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Article

Calculating Puerto Rico's Ecological Footprint (1970–2010) Using Freely Available Data

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Abstract: Ecological Footprint Analysis (EFA) is appealing as a metric of sustainability because it is straightforward in theory and easy to conceptualize. However, EFA is difficult to implement because it requires extensive data. A simplified approach to EFA that requires fewer data can serve as a perfunctory analysis allowing researchers to examine a system with relatively little cost and effort. We examined whether a simplified approach using freely available data could be applied to Puerto Rico, a densely populated island with limited land resources. Forty-one years of data were assembled to compute the ecological footprint from 1970 to 2010. According to EFA, individuals in Puerto Rico were moving toward sustainability over time, as the per capita ecological footprint decreased from 3.69 ha per capita (ha/ca) in 1970 to 3.05 ha/ca in 2010. However, due to population growth, the population's footprint rose from 1.00×10^7 ha in 1970 to 1.14×10^7 ha in 2010, indicating Puerto Rico as a whole was moving away from sustainability. Our findings demonstrate the promise for conducting EFA using a simplified approach with freely available data, and we discuss potential limitations on data quality and availability that should be addressed to further improve the science.

Keywords: ecological footprint; biocapacity; sustainability; regional assessment; Puerto Rico

1. Introduction

It is generally recognized that most of the developed world is using resources at a rate greater than Earth's ability to regenerate the resources [1]. Many responsible stewards recognize the need for conscientious resource use to not only increase longevity of their environmental system, but also, ideally, to become sustainable. This recognition has spurred the creation of a number of metrics or indicators that purport to capture sustainability (e.g., [2]). One commonly used metric of sustainability is Ecological Footprint Analysis (EFA), perhaps more appropriately called environmental footprint analysis [3,4]. EFA is often used alone or in conjunction with other metrics because it is straightforward in theory, easy to conceptualize, and appears to characterize the sustainability of an environmental system. EFA attempts to capture human impacts on the regenerative capacity of an environmental system [5] by identifying the amount of biologically productive (*i.e.*, bioproductive) land required to support a person's average annual consumption and waste production [1].

EFA methodology has been continually evolving since Wackernagel and Rees [1] introduced it, as researchers attempt to improve the methodology (e.g., [6–10]). Recently, there has been an effort by the EFA research community to establish and follow standards (see [4,11]). Following such standards can be expensive or impractical due to the extensive data needs. In fact, a typical EFA can use >150 variables (e.g., [12]). Unfortunately, these data often are difficult to obtain, can be questionable in terms of quality, or are not collected. To address these challenges, Hopton and White [4] proposed a simplified approach to EFA based on freely and readily available data sets. This simplified approach is particularly appealing because it provides a relatively straightforward process that can guide stakeholders to components of their system that deserve attention to improve sustainability [4]. This approach has been applied to the US and resulting trends emulate other studies [13].

This paper has two overlapping goals. The first is to conduct an EFA for the Commonwealth of Puerto Rico (hereafter Puerto Rico). Second, we test a simplified approach to EFA that requires a less extensive data set than traditional EFA [4]. This simplified approach has been applied to a sparsely populated agricultural region in southcentral Colorado [4,13], and Puerto Rico offers an antipodal system (*i.e.*, industrialized and densely populated) to test this methodology. In addition, we consider the applicability of the simplified methodology as an initial assessment of sustainability that can be computed more readily than methodologies adhering to Global Footprint Network (GFN) standards.

1.1. EFA Overview

Although EFA continues to evolve, some general principles are common to EFA studies. An EFA calculation essentially requires: (1) the population in the area of interest; (2) the amount of resources and energy consumed per capita; and (3) the amount of each biologically productive land type in the area under examination. Each set of variables is used in one of three accounting-type ledgers to calculate the supply (biocapacity) and demand (ecological footprint) of the system under study [1,5]. Resource consumption variables include food resources such as meat, dairy, fruits, and vegetables. Consumption is typically estimated 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 [1,5].

The energy balance component of the calculation considers both locally generated energy and, if known, energy embodied in traded goods [1,5]. Carbon content for primary fuel consumption is estimated and used to derive the amount of forest land necessary to sequester the resulting CO_2 emissions [5]. The total of resource consumption and energy consumption represents the ecological footprint.

The area of biologically productive land is measured to calculate the system's biocapacity. Bioproductive land is generally categorized into one of six types: energy, arable, forest, pasture, built, and sea (or fisheries). Land that does not fit one of these six categories is considered non-productive and is excluded from EFA accounting [5].

