Journal of Environmental Management 111 (2012) 279–286

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

A simplified ecological footprint at a regional scale

Matthew E. Hopton [a,*], Denis White [b]

[a] United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Sustainable Technology Division, Sustainable Environments Branch, Cincinnati, OH, USA

[b] United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects, Western Ecology Division, Corvallis, OR, USA

A R T I C L E I N F O

Article history:
Received 8 September 2010
Received in revised form
7 June 2011
Accepted 7 July 2011
Available online 26 October 2011

Keywords:
Ecological footprint
Biocapacity
Sustainability
Regional assessment

A B S T R A C T

We calculated an Ecological Footprint Analysis (EFA) at a regional scale. EFA captures the human impact on the environmental system by identifying the amount of biologically productive land necessary to support a person's level of consumption and waste generation. EFA is a commonly used metric of sustainability because it is easy to conceptualize and the calculation is relatively straightforward. Utilizing free, readily available data, we calculated an EFA for a region in southern Colorado. Gathering existing data at a regional scale is difficult because data are often collected at national or state levels. The lack of data is further confounded by the fact that data are often collected at intervals greater than one year. Variables that were missing data for certain years were estimated using linear interpolation. Data not available by county were scaled to the region from state or national level data. Thirty-five variables from 1980 to 2005 (26 years) were collected and used to calculate a time-dependent EFA and the resulting trend was visually examined. The available biocapacity in the region did not decrease during the period, but per capita biocapacity decreased due to population growth. Per capita biocapacity was at a period high of nearly 41 ha per person (ha/ca) in 1980 and steadily decreased to a low around 31 ha/ca in 2005. Ecological footprint remained constant over the 26-year period, varying from a low of 5.1 ha/ca in 1997 to a high of 5.5 ha/ca in 1985. A steady ecological footprint combined with a decreasing per capita biocapacity, implies the ecological reserve is decreasing and, thus, the region is moving away from sustainability. Although per capita consumption did not increase substantially during the 26 years, more people are drawing on a fixed quantity of resources. Our methodology is a simplified approach to EFA and does not follow standards that are currently being established. Adhering to the suggested standards would require obtaining data sets that consist entirely of national data. The national level data are replaced with data specific to the geographic area under examination when they are available. Although national data may represent the sub-national region under study, that substitution requires further investigation, especially in large, geographically and culturally varied nations such as the US. Nevertheless, this simplified methodology provides enough detail that stakeholders can identify areas of the system on which to focus attention to improve sustainability of the system.

1. Introduction

Ecological Footprint Analysis (EFA), more appropriately called environmental footprint (Eaton et al., 2007) analysis, is a commonly used metric of sustainability because it is straightforward in theory and easy to conceptualize. EFA attempts to capture human impacts on the regenerative capacity of an environmental system (Chambers et al., 2000) by identifying the amount of bioproductive land required to support a person's average annual consumption and waste production (Wackernagel and Rees, 1996). Since Wackernagel and Rees (1996) introduced it, EFA methodology has been continually evolving as researchers have attempted to improve the methodology (e.g., Lenzen and Murray, 2001; Luck et al., 2001; Medved, 2006; Monfreda et al., 2004; Wackernagel, 2009). In general, EFA categorizes bioproductive land into one of six types: energy, arable, forest, pasture, built, and sea. Land that does not meet one of these six categories is deemed non-productive and is not included in EFA accounting (Chambers et al., 2000). Furthermore, as part of the methodology, twelve percent of the land used to be set aside for biodiversity (Chambers et al., 2000, but see Noss and Cooperrider, 1994 for discussion of the appropriate percentage), but is no longer practiced (Global Footprint Network,

* Corresponding author. Present address: US EPA/ORD/NRMRL (MS 443), 26 W MLK Dr., Cincinnati, OH 45268, USA. Tel.: +1 513 569 7718; fax: +1 513 569 7677.
E-mail address: Hopton.Matthew@epa.gov (M.E. Hopton).

0301-4797/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.jenvman.2011.07.005

2009). EFA calculates the supply (biocapacity) of land available to support a population and the demand (ecological footprint) a population places on these six land categories by estimating how much land is being used to support the population. The biocapacity in a given region is compared to the ecological footprint of the population by subtracting demand from supply. Examining this balance sheet over time will reveal if there is an ecological reserve or deficit and if a population is moving toward or away from sustainability as defined by the EFA method.

This metric has been applied to numerous systems. For instance, EFA accounting has been conducted at global (e.g., WWF 2008), national (e.g., Erb, 2004; Lammers et al., 2008; Lenzen and Murray, 2001; Medved, 2006; Wackernagel and Yount, 1998; Wackernagel et al., 1999, 2004a; WWF, 2008), regional (e.g., Graymore et al., 2008; Huang et al., 2007; Pulselli et al., 2008; Zhao et al., 2008), and municipal (e.g., Collins et al., 2006; Scotti et al., 2009; Wood and Garnett, 2009) spatial scales. EFA has been conducted at industry or product level (e.g., wine – Niccolucci et al., 2008, university campus – Li et al., 2008, tourism - Patterson et al., 2007), and individual or household levels (e.g., Chambers et al., 2000) as well. Some researchers have conducted EFA analysis by comparing and contrasting multiple spatial scales (e.g., Lenzen and Murray, 2003; Luck et al., 2001).

We conducted conventional EFA accounting using the compound approach as introduced by Wackernagel and Rees (1996) and expanded by Chambers et al. (2000) because it is more inclusive and robust compared to the component-based approach (Chambers et al., 2000). In general, an EFA calculation requires four sets of variables: 1) the size of the population in the region of interest, 2) the amount of consumables in various categories used per individual, 3) the amount of energy of various types consumed per individual, and 4) the amount of biologically productive land, as defined by EFA, available in the region of interest. The consumption variables include the biotic resources such as meat, dairy, fruits, and vegetables. Consumption is usually calculated by adding the quantity of imported consumables to the amount produced in the system under study and subtracting the amount exported from the system. The remaining quantity is assumed to be consumed by the population (Chambers et al., 2000; Wackernagel and Rees, 1996). The energy balance element of the calculation considers both locally generated energy and, if known, energy embodied in traded goods (Chambers et al., 2000; Wackernagel and Rees, 1996). Primary fuel consumption is adjusted for carbon content and used to derive the amount of forested land necessary to sequester the resulting CO_2 emissions (Chambers et al., 2000). Lastly, the area (in hectares) of each of the six land categories of biologically productive land is measured to calculate the biocapacity. Each of these sets of variables is used in one of three accounting type ledgers to determine the supply (biocapacity) and demand (ecological footprint) of the environmental system (Chambers et al., 2000; Wackernagel and Rees, 1996).

