analysis. Given the globalised nature of modern trade, proponents of the Ecological Footprint approach argue that this analysis is a more accurate representation of existing circumstances (Wackernagel, 1994) where the geographic scale of consumption is variable while the global scale of production is usually fixed (Global Footprint Network, 2012). Recent community-led resurgence in the relevance of localised self-sufficiency (Holmgren, 2002; Peters et al., 2009; Hopkins, 2011) has seen some response from academia and government departments with recent studies including a report on the self-sufficiency of Hawaii County (Melrose and Delepart, 2012) and a comprehensive modelling of the agricultural carrying capacity of New York State (Peters et al., 2007). Adding to this renewed interest in carrying capacity modelling is the release of an online assessment tool for the Australian context, the Carrying Capacity Dashboard (http://dashboard.carryingcapacity.com.au/) (Lane, 2012).

The current global system of trade makes estimates of localised carrying capacity more complicated when production and/or consumption of any particular resource occur outside any localised boundary (Whyte and Beuret, 2004). Trade between different locations is actually an anathema to carrying capacity assessment at a theoretical level, given that carrying capacity estimates the productive potential of the landscape within a certain border at the exclusion of the land outside the border (Fearnside, 1986). However, from a practical perspective, populations have historically been inclined to trade a certain amount of material goods with others as a way of sharing any internal surplus and making up for shortfalls (Cohen, 1995). As such, even though the focus of carrying capacity models is generally local, it is also important that they address the issue of trade by finding ways to incorporate the extent and impact of imports and exports between otherwise notionally self-sufficient regions.

Carrying capacity models are the primary vehicle for the estimation of a population's self-sufficiency. From a resource perspective, the most important parameters determining carrying capacity are basic human needs essential for a population's physical survival including food (Hopfenberg and Pimentel, 2001), water, shelter and energy. Each of these parameters imparts land-usage requirements in different ways so their incorporation into carrying capacity modelling also differs. Additionally, the integration of these parameters is dependent on data availability – a factor which may differ from one location to the next. Consequently, while the basic structure

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of resource-based carrying capacity models may remain consistent between studies, no two approaches are likely to be exactly alike. A case study approach to the question of optimum parameter integration is thus a useful way in which to highlight parameter integration as it provides a contextualised example of the essential concepts. This paper describes a process for the inclusion and calibration of the most important resource-based parameters in a way that could potentially be replicated by other researchers in other locations.

1.1. Why resource-based?

Carrying capacity parameters are determined by the constraints by which populations are limited. These constraints may potentially be biophysically orientated such as resource needs and environmental impacts, or can also be societally focused (Lane, 2010). Viewed in isolation, the potential determinants of human carrying capacity could be analogous to Liebig's Law of the Minimum (Cohen, 1995). Liebig asserted that in agriculture, under steady-state conditions, a species' population size is constrained not by the total quantity of resources available, but by the scarcest resource. Relying solely on one factor is likely to offer only limited reliability as Liebig's Law does not adequately accommodate fluctuating environments, interactions amongst inputs, proportional relationships between populations and resources, and differing requirements of various populations (Cohen, 1995). Consequently, the determination of human carrying capacity necessitates the inclusion of an array of parameters (Fearnside, 1986). If all potential resources, impacts and societal constraints are to be incorporated into a carrying capacity model, the sheer size and complexity of the enterprise may render it beyond the scope of most projects. Consequently, a strategy for the prioritisation of some parameters over others is required.

One way by which to ascertain priority in the importance of carrying capacity modelling parameters is to ascribe them a chronological ordering. The pursuit of cultural endeavours described by Hardin (1986) is dependent on favourable biophysical conditions because without a healthy environment and adequate basic resources such as food and water, the inevitable poor-health of the population is likely to preclude such activity. Thus, it is possible to deduce that biophysical constraints have a higher chronological priority than societal aspirations. There are two forms of biophysical constraints: resource requirements and environmental impacts (Lane, 2010). The set of parameters related to resource requirements takes precedence over impacts because the degree of impact is often dictated by the amount of resources utilised. In a closed system (which carrying capacity assessment implies) there is a linear progression from resource production to resource usage (consumption) to resource assimilation (impacts and waste). Notwithstanding extreme environmentally destructive behaviour, the amount of resource assimilation is dictated by the amount of resources produced. The primary focus in this paper is placed on resource-based carrying capacity assessment modelling, with the majority of the parameters of Carrying Capacity Dashboard reflecting this bias.