Key calculations in the EFA are outlined as follows, using naming conventions from Hopton and White [4]. Conventional EFA accounting using the compound approach as introduced by Wackernagel and Rees [1] and expanded by Chambers *et al.* [5] was applied in this study because it is more inclusive and robust (but see [14]). In particular, the compound approach is stronger than component-based calculations in terms of data reliability (see [5] pp. 67–74). The population's ecological footprint is denoted as *EF*, the per capita ecological footprint as *ef*, the population's biocapacity as *BC*, and the per capita biocapacity as *bc*. 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 area under study (*N*). The average demand or ecological footprint per capita (*ef*) is computed by summing all the 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). These areas often are converted to global hectares to express a world average (e.g., [11]), but here we simply use hectares (following [4,13]) or hectares per person, as appropriate. An ecological footprint (*EF*) for the entire system under study 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 *N*.

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. Conversely, the system is considered sustainable if there is an ecological reserve ($ef < bc$ or $EF < BC$). However, there is some question about the accuracy of identifying a system as sustainable (see [15]) because sustainability is, ultimately, a global issue (e.g., [15,16]). Thus, an assessment is conducted of the system's movement toward or away from sustainability by examining the ecological balance through time. 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 [4]. Conversely, a system is considered moving toward sustainability if the ecological reserve is increasing, or if a deficit exists, the deficit is decreasing over time.

1.2. Puerto Rico Case Study

This analysis was part of a broader, multi-stakeholder effort to quantify sustainability in Puerto Rico by "establish[ing] a dialogue between researchers and decision-makers and facilitate[ing] research to be used in policy and decision-making" [17]. United States Environmental Protection Agency (US EPA) Office of Research and Development was contacted by US EPA Region 2 to assist with quantifying sustainability in Puerto Rico. This project was conducted in collaboration with a number of US Federal agencies, Puerto Rico government agencies, nongovernmental organizations, and academic researchers (see Appendix A in [17]). The primary motivation for the EFA and the other sustainability metrics was "to produce a straightforward, inexpensive methodology to measure and monitor the prosperity and environmental quality of a regional system" [17].

Puerto Rico is a densely populated island with limited land resources [18]. Puerto Rico's population rose from approximately 2.7 million in 1970 to 3.7 million in 2010. In light of increasing population pressure, local policy makers recognize the importance of land use decisions for the island's sustainability. In fact, Puerto Rico incorporated sustainability language into policy and law in an effort to move the island toward sustainability. Specifically, the Sustainable Development Public Policy Act [19] states:

> The strategy for the sustainable development of Puerto Rico must acknowledge the need for a new vision that gives greater relevance to the environment and natural resources upon which the same is based; particularly with respect to the use of land and water resources, transportation, the production of energy, the management of solid waste and liquids, and the management of our coastal zone. We must support the continuation of our economic development, but in a sustainable manner, to ensure ourselves of the fact that the cost of such development is neither the excessive degradation and destruction of the environment and the natural resources nor social injustice.

Beyond Puerto Rico's focus on sustainability, the island was an appropriate study system because islands are ideal for studying and measuring sustainability due to their easily detectable limits and defined flow of materials [20]. As an island, one would assume the government has a good idea what enters and exits the borders. However, because Puerto Rico is both an independent nation and a territory of the US, EFA required a number of assumptions unique to this study, as discussed below. To this point, we note shortcomings in the collection and distribution of relevant data by government entities.

Although Puerto Rico was generally a good candidate to test this simplified EFA methodology, data challenges in this study may offer useful perspectives for those implementing EFAs in other areas. For example, data needs of traditional EFA accounting under GFN standards are relatively straightforward, but 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 national or sub-national boundaries that do not collect or provide such data. To overcome this difficulty, researchers often approximate values for many of the variables or use values from disparate years (e.g., [21]). Puerto Rico is unique in that it is both autonomous and its people are citizens of the US (e.g., [22]). Similar to other sub-national regions, it is often difficult to obtain data for smaller political units. Thus, depending on the data required we were limited by data availability and questionable data quality over the 41 years (1970–2010) of analysis, a challenge with even the 34 variables used in the simplified approach. Initially, we attempted to use GFN National Footprint Account (NFA) data for Puerto Rico and compare the results to the simplified approach. However, these data are not made publicly available due to questionable data quality (Jason Ortego, GFN, pers. comm.). In place of a comparison between EFA following GFN standards and the simplified approach, we restricted the analysis to only the simplified approach and attempted to limit the variables to data specific to the island.

2. Methods

We gathered freely available data to perform a simplified EFA for Puerto Rico from 1970–2010 (Supplementary Table S1). These data were obtained at the scale of Puerto Rico or municipios, which are legal divisions similar to US counties. However, because data for some essential components of a footprint analysis were not available for Puerto Rico, it was necessary to utilize data that were not specific to the island. When necessary, data that were available only at the US level were scaled to the territory based on per capita rates in the larger system (Table 1). Data reported less frequently than annually were linearly interpolated to fill missing years.