Note that we deviate slightly from the naming convention commonly employed in an EFA (e.g., Chambers et al., 2000; Wackernagel and Rees, 1996) in an attempt to make the text easier to follow. It is typical for the population's ecological footprint to be denoted with *EF* and the per capita ecological footprint identified with *ef*. To be consistent with this format, we have deviated from the convention by representing the population's biocapacity (typically denoted as BC_p) as *BC* and the per capita biocapacity as *bc* (compared to the frequently used BC_c). The amount of land area appropriated per capita (aa_i) for each major consumption item (c_i) is estimated by dividing c_i by the population of the region (*N*). The average demand or ecological footprint per capita (*ef*) is computed by summing all the ecosystem areas appropriated (aa_i) by all purchased items in the annual consumption of goods and services. Each item is converted into a footprint value, represented as hectares per capita (ha/ca). Often these areas are adjusted to express a world average and are converted to global hectares (e.g., Global Footprint Network, 2009). An ecological footprint (*EF*) for the entire system or region is calculated by multiplying *ef* by the population size (*N*). The biocapacity for the population (*BC*) is the number of hectares of each of the six bioproductive land categories in the area under study. A per capita biocapacity (*bc*) is calculated by dividing the region's *BC* by the population of the region.

An ecological balance is calculated by subtracting *EF* from *BC* to determine if there is an ecological deficit or reserve. If *EF* exceeds *BC*, an ecological deficit exists and the system is considered unsustainable regionally. Conversely, the system is considered sustainable if there is an ecological reserve ($ef < bc$ or $EF < BC$). However, because we question the accuracy of identifying a system as sustainable (see Heberling and Hopton, 2012), we identify a system's movement toward or away from sustainability by examining the ecological balance. A system is considered moving away from sustainability if the ecological reserve is decreasing or, if there is an ecological deficit, the deficit is increasing through time.

2. Materials and methods

The data needs of traditional EFA accounting are relatively straightforward, although they can be intensive. EFA requires food consumables such as meat, dairy, fish, fruits and vegetables, animal feed, roots and tubers, and pulses (i.e., legumes), and per capita energy consumption. This level of detail creates difficulty when analyzing sub-national regions because it is often difficult to obtain data for local areas, especially parts of states. To overcome this quandary, researchers often approximate values for many of the variables or use values from disparate years (e.g., Bagliani et al., 2008). This occurs because data on consumption patterns are more likely to be collected for national and even state level rather than for smaller political units. Thus, depending on the data required, we were limited by data availability due to the regional nature of our study and the requirement for 26 consecutive yearly (1980–2005) values. Rather than calculating a national EFA and scaling it to the region by multiplying by the population of the region, we decided to reduce the number of variables to those that were necessary to calculate the EFA for the region. Because our goal was to calculate a simplified ecological footprint for the region and not necessarily a more detailed ecological footprint as calculated in Wackernagel et al. (2005), we attempted to restrict our variables to data specific to the region (i.e., county data). However, because data for some essential components of a footprint analysis were not available at the individual or county level, we had to utilize data that were not specific to the region. When necessary, data that were available only at the state or national level were scaled to the region of study based on per capita rates in the larger systems (Table 1). Data that were reported less frequently than annually were linearly interpolated to fill missing years.

2.1. Data, variables, and sources

We selected variables easily obtained and freely available, thereby enabling a calculation that could be undertaken by virtually any entity interested in conducting its own EFA. Most variables were recorded as reported from the original data source (Table 1). However, biocapacity was calculated for some land categories, rather than using a reported value from the data. Specifically, arable land was reported for each county in the National Agricultural Statistics Service (NASS) report at 5-year intervals (NASS, 1984, 1989, 1994, 2009a, 2009b). Pasture was estimated using the NASS reports by subtracting the hectares of arable land from total

Table 1
Scale and source of data for the variables used to calculate ecological footprint for the SLB. Data available at scales other than county were scaled to the county level based on population levels in each county for a given year.

