

# **TRACKING THE HUMAN SOURCES OF ECOLOGICAL FOOTPRINTS**

## **The STIRPAT Research Program\***

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## **GLOBAL ENVIRONMENTAL CHANGE:**

- **CUMULATIVE EFFECTS:**

**EFFECTS THAT ARE LOCAL IN DOMAIN BUT SO WIDELY REPLICATED THAT IN SUM THEY HAVE GLOBAL CONSEQUENCES (e.g. DEFORESTATION)**

- **SYSTEMIC EFFECTS:**

**EFFECTS THAT OCCUR ON LARGE SPATIAL SCALES OR ALTER THE FUNCTION OF LARGE SYSTEMS (e.g. OZONE DEPLETION)**

## **ANTHROPOGENIC DRIVERS OF GLOBAL ENVIRONMENTAL CHANGE (GEC):**

- **POPULATION**
- **AFFLUENCE (CONSUMPTION)**
- **TECHNOLOGY**
- **INSTITUTIONS (POLITICAL, ECON, SOCIAL)**
- **CULTURE (INCLUDING VALUES & BELIEFS)**

## **QUESTIONS FRAMING THE STIRPAT RESEARCH PROGRAM:**

- **HOW MIGHT WE BETTER UNDERSTAND THE LINKAGES BETWEEN POPULATION, RESOURCES, AND ENVIRONMENTAL IMPACT?**
- **HOW MIGHT WE PROCEED TO DEVELOP ORGANIZED RESEARCH PROGRAMS TO EXAMINE THESE LINKAGES?**
- **HOW MIGHT WE DISCIPLINE OUR CONCEPTUAL MODELS WITH EMPIRICAL TESTS?**



**WE PREFER TO CONDUCT DETAILED ANALYSES OF  
SIMPLE QUESTIONS RATHER THAN SUPERFICIAL  
ANALYSES OF COMPLEX QUESTIONS.**

**John Schellnhuber**

**GEOSCOPE, Berlin 25 October 2001**

## **THE LIMITS OF MODELS:**

**IT IS IMPOSSIBLE TO SIMULTANEOUSLY MAXIMIZE GENERALITY, REALISM, AND PRECISION IN ANY MODEL.**

**THIS LIMITATION RESULTS IN THREE OPTIONS:**

- (1) SACRIFICE GENERALITY TO REALISM AND PRECISION**
- (2) SACRIFICE REALISM TO GENERALITY AND PRECISION**
- (3) SACRIFICE PRECISION TO REALISM AND GENERALITY**

Source: Levins, Richard. 1966. "The Strategy of Model Building in Biology." *American Scientist* 54:421-431.

## **ECOLOGICAL FIRST PRINCIPLES:**

**NATURE PROVIDES ECOLOGICAL CAPITAL AND SERVICES. FACTORS IMPACTING THEM ARE:**

**FOR ALL SPECIES: (1) THE NUMBER OF MEMBERS**

**(2) GEOGRAPHIC SPACE FOR  
THE POPULATION**

**(3) RATE AT WHICH THEY  
CONSUME RESOURCES**

**FOR HIGHER**

**ORDER SPECIES: (4) TOTAL WASTE DISPOSAL**

**(5) TECHNOLOGY**



$$\mathbf{I = PAT}$$

Accounting Version

**I**mpacts are due to

**P**opulation

**A**ffluence

**T**echnology



**ACCOUNTING VERSION (OR IDENTITY)**

**IMPACTS TO THE ENVIRONMENT =  $\varphi(P, A, T)$**

**STOCHASTIC VERSION (ACCOUNTING FOR ERROR)**

**IMPACTS TO THE ENVIRONMENT =  $\varphi(P, A, T) + \epsilon$**

## Typical Application:

**Basic Identity:**  $I = PAT$

**Form:**  $T = I/(P*A)$  SOLVE FOR T

**Data:** Typically % Changes

### Example (Commoner 1992)

From 1950 to 1967, following changes:

<u>Synthetic Pesticide Use</u>	<u>Population</u>	<u>Production/ Affluence</u>	<u>Technology</u>
+266%	+30%	+5%	?

$$T = 3.66 / (1.3 \times 1.05) = 2.68$$

$$T = 2.68 - 1.00 (100) = 168\% \text{ increase}$$



# STIRPAT

**S**Tochastic estimation of  
**I**mpacts by  
**R**egression on  
**P**opulation  
**A**ffluence  
**T**echnology



## **Basic STIRPAT Stochastic Form:**

$$\mathbf{I}_i = \mathbf{a} \mathbf{P}_i^b \mathbf{A}_i^c \mathbf{T}_i^d \mathbf{e}_i$$

## **STIRPAT ESTIMATION FORMULA:**

$$\text{LOG } I = \text{LOG } a + b \text{ Log } P + c \text{ Log } A + \log e$$

**OR**

$$\text{LOG } I = a + b \text{ Log } P + c \text{ Log } A + e$$

**Where:    a = LOG a**  
**e = LOG e**

## **STIRPAT in Polynomial Form:**

$$\mathbf{Ln(I) = a + bLn(P) + cLn(A) + dLn(A)^n + f Ln(T) + e}$$

## **ECOLOGICAL FOOTPRINT:**

- **BASIC IDEA: THE CUMULATIVE ENVIRONMENTAL IMPACT CAN BE CONSIDERED A FUNCTION OF CONSUMPTION LEVELS**
- **A CONVERSION OF CONSUMPTION INTO A BIOPHYSICAL METRIC (PRODUCTIVE LAND AREA)**
- **AN OPERATIONAL MEASURE OF PLANETARY LOAD (DEFINED AS POPULATION X's CONSUMPTION PC)**
- **ADDING TECHNOLOGY TO THE DEFINITION OF PLANETARY LOAD RESULTS IN THE I=PAT**



## **THE ECOLOGICAL FOOTPRINT (EF):**

**THE ECOLOGICAL FOOTPRINT (EF) IN ANY GIVEN YEAR IS THE AMOUNT OF BIOLOGICALLY PRODUCTIVE LAND (NATURE'S CAPITAL) NEEDED TO REGENERATE HUMANKIND'S CONSUMPTION AND ABSORB ITS WASTES.**

## **IMPORTANT CAVEAT:**

**THE EF MEASURES PRESSURE OR LOAD ON NATURAL CAPITAL AND SERVICES, NOT THE ACTUAL IMPACTS TO THE INVENTORY OF RESOURCES**

# **ECOLOGICAL FOOTPRINT: ELEMENTS OF CONSUMPTION**

## **FIVE COMPONENTS:**

- 1. FOOD**
- 2. HOUSING**
- 3. TRANSPORTATION**
- 4. CONSUMER GOODS**
- 5. SERVICES**

# **ECOLOGICAL FOOTPRINT (EF): BIOPHYSICAL UNITS**

## **SIX COMPONENTS:**

- 1. ARABLE LAND (GROWING CROPS)**
- 2. PASTURE LAND (ANIMAL GRAZING)**
- 3. FORESTED LAND (TIMBER PRODUCTS)**
- 4. SEA SPACE (PRODUCTIVE FISHING GROUNDS)**
- 5. BUILT-UP LAND (INFRASTRUCTURE FOR HOUSING, TRANSPORTATION, INDUSTRY, HYDROELECTRIC POWER)**
- 6. ENERGY LAND (TO SEQUESTER CO<sub>2</sub> EMISSIONS)**