2.1. Data, *Variables*, *and Sources*

2.1.1. Biocapacity

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 municipio in the National Agricultural Statistics Service's (NASS) Census of Agriculture report at various intervals [23–30]. Pasture was estimated using the NASS reports by subtracting the hectares of arable land from total farmland, thereby assuming farmland that is not planted for crops is probably grazed. Forest was estimated from a number of publications [31–33] and shows a general increase through time due to abandonment of agriculture (e.g., [33]). Built land was obtained from the US Census Bureau from the land area reported for each Census-designated place in each municipio. Sea was treated as a constant at 492,083 ha [34,35]. Lastly, energy land is the amount of forested land required to sequester CO_2 produced from energy consumption (e.g., [1,5]). This value was zero hectares (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. Figure 1 shows a map of the different EF biocapacity land categories in Puerto Rico.

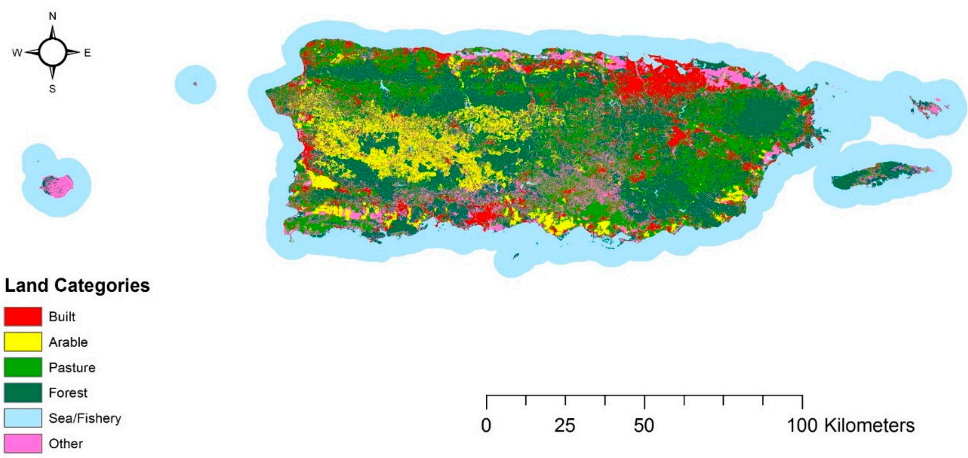

Figure 1. Six Ecological Footprint Analysis (EFA) land categories in Puerto Rico. Note the sea land category is for illustrative purposes only and not to scale.

2.1.2. Consumption

Energy consumption data for Puerto Rico were obtained from the US Department of Energy's Energy Information Administration (EIA; [36]). Per capita consumption was calculated for the island and included coal, natural gas, petroleum, and hydroelectric categories. Energy consumption was converted to area of forest and the corresponding energy land required for CO_2 sequestration, following Chambers *et al.* [5].

Per capita food consumption for the US, from US Department of Agriculture's Economic Research Service [37], was used to estimate food consumption for the area under study. Because data were already provided 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 type 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 supporting consumption levels for the island's population.

Global yields were used because it is unlikely that most items consumed in Puerto Rico were produced on the island. Global yields were taken from Chambers *et al.* ([5]: pp. 70–73) and were assumed 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 sub-national area. However, more accurate annual values are unlikely to have a large influence on the results because it is unlikely they would change appreciably on a year-to-year basis (e.g., [13]); for example, McIntyre *et al.* ([12]) showed no change in global yield for years 1995 and 2003. On the other hand, there could be changes over long periods examined such as the length of our study period (see [38]). Using static yields over time may overlook improvements in agricultural production efficiency over the study period, and thus our ecological footprint estimates may be somewhat conservative in earlier years and inflated in years that are more recent.

Many studies suggest converting footprints into global hectares (gha) in order to allow comparison of EFAs between systems (e.g., [39,40] but see [14]). A global hectare is "normalized to the area-weighted average productivity of biologically productive land and water in a given year" [41,42]. In other words, a global hectare is the global average of productivity (*i.e.*, kg produced per one hectare of land or water). 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., [5,40]), but a complete set is difficult to obtain without additional expense (e.g., the period examined here would cost >$39,000; Jason Ortego, GFN, pers. comm.). Because our study was practical, rather than academic in nature, and a primary goal was to calculate Puerto Rico's ecological footprint using freely available data, we used local ha as the working unit (following [4]). Moreover, the study in southcentral Colorado [4,13] demonstrated although the absolute values differed, the trends remained virtually identical. Note that our *ef* values were effectively reported in world average hectares because much of Puerto Rico's consumption is sourced from outside the local area.

3. Results and Discussion

3.1. Biocapacity (Supply)

We assembled 41 years (1970–2010) of data consisting of 34 variables (Table 1), and estimated biocapacity and ecological footprint for those years. The biocapacity trend for the 41-year period was relatively flat, beginning at a peak of nearly 0.35 hectares per capita (ha/ca) in 1970, decreasing to a low of 0.27 ha/ca in 2000 and rebounding slightly to 0.30 ha/ca in 2009 (Figure 2a). During the period of study, forest increased, built land increased, and pasture and arable land decreased. Specifically, biocapacity of forest increased from 0.06 ha/ca to 0.13 ha/ca and pasture declined from 0.05 ha/ca to 0.02 ha/ca (Figure 3). Arable land declined during the 41-year period, starting at 0.05 ha/ca in 1970 and down to 0.01 ha/ca in 2010 (Figure 3). Sea declined from 0.18 ha/ca in 1970 to 0.13 ha/ca in 2010. Built land increased slightly during the 41 years, but available built land remained constant at 0.03 ha/ca. In absolute terms, the number of hectares of forest land increased, sea remained constant, and arable and pasture land decreased during the 41 years.