Scale	Variable	Purpose/Notes	Source	Website	Specific data link
National					
	Consumption of animal products (lbs/capita)	Includes bovine, buffalo, sheep, goat, non-bovine, milk, cheese, butter, eggs, and fish categories	USDA Economic Research Service	www.ers.usda.gov	www.ers.usda.gov/Data/FoodConsumption/FoodAvailQueriable.aspx
	Cereal consumption (lbs/capita)	Includes cereals, wheat, and maize categories	USDA Economic Research Service	www.ers.usda.gov	www.ers.usda.gov/Data/FoodConsumption/FoodAvailQueriable.aspx
	Fruit & vegetable consumption (lbs/capita)	Includes vegetables, fruit, animal feed, roots, tubers, and pulses consumption	USDA Economic Research Service	www.ers.usda.gov	www.ers.usda.gov/Data/FoodConsumption/FoodAvailQueriable.aspx
State					
	Fossil fuel (Gj/year)	Includes coal, natural gas, and petroleum consumption	Energy Information Administration	www.eia.doe.gov	www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=COLORADO
	Nuclear electric consumption (million kWh)		Energy Information Administration	www.eia.doe.gov	www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=COLORADO
	Hydro-electric consumption (million kWh)		Energy Information Administration	www.eia.doe.gov	www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=COLORADO
	Wood and waste consumption (trillion BTU)		Energy Information Administration	www.eia.doe.gov	www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=COLORADO
County					
	Population (persons)		Bureau of Economic Analysis	www.bea.gov	www.bea.gov/regional/reis/default.cfm?selTable=CA1-3&section=2
	Land area (ha)		US Census Bureau	www.census.gov	quickfacts.census.gov/qfd/states/08000.html and for US
	Built land (ha)	Census-designated places based on 1990 and 2000 data	US Census Bureau	www.census.gov	www.census.gov/geo/cob/bdy/pl/pl90e00/pl08_d90_e00.zip
	Forest including deforestation (ha)	1987, 1997, 2002 and treated as a constant	USDA Forest Service	www.fia.fs.fed.us	www.fia.fs.fed.us/tools-data/spatial
	Arable land (ha)	1982, 1987, 1992, 1997, 2002, 2007	USDA Agricultural Statistics	www.agcensus.usda.gov	http://www.agcensus.usda.gov
Calculated					
	Pasture (ha)	Total farmland minus arable land; values reported as "D" in report are listed as values from adjacent survey	USDA Agricultural Statistics	www.agcensus.usda.gov	
	Sea (ha)	No sea category in biocapacity in SLB			No sea category in biocapacity in SLB
	Forest harvest (MBF)		1. USDA Forest Service	1. Data generated by Bruce F. Short, Biological Resources Staff Officer, San Luis Valley Public Lands Center	1. Bruce F. Short, Biological Resources Staff Officer, San Luis Valley Public Lands Center, 1803 West Highway 160, Monte Vista, CO 81144, bshort@fs.fed.us, phone (719) 852-6225
			2. USDA Natural Resources and Conservation Service	2. National Resources Inventory 2001 Annual NRI, Urbanization and Development of Rural Land, July 2003 (and see www.nrcs.usda.gov/technical/land)	2. USDA, Natural Resources and Conservation Service, National Resources Inventory 2001 Annual NRI, Urbanization and Development of Rural Land, July 2003 (and see www.nrcs.usda.gov/technical/land)
	Energy land (ha)				Based on CO_2 production and subtracted from forest land. Thus, biocapacity is zero.
	Non-productive land (ha)	Total land area minus the sum of EF land area			Total land area minus the sum of EF land area

farmland. Forest was estimated from United States Department of Agriculture (USDA) Forest Service data and subtracting the amount of harvested forest for each county. Built land was obtained from the US Census Bureau from the land area reported for each Census-designated place in each county. Because the region is land-locked and there is minimal surface water in this high desert, there was no bioproductive area for the sea category. Lastly, energy land is the amount of forested land required to sequester CO_2 produced from energy consumption. This value was 0 ha on the supply side of the equation because it is not a supply, *per se*. Energy land is obtained by subtracting from forest the area necessary to sequester CO_2 and, therefore, does not exist before CO_2 is produced.

Energy consumption data for the State of Colorado were obtained from the Department of Energy's Energy Information Administration (EIA; EIA, 2006). We assumed that EIA data calculated on a per capita usage and multiplied by the population of the SLB were sufficient to estimate the energy consumption. We justified this assumption by comparing coal and natural gas consumption in the SLB to their consumptive use for the State of Colorado. SLB regional consumption differed by approximately 1.8% (coal) and 0.33% (natural gas) of estimated consumption based on EIA state use (USEPA, 2010). In addition, we estimated propane use based on heating degree days in the SLB and were within 7.8% of propane consumption based on EIA state use (USEPA, 2010). We decided the more readily available EIA data adequately represented consumption for these sources. Using EIA data for Colorado, consumption was calculated as per capita for the state and included coal, natural gas, petroleum, nuclear, hydroelectric, and wood and waste categories. An added benefit of using EIA data, the petroleum category includes motor fuel, thereby capturing energy consumption for transportation in the SLB. Energy consumption was converted to area of forest and the corresponding energy land required for CO_2 absorption, following Chambers et al. (2000).

Per capita food consumption for the US, from USDA Economic Research Service (USDA-ERS, 2009), was used to estimate food consumption for the region under study. Because data were already in quantity consumed, it was not necessary to subtract exports from imports and production to estimate consumption. Each food item was assigned to an appropriate land category and a per capita footprint was calculated for each food item by dividing the kg consumed by the global yield for that kind of land and dividing the result by the population of the region. The footprint for each land category was summed to produce the amount of land required to support levels of consumption of the population of the region.

Global yields were used because it is unlikely that most items consumed in the region were produced in the region. Global yields were taken from Chambers et al. (2000: 70–73) and were assumed to be constant for all years. Ideally, global yields and conversion factors (see below) would be calculated for each year and would result in a better estimate of the EFA for a region. However, more accurate annual values are unlikely to have a large influence on the results because it is unlikely they would change very much on a year-to-year basis or during the length of our study period. Another compromise in our analysis is that many items are not included in this EFA, for reasons discussed above.

Many studies suggest converting footprints into global hectares (gha) in order to allow comparison of EFAs between systems (e.g., Wackernagel et al., 2004b; Wiedmann and Lenzen, 2007). A global hectare is "normalized to the area-weighted average productivity of biologically productive land and water in a given year" (Global Footprint Network, 2008). In other words, a global hectare is the global average of productivity (i.e., kg produced) per 1 ha of land or water and facilitates comparison between EFAs for different nations. Equivalence factors and yield factors are necessary to convert actual ha into gha and they can be obtained from the literature for certain years (e.g., Chambers et al., 2000; Wackernagel and Yount, 1998), but a complete set is difficult to obtain without additional expense. To overcome this lack of factors, we recorded values from Chambers et al. (2000) and McIntyre et al. (2007) for alternative calculations using gha. However, our goal was not to produce a mechanism by which regions can be compared but rather to enable a region to analyze their movement toward or away from sustainability and manage accordingly. Moreover, because the purpose of our study was practical, rather than academic in nature, we decided to use local hectares as the working unit (in actuality, our *ef* values were in world average hectares because much of what the population of a typical region in the US consumes likely comes from outside the local area). Lastly, as an *a priori* comparison, we conducted an EFA for the US to compare the methodology employed for SLB, using the same variables and data sources (Table 1).