2. Method

This paper will describe the parameters necessary for the development of Australian resource-based carrying capacity assessment tools by using the example of the Carrying Capacity Dashboard. Despite limiting the scope of this analysis to a resource-orientation, the breadth of potential parameters for subsequent modelling is still significant. To simplify a complex array of components, modelling for the Dashboard is categorised under five main headings: scalar, land-use, resource-use, temporal and population. The scalar and land-use categories are both spatially derived, the resource and population parameters relate to societal characteristics and the temporal parameters affect potential future time-frames.

2.1. Scalar parameters

Carrying capacity assessment, by definition, necessitates the delineation of geographic boundaries within which the population is relatively self-reliant for their resources. Politically dictated delineation is a common method of achieving such small-scale boundaries, with the carrying capacity modelling of the Douglas (Banfield, 2000) and Noosa Shires (Summers, 2004) highlighting this approach. Politically defined boundaries are susceptible to alteration, complicating future analysis (Lane, 2010) and may not define areas of land best suited to supporting a relatively self-sufficient population. Consequently, topographically defined boundaries are more likely to offer long-term and practical landscape delineation. In Australia, catchment areas defined by watersheds are being recognised as useful divisions of the landscape, particularly in addressing land degradation problems (Williams and Walcott, 1998).

While aiming to provide modelling at a number of concurrent geographic scales, ultimately, the key determinant for landscape boundary delineation for the Dashboard model was the availability of Australian Bureau of Statistics (ABS) agricultural yield data (Australian Bureau of Statistics, 2006b). Given that this data is pivotal in the estimation of carrying capacity, the Dashboard's scale of analysis was matched to that of the ABS datasets. Currently ABS agricultural production data is collected by a nation-wide census (Australian Bureau of Statistics, 2008a) every five years (e.g. 2001, 2006, and 2011) while representative sample surveys (Australian Bureau of Statistics, 2011b) are used on a yearly basis between censuses. Regional Natural Resource Management Area (NRM) data is a recent addition to ABS's datasets. Although state and territory boundaries influence NRM delineation, they are generally based on catchments or bioregions, so are well suited to carrying capacity analysis. The 52 NRMs, together with seven states and Australia as a whole make up the 60 zones incorporated into Dashboard modelling (Fig. 1).

In accord with Peters et al. (2007) who utilised five years of agricultural data for their carrying capacity assessment of New York State (1999–2003), modelling for the Dashboard used five years of ABS agricultural data (2006–2010) in order to derive average yield values for each crop. Given that yield data can fluctuate from year to year, the approach of Peters et al. (2007) to average a number of years of production provided a reliable methodology for accommodating such variability. However, it is important that the years used to gauge this average are in fact indicative of likely future yields. Given that climatic conditions, particularly rainfall, are key determinants of agricultural production (Wimalasuriya et al., 2008), an analysis of climatic data was undertaken for the years 2006–2010 to ascertain if they were typical. Records from the Australian Bureau of Meteorology (Table 1) show that this period was in fact reasonably representative of the long-term average national rainfall.

The array of yield data, primarily from ABS sources, for the 60 zones and 134 resource commodities (e.g. apples, wheat, and peanuts) resulted in a corresponding 8040 pieces of 5-year average yield data, all calibrated to a common measure (tonnes per hectare).

2.2. Land-use parameters

Land availability according to its usage type is a key determinant of a region's carrying capacity. The Dashboard modelling accommodates five types of land-use: cropping, pasture,