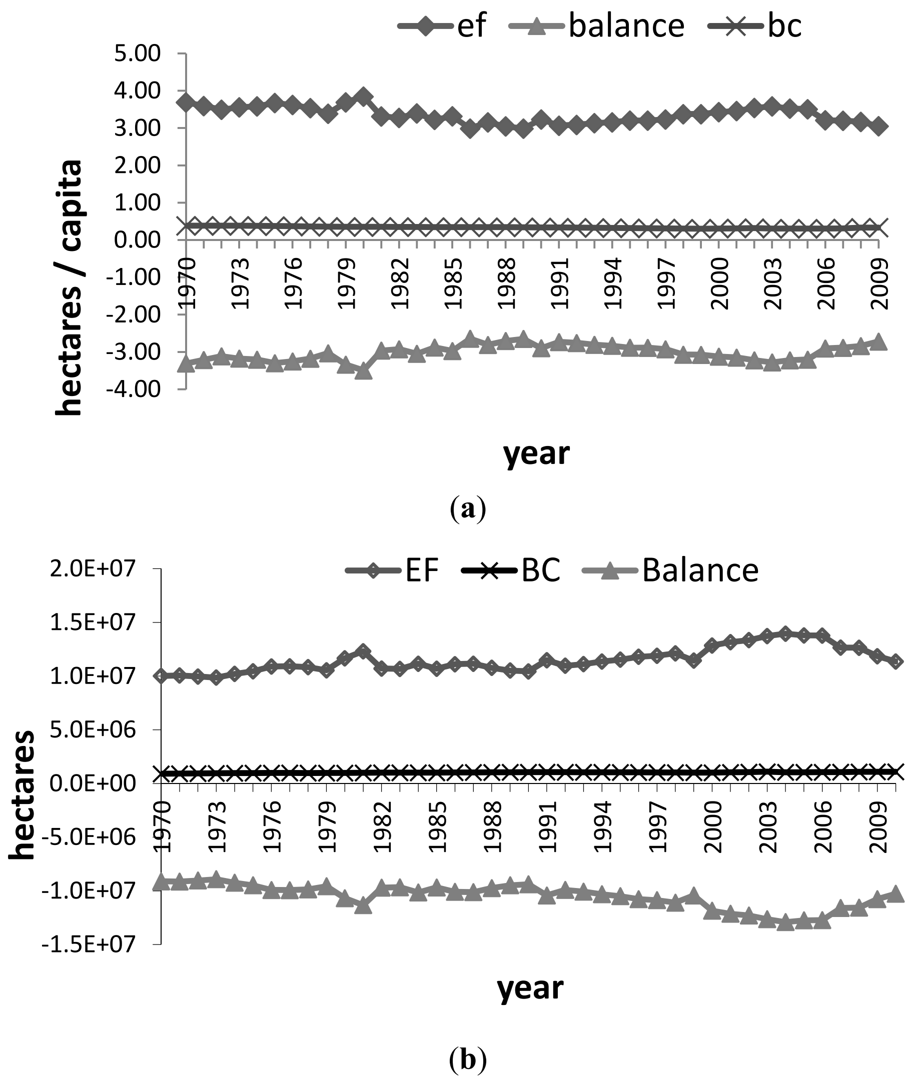

Figure 2. Ecological footprint (*ef*, *EF*) and biocapacity (*bc*, *BC*) for Puerto Rico, 1970–2010, presented (**a**) per capita and (**b**) for the entire population.

Although the total amount of bioproductive land increased slightly during the period examined (Figure 2b), primarily due to an increase in forest land likely attributable to abandonment of agriculture [33], the available per capita biocapacity (*bc*) decreased during the 41 years from 0.35 ha/ca to 0.30 ha/ca (Figure 3). The decrease in *bc* seems to be due, primarily, to population growth in the region as the population increased from approximately 2.7 million to 3.7 million people. An increasing population draws on a constant amount of land, resulting in a decreasing amount of bioproductive land per person. The results suggest the overall increase in *BC* for Puerto Rico was moderate, especially when compared to the decline in *bc* (Figures 2 and 3). Hence, as the population size increased, the benefit of additional forest land was overwhelmed, resulting in fewer resources available per person. This suggests that population increase has a great effect on biocapacity.