3. Results

We were able to assemble 26 years (1980–2005) of data consisting of 35 variables (Table 1) and to estimate biocapacity and ecological footprint for those years. Biocapacity shows a decreasing trend for the 26-year period, beginning at a peak of nearly 41 ha per capita (ha/ca) in 1980 and decreasing to around 31 ha/ca in 2005 (Fig. 1a). Ecological footprint was relatively flat, varying from a low of 5.10 ha/ca in 1997 to a high of 5.5 ha/ca in 1985 (Fig. 1a). Subtracting *ef* from *bc* provides the ecological balance and reveals the SLB had an ecological reserve, although it was declining, during the period examined. The reserve was at a period high of 35.08 ha/ca in 1980 and declined steadily through 2005 when the ecological balance was 25.93 ha/ca.

Biocapacity for the US shows a decreasing trend for the 26-year period, peaking at more than 4.1 ha/ca in 1980 and steadily decreasing to nearly 3.1 ha/ca in 2005 (Fig. 1b). Ecological footprint increased during the same period, with a period low of nearly 4.8 ha/ca in 1982 and peaking at 5.6 in 2005. The ecological balance indicates the US is in deficit during the entire 26-year period (Fig. 1b).

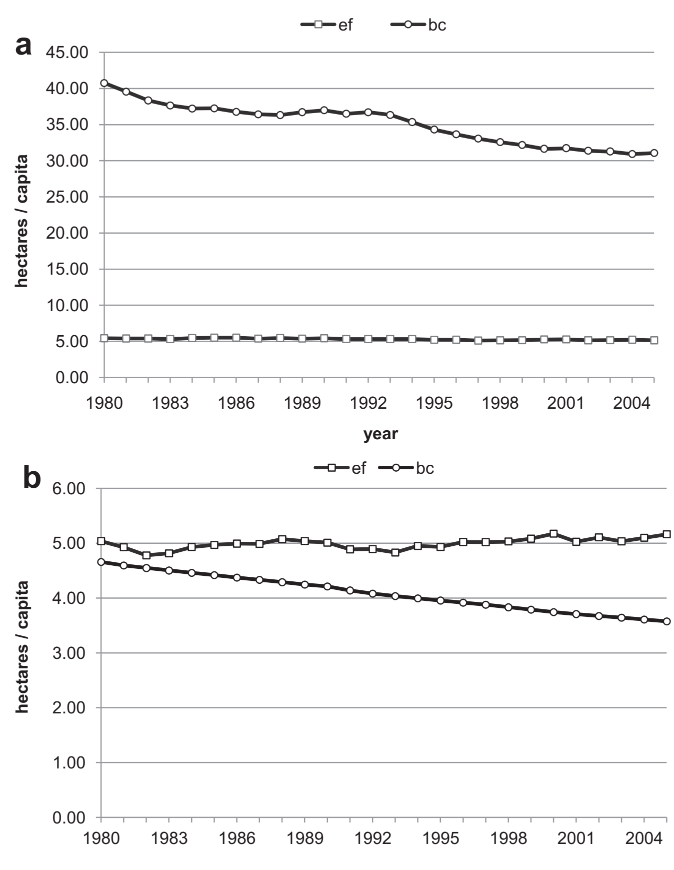

Fig. 1. Per capita biocapacity (*bc*) compared to per capita ecological footprint (*ef*) for 26 years in the San Luis Basin (a) and United States (b).

4. Discussion

4.1. Biocapacity (supply)

Although the SLB appears to have an abundance of biocapacity, this is a result of low population density and large area of pasture and arable lands. These two land types typically increase the human carrying capacity of a system and are heavily weighted in EFA as is evident in the high productivity values they are assigned in the methodology. Moreover, an abundance of forest is available to sequester CO_2 and provide renewable wood products. However, it must be remembered the SLB is part of a larger system and resources produced in the region help support that larger system, including the rest of the US and world.

The decrease in *bc* seems to be due, primarily, to population growth in the region. An increasing population draws on a relatively fixed supply of bioproductive land in the SLB, resulting in a decreasing amount of bioproductive land per person. Specifically, biocapacity of forest declined from 22.93 ha/ca to 18.56 ha/ca and pasture declined from 12.13 ha/ca to 7.17 ha/ca (Fig. 2). Arable land was variable during the 26-year period, starting at 5.67 ha/ca in 1980, peaking in 1990 at 5.96 ha/ca, declining to 5.13 ha/ca in 2000, and rising to 5.33 ha/ca in 2005 (Fig. 2). During this period, built land increased slightly during the 26 years (from 0.12 ha/ca to 0.15 ha/ca; Fig. 2). In absolute terms, the number of hectares of arable land increased, the hectares of forest remained constant, and the hectares of pasture decreased in the SLB region during the 26 years. The results suggest the overall decline in *BC* for the region was minimal, especially when compared to the decline in *bc* (Fig. 1a). Hence, as the population size increased, more people were drawing on the same number of hectares of resources, resulting in fewer resources available per person. This indicates the decrease in biocapacity of forest and pasture land categories were due to population growth and the *bc* available from these land categories. Conversely, although biocapacity of arable land was variable, there was an overall decrease (Fig. 2), indicating an increase in the supply of total hectares of arable land in the region that did not quite keep pace with population growth. Lastly, the amount of built land increased from 4572 ha in 1980 to an estimated 7350 ha in 2005. This is an increase of more than 60% and represents land that typically, according to EFA accounting, was agricultural land. In summary, the overall decrease in biocapacity in the SLB in these calculations is largely due to population increase. If the region were a self-reliant, closed system, the carrying capacity of the system is far from reached and many more individuals could be supported. However, because the SLB provides resources to support the larger system, and draws on resources from outside the region (i.e., it is not a closed system), the excess biocapacity should be evaluated with that in mind.

4.2. Ecological footprint (demand)

Unlike the US (e.g., Wackernagel and Yount, 1998; WWF, 2008), the average ecological footprint of individuals in the SLB decreased slightly (with some variation) during the time analyzed (Fig. 1), although we have not figured out how to estimate confidence intervals (see USEPA, 2010). However, although *ef* showed a general decrease, the total EF for the SLB increased slightly likely due to an increase in population in the SLB.

Examining the individual land categories and the energy footprint can help identify components responsible for trends (Fig. 3). Overall, demand placed on each of the land categories remained relatively constant during the 26-year period, except for forest (Fig. 3). Per capita demand on pasture, arable, built, sea, and energy lands have remained stable, as consumption did not increase dramatically during the period. However, during the same period the area of forest remained constant while forest harvest increased from 23 973 million board feet (MBF) in 1980 to 35 251 MBF in 1989 and has been declining since to 4444 MBF in 2005. This coupled with the increase in population resulted in a decrease in area of forest available per capita in the region.

Focusing on energy land, there was a general increase in total energy consumption from fossil fuels for the region. However, although there was some variability, per capita energy footprint revealed a slight decline for coal, natural gas, and petroleum consumption (slope = −0.0021, −0.002, and −0.004, respectively) in the 26-year period; however, assumptions in our methods make these estimates uncertain. Energy consumption from nuclear and hydroelectric was nonexistent. Wood and waste usage, however, increased during the first 6 years of the period analyzed and has been decreasing both per capita and for the population since 1986 (Fig. 4). The US Census Bureau provides a category of number of homes using wood for heating and this value for the SLB decreased from 1990 to 2000 census from 3750 to 2327 homes (US Census Bureau, 1990, 2000), suggesting that such a reduction is realistic.

4.3. US ecological footprint analysis

Because EFAs usually reveal patterns for the US where ecological deficit (*ef* > *bc* or *EF* > *BC*) is the rule, as demonstrated by the

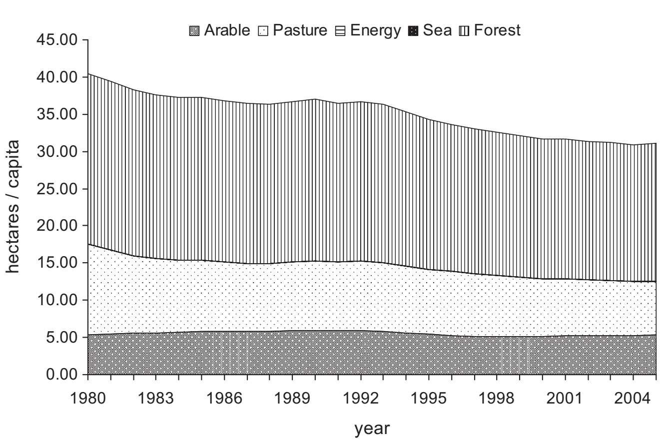

Fig. 2. Available biocapacity (*bc*) for the five footprint land categories over a 26-year period in the San Luis Basin, Colorado. Note that built-up land has no biocapacity and is not included in the figure.

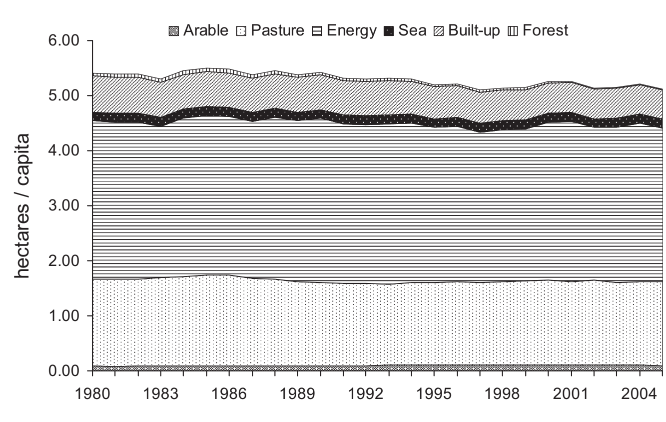

Fig. 3. Ecological footprint (*ef*) and the demand placed on each of the six land categories over a 26-year period in the San Luis Basin, Colorado.

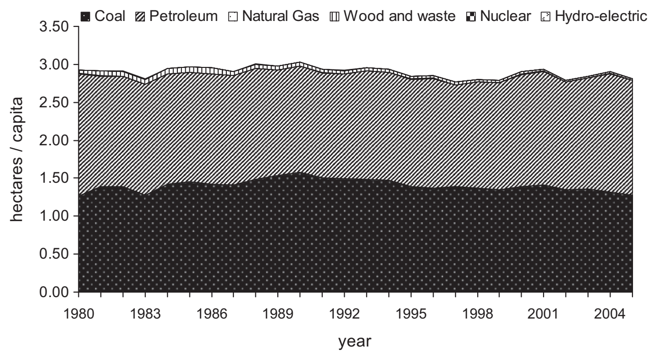

Fig. 4. Energy consumption (ha per person) by major energy source over a 26-year period in the San Luis Basin, Colorado.

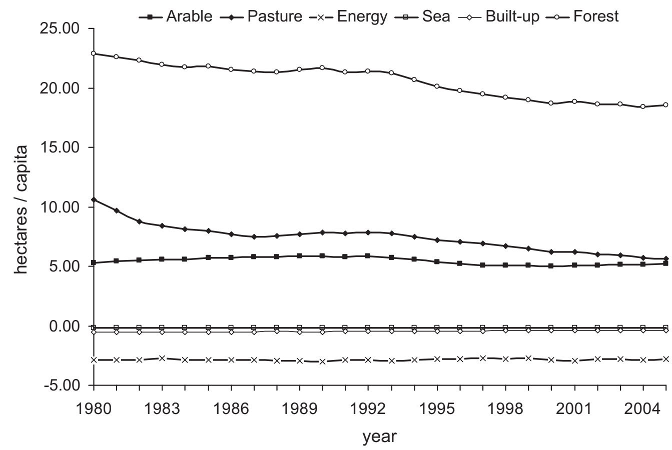

Fig. 5. Ecological balance (ha/ca) of the different land categories in the SLB. Balance equals biocapacity per capita minus the ecological footprint for the SLB region. Positive values represent a surplus of biocapacity and negative values represent a deficit of biocapacity.

analysis for Utah (McIntyre et al., 2007), and because the analysis for the SLB reveals an ecological reserve, we decided to conduct an EFA for the US to test the methodology employed for SLB, using the same variables and data sources (Table 1). This analysis indicated the US has an ecological deficit and ecological footprint had already exceeded biocapacity by 1980. EFAs for the US usually identify an ecological deficit occurring around 1970 (e.g., Global Footprint Network, 2009). The differences in the results between US and SLB increased our confidence that our methodology captured trends in the SLB, rather than merely duplicating that of the larger system. Note that conversion of US land areas to gha does not show an ecological deficit, but does indicate a trend away from sustainability. This discrepancy is likely due to missing variables on the demand side of the equation.