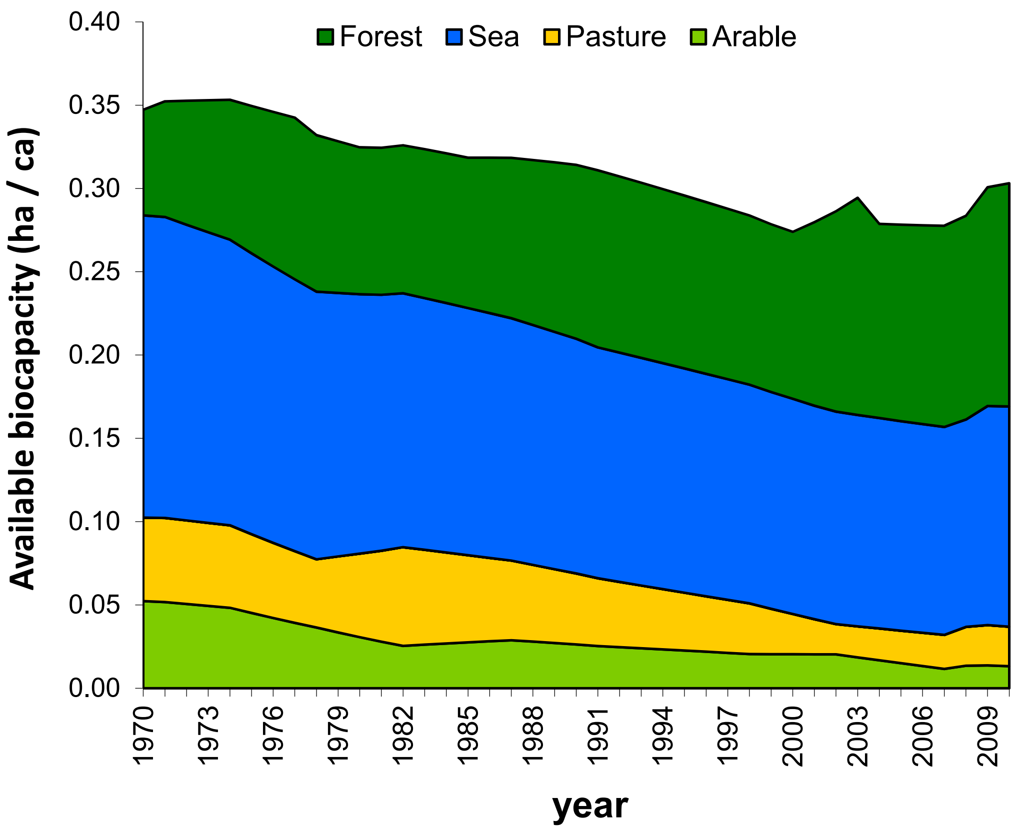

Figure 3. Available biocapacity (*bc*) for the ecological footprint land categories over a 41-year period in Puerto Rico. Note that built-up land has no biocapacity and is not included in the figure.

3.2. Ecological Footprint (Demand)

Per capita ecological footprint shows a minor decrease, varying from a high of 3.69 ha/ca in 1970 and declining to 2.99 ha/ca in 1990 and rebounding slightly thereafter (Figure 2a). Subtracting *ef* from *bc* provides the ecological balance and reveals Puerto Rico had an ecological deficit, although it was improving, during the period examined. The deficit was at a period high of −3.52 ha/ca in 1981 and generally declined through 2010 when the ecological balance was −2.75 ha/ca (Figure 2a). Overall, demand placed on each of the land categories remained relatively constant during the 41-year period, except for pasture and energy land (Figure 4). Per capita demand on arable, built, and sea lands have remained stable, as consumption did not increase dramatically during the period. However, during the same period the area of pasture and energy land varied relative to the other land types (Figure 4).