4.4. Global hectares

Converting ha into gha increases *ef* by less than 10%, or about 0.5 ha and available *bc* more than doubles. For example, in 1980 the *ef* was 5.41 ha (5.94 gha) and *bc* was 40.61 ha (88.06 gha). The ecological reserve was 35.20 ha (82.13 gha). In 2005 *ef* was 5.13 ha (5.51 gha), *bc* was 31.21 ha (72.37 gha), and the balance was 26.08 ha (66.86 gha). Of course, the conversion from ha to gha would be better using year specific yield and equivalence factors, but the difference likely would be minor. For example, Lammers et al. (2008) report an equivalence factor for energy land of 1.36 in 1980 and 1.38 in 2003 in their time-series analysis of Ireland. However, our interest was in trends (i.e., is the system moving toward or away from sustainability), not necessarily the actual value and may not be worth the added expense or difficulty. Nonetheless, we think using ha is acceptable if one is not comparing between different regions.

4.5. Examination of sustainability

Whether using ha or gha, our analysis suggests the SLB is moving away from sustainability, on both a per capita basis (Fig. 1a) and a population basis. Although the *ef* remained relatively flat during the 26 years (which would suggest the SLB was not moving away from sustainability), available *bc* decreased because of increasing population size. These trends reveal a decreasing ecological reserve (the space between the two lines is decreasing; Fig. 1a). The decrease in the ecological reserve over the 26 years was amplified on a population level examination. The *EF* was increasing and *BC* was decreasing through time (Figs. 1a and 5). This was evident in the individual land categories as well. For example, per capita food consumption (e.g., meat, cereal, fruit and vegetable, and fish) increased during the period, requiring more bioproductive land to satisfy the consumption and the amount of available arable and pasture land per capita decreased. The overall result was a decreasing surplus of bioproductive land (Fig. 1a) that was available to support the population in the SLB. If the trend continues, *ef* will eventually overshoot *bc*, resulting in an ecological deficit.

Although our analysis suggests the *ef* is relatively low, one potential flaw was the large number of missing variables that represent embodied energy in goods and services. For example, Utah Vital Signs reported over 2 gha/ca were required to meet the consumptive levels for Utah in 1990 and about 1.5 gha/ca in 2003 (McIntyre et al., 2007). When compared to the food and energy consumption for Utah in 1990 (5.26 gha/ca) and 2003 (5.82 gha/ca), it is not an inconsequential quantity. However, these variables do not represent such a large part of EFA that they alter the trends captured by food and energy consumption. It is important to note that a portion of data in that report came from both US and Utah consumption rates and may or may not accurately represent consumptive levels for the Utah population.

The trends in the SLB were not unexpected. Because of the economic, environmental, and social characteristics of the SLB, we did not expect a substantial amount of change to occur during the 26 years examined. The SLB is an agricultural-based region and has many traits that accompany this type of society (e.g., San Luis Valley Development Resources Group, 2007). Moreover, the SLB functions as a resource exporting region, providing much of its bioproductive land and resources to support larger systems, which include those of Colorado, the US, and the world (San Luis Valley Development Resources Group, 2007).

4.6. Strengths and weaknesses of methodology

Although there were several methodologies used early on in EFA accounting, recently there has been a push to standardize the methods (e.g., Global Footprint Network 2009; Wackernagel, 2009). Specifically, a couple of groups have proposed their methodology as a standard (e.g., Kitzes et al., 2009 - Global Footprint Network, Best Foot Forward; Venetoulis and Talberth, 2008 - Redefining Progress) and a number of organizations are following these standards. Unfortunately, these groups do not publish their complete methodologies or data, in part because they provide a commercial EFA calculating service. Because the groups do not provide the information free of charge or make it readily available, it is difficult to conduct an EFA with limited budgets which was one of our goals. Moreover, this standardization has some drawbacks that make the calculation more difficult than it need be. First, the standard recommends starting with national level data and replacing with data specific to the geographic area under examination when they are available. However, a subsystem or region may not reflect a national average, or levels of consumption may not be typical and this could be concealed using national data. Thus, scaling these variables to the population of the subsystem may not adequately represent the subsystem. Second, these groups do not make the factors that are necessary for conversion to a common normalized unit (gha) readily available. Our goal in this project was not to create a "better" or more accurate EFA; rather, it was to make the methodology more accessible and usable for the end user while still being adequate for sustainability analysis.

5. Conclusions

The simplified EFA conducted captured a trend indicating the SLB was moving away from sustainability. There are a number of strengths and weaknesses to the methodology we employed. The greatest strength of our methodology is the use of readily available data that makes the methodology available to any entity interested in computing their ecological footprint to determine if their system is moving toward or away from sustainability. The greatest weakness of our methodology may be the exclusion of potentially important variables. The lack of data at sub-national scales resulted in the exclusion of well over 100 variables that are typically included in a traditional footprint account. All of the variables usually included in the embodied energy component, as well as some other variables, were excluded. In addition, the footprint methodology in general does not take into account exports of natural resources that may lower the biocapacity. Another limitation is the lack of data for each year of our study. For example, we had data at five-year intervals for agricultural production from the Census of Agriculture and ten-year intervals for population and housing variables from the Decennial Census of Population and the census years did not align (i.e., decennial censuses were 1980, 1990, and 2000 whereas the agricultural censuses were 1978, 1982, 1987, 1992, 1997, and 2002). We used linear interpolation to estimate the values for missing years. Because of these imputations, we were limited in performing statistical analysis on trends in the results (e.g., a Mann–Kendall test for trends or time-series analysis). Such interpolation would bias the trend; especially if a measure of uncertainty was available and we could statistically test the trend (USEPA, 2010). Nonetheless, after calculating the ecological footprint for the US using the same variables employed in our study, we are confident the methodology does an acceptable job capturing trends in an EFA for a region, which was a central goal of this project. Although important, the embodied energy component of a typical ecological footprint account generally accounts for less than the food and energy consumption components. For instance, Lammers et al. (2008) found that less than 1 ha per capita was from the embodied energy component. These weaknesses, then, need to be balanced with the availability of the method and its relative ease of use. However, there is enough detail in the account that stakeholders can identify areas of the system on which to focus attention to improve sustainability of the system.

Acknowledgments

The authors thank J. Ashby, M. Britten, F. Bunch, A. Hutchinson, S. Johnson, S. Rebain, R. Sparks, J. Stump, A. Valdez, S. Vandiver, R. Weston, and M. Young for directing us to or providing data for the calculations made here. We thank several people for providing data, including K. Worthington (Xcel Energy), J. Waugh (Rural Electric Co-op), B. Short (USDA-FS), and P. Magee (San Luis Valley GIS/GPS Authority). This manuscript was improved by helpful comments from B. Bakshi, M. Luck, D. Stern, D. Tilley, and three anonymous reviewers. Although the research described in this article has been funded wholly (or in part) by the US Environmental Protection Agency, it has not been subjected to Agency level review. Therefore, it does not necessarily reflect the views of the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

Bagliani, M., Bravo, G., Dalmazzone, S., 2008. A consumption-based approach to environmental Kuznets curves using the ecological footprint indicator. Ecological Economics 65, 650–661.

Chambers, N., Simmons, C., Wackernagel, M., 2000. Sharing Nature's Interest: Ecological Footprints as an Indicator of Sustainability. Earthscan Publications, Ltd., London, 185 pp.

Collins, A., Flynn, A., Wiedmann, T., Barrett, J., 2006. The environmental impacts of consumption at a subnational level. Journal of Industrial Ecology 10, 9–24.

Eaton, R.L., Hammond, G.P., Laurie, J., 2007. Footprints on the landscape: an environmental appraisal of urban and rural living in the developed world. Landscape and Urban Planning 83, 13–28.

EIA (Energy Information Administration), 2006. State Energy Data 2006: Consumption. State Energy Data System. http://www.eia.doe.gov/emeu/states/_seds.html (Last accessed 17.03.08.).

Erb, K.-H., 2004. Actual land demand of Austria 1926–2000: a variation on ecological footprint assessments. Land Use Policy 21, 247–259.

Global Footprint Network, 2008. The Ecological Footprint Atlas 2008, Version 1.0. Available online at. Global Footprint Network. http://www.footprintnetwork.org (Last accessed 21.07.09.).

Global Footprint Network, 2009. Ecological Footprint Standards 2009. Available at online at. Global Footprint Network. www.footprintstandards.org (Last accessed 09.05.11.).

Graymore, M.L.M., Sipe, N.G., Rickson, R.E., 2008. Regional sustainability: how useful are current tools of sustainability assessment at the regional scale? Ecological Economics 67, 362–372.

Heberling, M.T., Templeton, J.J, Wu, S., 2012. Green net regional product for the San Luis Basin, Colorado: an economic measure of regional sustainability. Journal of Environmental Management 111, 287–297.

Huang, Q., Wang, R., Ren, Z., Li, J., Zhang, H., 2007. Regional ecological security assessment based on long periods of ecological footprint analysis. Resources. Conservation and Recycling 51, 24–41.

Kitzes, J., Galli, A., Bagliani, M., Barrett, J., Dige, G., Ede, S., Erb, K., Giljum, S., Haberl, H., Hails, C., Jolia-Ferrier, L., Jungwirth, S., Lenzen, M., Lewis, K., Loh, J., Marchettini, N., Messinger, H., Milne, K., Miles, R., Monfreda, C., Moran, D., Nakano, K., Pyhälä, A., Rees, W., Simmons, C., Wackernagel, M., Wada, Y., Walsh, C., Wiedmann, T., 2009. A research agenda for improving national ecological footprint accounts. Ecological Economics 68, 1991–2007.

Lammers, A., Moles, R., Walsh, C., Huijbregts, M.A.J., 2008. Ireland's footprint: a time series for 1983–2001. Land Use Policy 25, 53–58.

Lenzen, M., Murray, S.A., 2001. A modified ecological footprint method and its application to Australia. Ecological Economics 37, 229–255.

Lenzen, M., Murray, S.A., 2003. The ecological footprint – issues and trends. ISA research Paper 01–03, the University of Sydney integrated sustainability analysis, 27 pp. Available online at http://www.isa.org.usyd.edu.au/publications/documents/Ecological_Footprint_Issues_and_Trends.pdf. (Last accessed 13.07.09.).

Li, L., Chenghua, L., Qi, W., Zhijiang, W., Liyu, D., 2008. Detailed ecological footprint accounting of Liaoning in 2006. Chinese Journal of Population, Resources and Environment 6, 78–87.

Luck, M.A., Jenerette, G.D., Wu, J., Grimm, N.B., 2001. The urban funnel model and the spatially heterogeneous ecological footprint. Ecosystems 4, 782–796.

McIntyre, S., Peters, H.M., Christensen, M.H., Emmi, P.C., Martinson, W., Mielke, M., Senbel, M., Stark, D.O., 2007. The Ecological Footprint of Utah: A Sustainability Indicators Project of the Utah Population and Environment Coalition, Utah Vital Signs, 26 June. 59 pp. Available online at. http://www.utahpop.org/vitalsigns/research/report_2007.htm (Last accessed 13.07.09.).

Medved, S., 2006. Present and future ecological footprint of Slovenia–the influence of energy demand scenarios. Ecological Modelling 19, 25–36.