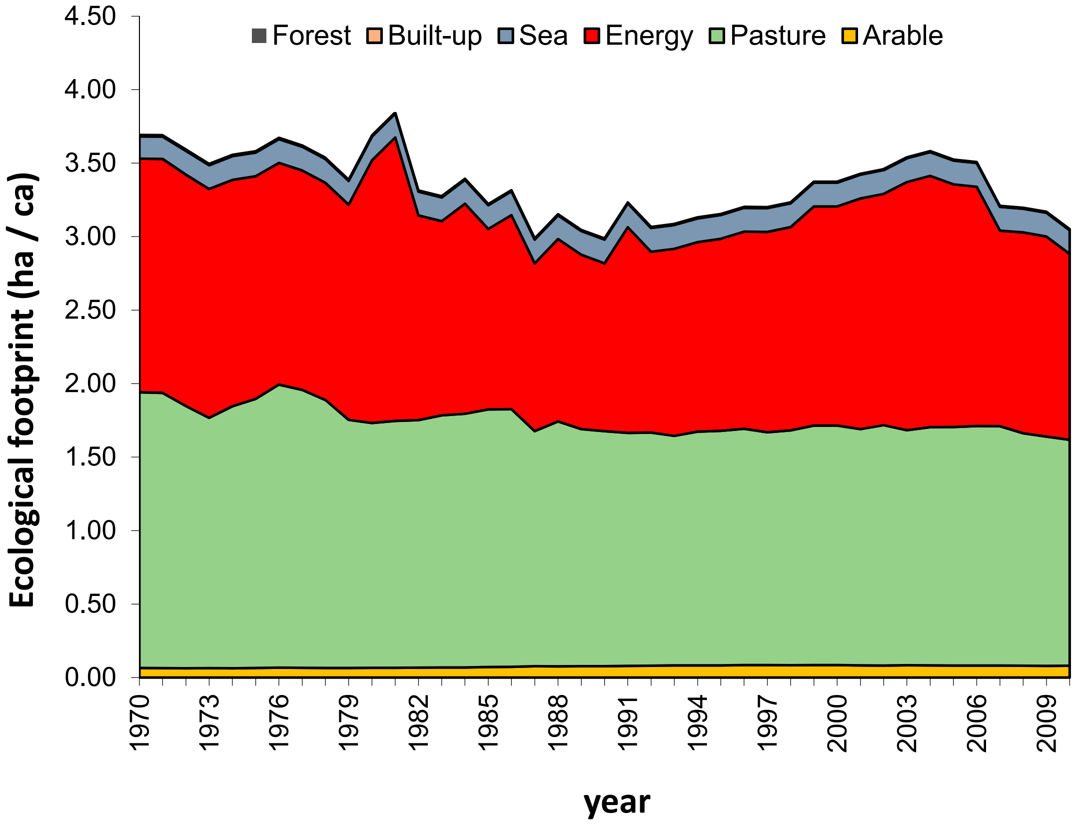

Figure 4. Ecological footprint (*ef*) and the demand placed on each of the six land categories over a 41-year period in Puerto Rico. Built-up land is too small (0.03 ha/ca) to view in figure. Most of the forest is converted into energy land. Forest land is plotted above the sea category and not discernable.

Focusing on energy land, there was a minor decrease in total energy consumption from fossil fuels for the island, but it was quite variable (Figure 5). Petroleum consumption exhibited the most change through time and coal consumption increased substantially around 2003 (Figure 5). The overall reduction in energy consumption may be attributable to improved energy efficiency, but assumptions in our methods make these estimates uncertain and additional information is needed to determine if the values reflect reality or are a result of poor data. Energy consumption from nuclear, hydroelectric, and wood and waste were virtually nonexistent in the data during the period examined.

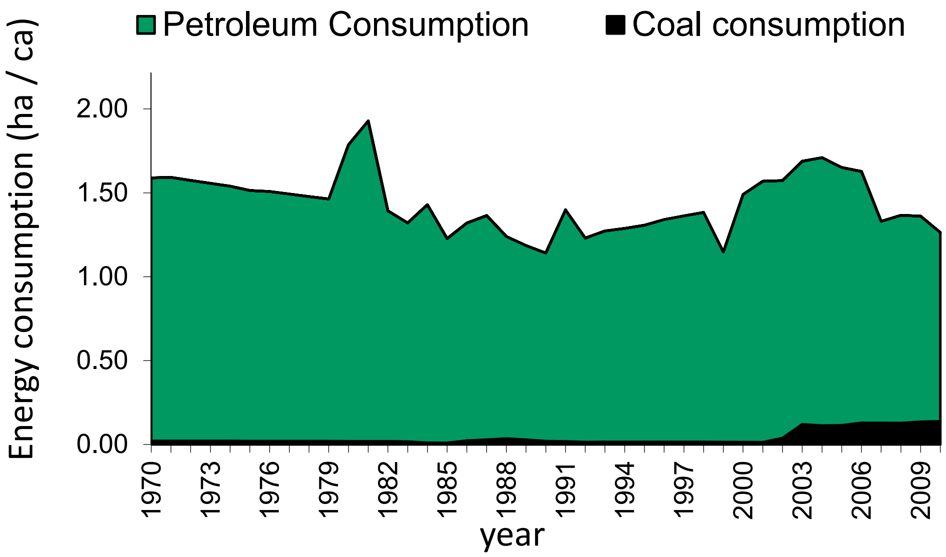

Figure 5. Energy consumption per capita by major energy source over a 41-year period in the Puerto Rico.

Unlike the US as a whole (e.g., [40–42]), the average ecological footprint of individuals in Puerto Rico decreased slightly (with some variation) during the time analyzed (Figure 2). However, there is a difficulty characterizing uncertainty in EFA (see [13]), so in reality *ef* may have been unchanged or even increased slightly. Examining the individual land categories and the energy footprint can help identify components responsible for the trends (Figure 4). Although *ef* showed little change, the total *EF* for Puerto Rico increased from around 1.0×10^7 ha in 1970 to a high of nearly 1.4×10^7 ha in 2004. The slight improvements made in terms of *ef* were annulled by the increasing *EF* attributable to growing population over time.