Monfreda, C., Wackernagel, M., Deumling, D., 2004. Establishing national natural capital accounts based on detailed ecological footprint and biological capacity assessments. Land Use Policy 21, 231–246.

NASS (National Agricultural Statistics Service, United States Department of Commerce, Bureau of the Census), 1984. United States Census of Agriculture: 1982. In: Geographic Area Series; Part 6 Colorado State and County Data, vol I. US Government Printing Office, Washington, DC.

NASS (National Agricultural Statistics Service, United States Department of Commerce, Bureau of the Census), 1989. United States Census of Agriculture: 1987. In: Geographic Area Series; Part 6 Colorado State and County Data, vol I. US Government Printing Office, Washington, DC.

NASS (National Agricultural Statistics Service, United States Department of Commerce, Bureau of the Census), 1994. United States Census of Agriculture: 1992. In: Geographic Area Series; Part 6 Colorado State and County Data, vol I. US Government Printing Office, Washington, DC.

NASS (National Agricultural Statistics Service, United States Department of Commerce, United States Department of Agriculture), 2009a. United States Census of Agriculture: 1997. Available online at. http://www.nass.usda.gov/Statistics_by_State/Colorado/index.asp (Last accessed 26.06.09.).

NASS (National Agricultural Statistics Service, United States Department of Commerce, United States Department of Agriculture), 2009b. United States Census of Agriculture: 2002. Available online at. http://www.nass.usda.gov/Statistics_by_State/Colorado/index.asp (Last accessed 26.06.09.).

Niccolucci, V., Galli, A., Kitzes, J., Pulselli, R.M., Borsa, S., Marchettini, N., 2008. Ecological Footprint analysis applied to the production of two Italian wines. Agriculture, Ecosystems and Environment 128, 162–166.

Noss, R.F., Cooperrider, A.Y., 1994. Saving Natures Legacy – Protecting and Restoring Biodiversity. Island Press, Washington, DC.

Patterson, T.M., Niccolucci, V., Bastianoni, S., 2007. Beyond "more is better": ecological footprint accounting for tourism and consumption in Val di Merse, Italy. Ecological Economics 62, 747–756.

Pulselli, F.M., Ciampalini, F., Leipert, C., Tiezzi, E., 2008. Integrating methods for the environmental sustainability: the SPIn-Eco project in the Province of Siena (Italy). Journal of Environmental Management 86, 332–341.

San Luis Valley Development Resources Group, 2007. Comprehensive Economic Development Strategy. Accessed at. http://www.slvdrg.org/ceds.php on June 17, 2009.

Scotti, M., Bondavalli, C., Bodini, A., 2009. Ecological Footprint as a tool for local sustainability: the municipality of Piacenza (Italy) as a case study. Environmental Impact Assessment Review 29, 39–50.

US Census Bureau, 1990. 1990 Census, Summary File 1, Table DP-5. Profile of Selected Housing Characteristics, Colorado. US Department of Commerce, Washington, DC. http://factfinder.census.gov (Last accessed 15.05.09.).

US Census Bureau, 2000. 2000 Census, Summary File 1, Table DP-4. Profile of Selected Housing Characteristics, Colorado. US Department of Commerce, Washington, DC.

USDA-ERS (United States Department of Agriculture Experimental Research Station), 2009. U.S. Per Capita Food Availability Data Sets. http://www.ers.usda.gov/Data/FoodConsumption/FoodAvailIndex.htm (Last accessed 17.04.09.).

USEPA, 2010. San Luis Basin Sustainability Metrics Project: A Methodology for Evaluating Regional Sustainability. EPA, # EPA/600/R-10/182, xxxvii+224 pp.

Venetoulis, J., Talberth, J., 2008. Refining the ecological footprint. Environment, Development and Sustainability 10, 441–469.

Wackernagel, M., 2009. Introduction: methodological advancement in footprint analysis. Ecological Economics 68, 1925–1927.

Wackernagel, M., Monfreda, C., Erb, K.-H., Haberl, H., Schulz, N.B., 2004a. Ecological footprint time series of Austria, the Philippines, and South Korea for 1961–1999: comparing the conventional approach to an 'actual land area' approach. Land Use Policy 21, 261–269.

Wackernagel, M., Monfreda, C., Schulz, N.B., Erb, K.-H., Haberl, H., Krausmann, F., 2004b. Calculating national and global ecological footprint time series: resolving conceptual challenges. Land Use Policy 21, 271–278.

Wackernagel, M., Moran, D., Wermer, P., Goldfinger, S., Deumling, D., Murray, M., 2005. National Footprint and Biocapacity Accounts 2005: The Underlying Calculation Method. Global Footprint Network, Oakland, 33 pp.

Wackernagel, M., Onisto, L., Bello, P., Linares, A.C., López Falfán, I.S., Méndez García, J., Suárez Guerrero, A.I., Suárez Guerrero, M.G., 1999. National natural capital accounting with the ecological footprint concept. Ecological Economics 29, 375–390.

Wackernagel, M., Rees, W., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, BC, 160 pp.

Wackernagel, M., Yount, J.D., 1998. The ecological footprint: an indicator of progress toward regional sustainability. Environmental Monitoring and Assessment 51, 511–529.

Wiedmann, T., Lenzen, M., 2007. On the conversion between local and global hectares in ecological footprint analysis. Ecological Economics 60, 673–677.

Wood, R., Garnett, S., 2009. An assessment of environmental sustainability in northern Australia using the ecological footprint and with reference to indigenous populations and remoteness. Ecological Economics 68, 1375–1384.

WWF, 2008. Living Planet Report 2008. Published in October 2008 by WWF–World Wide Fund For Nature (formerly World Wildlife Fund), Gland, Switzerland. Available online at. http://assets.panda.org/downloads/living_planet_report_2008.pdf (Last accessed 23.07.09.).

Zhao, S., Hong, H., Zhang, L., 2008. Linking the concept of ecological footprint and valuation of ecosystem services: a case study of economic growth and natural carrying capacity. International Journal of Sustainable Development & World Ecology 15, 448–456.