3.3. Examination of Sustainability

The strengths and weakness of EFA have been discussed by many and the discussion is ongoing (e.g., [43,44]. As pointed out in numerous studies (e.g., [15,45]), EFA is useful for providing a basic overview of sustainability of an environmental system and can provide monitoring and a warning to advise policy makers to look more closely at their system, but it needs to be used in concert with other metrics and indicators. Several authors have discussed how such information can be used in policy decisions (e.g., [38,44–46], but it has not been fully explored [45]. USEPA [17] participated in a dialogue with researchers, decision makers, and policy-makers, but it is not the goal of this paper to suggest or direct policy. Moreover, end users must recognize EFA results come with a number of caveats and cautions because a single metric may not capture the state of a system adequately for the basis of policy decisions.

Our analysis suggests that while overall biocapacity (*BC*) increased slightly, Puerto Rico as a whole was moving away from sustainability because population growth drove increases in total resource demand (*EF*; Figure 2b). On a per capita basis the situation was more optimistic because *ef* decreased slightly during the 41 years and available *bc* was virtually flat (Figure 2a). Whereas the per capita ecological deficit decreased over the 41 years, the deficit generally increased for the entire population (Figure 2b). As noted above, these observed trends could be impacted by our assumption of static agricultural yields over time. In particular, our EFA estimates may be conservative in earlier years and inflated in more recent years. Therefore, although per capita biocapacity decreased when using static yields, it remains unknown whether gains in agricultural efficiency might have compensated for rapid population growth, which would influence our interpretation of Puerto Rico's total EFA through time. Additionally, the use of global average yields to represent biocapacity for Puerto Rico's land/sea area likely contains some unknown error because production in Puerto Rico is not equivalent to the global average. The methods used here could be strengthened by comparing the effects of using local *vs.* global yields, and by accounting for the proportion of consumed goods produced within Puerto Rico *vs.* abroad.

The effects of population growth were evident in the individual land categories as well. For example, per capita demand on pasture and arable land was relatively stable through time (Figure 4), but per capita biocapacity for those land categories was reduced sharply as the population grew from 2.7 million to 3.7 million people. The overall result was an increasing deficit of bioproductive land per capita (Figure 3) that was available to support the population on the island.

Although this analysis suggests that Puerto Rico's *ef* is relatively low compared to the United States (e.g., 2005 values = 3.52 ha/ca *vs.* 5.11 ha/ca, respectively; [4]), one potential flaw in our study was the large number of missing variables that represent embodied energy in goods and services. It is unknown if the available data represent overall consumption patterns and can capture the trend in the system. Comparing the simplified approach to a complete EFA would provide such information, but data limitations must be addressed (see [4]). For example, using US data for some categories may not reflect Puerto Rico consumption.

Puerto Rico is an industrialized region that has changed dramatically in recent decades (e.g., [18,47]). Given the island's growing population and limited natural resources, we expected Puerto Rico to mimic similar settings and exhibit an increasing ecological deficit over the period. Instead, we observed a slight decrease in the per capita ecological deficit (Figure 2a), contrary to many industrialized nations, and individuals show a trend of moving toward sustainability. This raises the question as to whether the per capita reduction in *ef* was due to economic conditions, a conscious effort to reduce resource use, or some other factors. More research is warranted to identify these causes. Unfortunately, improvements in *ef* were overshadowed by population increase during the 41 years that resulted in a trend of the island as a whole moving away from sustainability (although there has been an upswing since 2006; Figure 2b).

Several methodologies were used early on in EFA accounting, but recently there has been a push to standardize the methods (e.g., [10,11]) and a few methodologies are proposed as a standard (e.g., [48]—Redefining Progress; [42,44]—Global Footprint Network, Best Foot Forward). Hopton and White [4] discuss some of the drawbacks to the proposed standardization and the strengths and weaknesses of the simplified methodology used in this analysis, most of which are related to data issues (number of variables, availability, *etc.*). Whereas the simplified approach is appealing because it leverages free and readily available data, it remains unknown how lacking data on embodied energy in goods and services affects our findings. From a practical standpoint, the ultimate question regarding the strength or weakness of the simplified approach employed here is if it adequately captures trends that can draw attention to a problem and enable decision makers to investigate if action is necessary to move the system toward sustainability and start examining what actions are needed. The goal was not to create a more accurate EFA, but instead to make the methodology more accessible and usable for the end user while still being rigorous for sustainability analysis. As such, the simplified approach appears to characterize the system and demonstrates an overall movement away from sustainability. However, the simplified method can still be improved by identifying the best freely available data sources, and by comparing results from the simplified approach to those obtained following more intensive yet costly EFA standards.

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

Variable	Purpose/Notes	Source	URL
United States data			
Consumption of Animal Products (lbs./capita)	Includes bovine, buffalo, sheep, goat, non-bovine, milk, cheese, butter, eggs, and fish categories; Last updated 25 January 2013	USDA Economic Research Service	http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx
Cereal Consumption (lbs./capita)	Includes cereals, wheat, and maize categories	USDA Economic Research Service	http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx
Fruit & Vegetable Consumption (lbs./capita)	Includes vegetables, fruit, animal feed, roots, tubers, and pulses consumption	USDA Economic Research Service	http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx
Puerto Rico data			
Fossil Fuel (Gj/year)	Includes coal, natural gas, and petroleum; assume all produced was consumed; coal interpolated using 1983–2002 data (did not include post-2002 due to large increase) consumption	Energy Information Administration	http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm
Nuclear Electric Consumption (million kWh)	None reported	Energy Information Administration	http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm
Hydro-electric Consumption (million kWh)		Energy Information Administration	http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm
Wood and waste Consumption (trillion BTU)	None reported	Energy Information Administration	http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm

Table 1. *Cont.*

Variable	Purpose/Notes	Source	URL
Municipio data			
Population (persons)	Interdecadal values from PR Planning Board	US Census Bureau, Puerto Rico Census of Population; and Puerto Rico Planning Board, Economic and Social Planning Program, Office of the Census	http://www.census.gov/popest/data/intercensal/puerto_rico/pr2010.html
Land Area (ha)	Treated as a constant	US Census Bureau	http://www.census.gov/prod/cen2000/phc-1-53-ENG.pdf
Built land (ha)	1991—Pares-Ramos *et al.* 2008, 10.5%; 2000—Pares-Ramos *et al.* 2008; 11% census bureau, census designated place says 111709 ha or 431.31 mi^2; 2003—Martinuzzi *et al.* 2007; 2006—calculated from GAP layer (urban and barren), but GAP metadata indicate 101844 ha "urban and barren"; 2010—US Census Bureau, Census Designated Places; missing values linearly interpolated	[49,50]; GAP Analysis; US Census Bureau	
Forest (ha)	1969, 1977, 1980, 1985, 1991, 2003; linearly interpolate missing years	[31,32,33]	
Arable land (ha)	Census of Agriculture (1974, 1978, 1982, 1987, 1998, 2002, 2007; Pares-Ramos 2008; agricultural land increased from 6% in 1940 to 40% in 2000. Arable land < 2002 is "cropland harvested" > 2001 is "harvested cropland"	USDA Agricultural Statistics	http://www.agcensus.usda.gov
Pasture (ha)	Census of Agriculture (1974, 1978, 1982, 1987, 1998, 2002, 2007; pasture < 2002 "cropland in cultivated and improved pasture" > 2001 "cropland used only for pasture or grazing"	USDA Agricultural Statistics	
Sea (ha)	Treated as a constant—1899.94 mi^2 × 258.999 ha/mi^2 = ha; 2000 census places.xlsx; phc-3-53-eng2000.pdf; Water area is the sum of the surfaces of all inland water bodies, such as lakes, reservoirs, or rivers, as delimited by international boundaries and/or coastlines	US Census Bureau	http://www.census.gov/prod/cen2000/phc-1-53-ENG.pdf

Table 1. *Cont.*

Variable	Purpose/Notes	Source	URL
Calculated values			
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		

4. Conclusions

The ultimate goal of sustainability research is to improve the human condition, and a primary step in doing so is making available necessary data that can be used with confidence and accurately represent the state of the system. As an island of relatively small size and a large population, Puerto Rico has an obvious interest in managing their system toward sustainability. This simplified EFA indicated Puerto Rico as a whole was moving away from sustainability, although per capita ecological footprint (*ef*) generally declined over time. However, concerns about data quality and availability bring to question the accuracy of the results from this examination. In this case, data unavailability and questionable data quality precluded comparison of the simplified EFA approach to more comprehensive EFA methodologies with high data demands. Because most metrics that purport to quantify sustainability require large amounts of data, it is important these data are accurate and readily available. Data need to be collected on a regular basis, have quality checks in place to ensure they meet international standards, and, most important, the data must faithfully represent reality. Once data quality and availability are consistent, researchers can identify or create metrics that enable decision makers to manage their system to the benefit of citizens and move toward sustainability. Once improved metrics are created, then researchers can help decision makers identify indicator variables to ease the calculation process (e.g., identify easily obtained variables that correlate with metric results for a perfunctory analysis of one's system; see [51]) and determine what is best for their particular system. The ultimate goal of sustainability research is to improve the human condition, and a primary step in doing so is making available necessary data that can be used with confidence and accurately represent the state of the system. As an island of relatively small size and a large population, Puerto Rico has an obvious interest in managing their system toward sustainability. This simplified approach to EFA offers a promising methodology to characterizing the island's sustainability on an annual basis, but the unavailability of more detailed data prevents systematic comparison with methodologies adhering to GFN standards. Continued research will help guide researchers to the most important data to collect and disseminate, and ultimately, monitoring the ecological footprint will help decision makers create the best system for the people of Puerto Rico.

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Author Contributions

Matthew Hopton designed and performed the research, analyzed the data, and wrote the paper. Adam Berland contributed to interpreting the data and writing the paper. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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