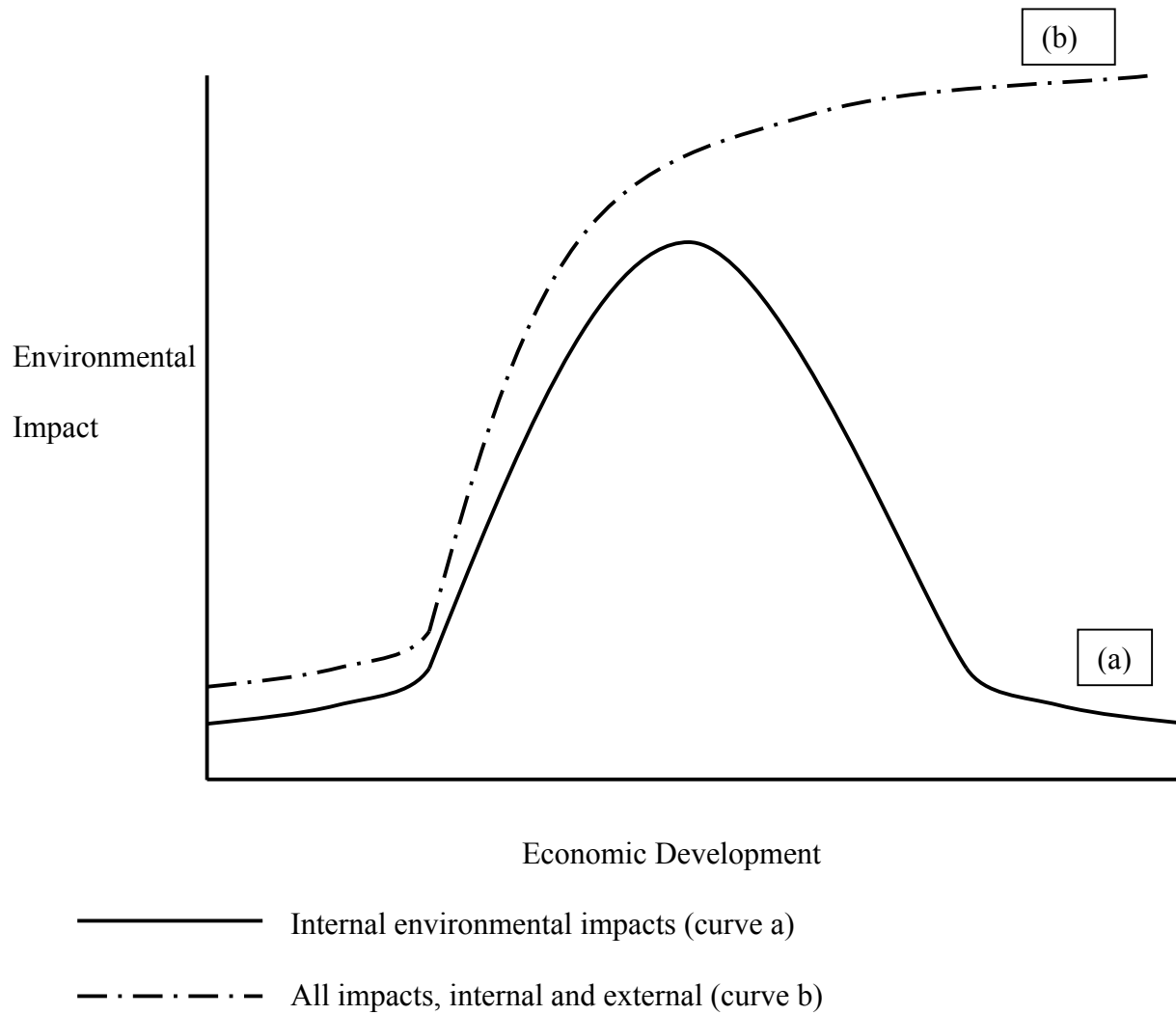
**AGGREGATE EF: THE SEPARATE MEASURES CAN BE SUMMED INTO AN OVERAL ECOLOGICAL FOOTPRINT**



## **2001: SELECTED ECOLOGICAL FOOTPRINT DATA:**

- **WORLD PRODUCTIVE LAND AREA = 11.3 BILLION HECTARES**
- **PER CAPITA PRODUCTIVE LAND AREA = 1.85 HECTARES**
- **WORLD ECOLOGICAL FOOTPRINT = 13.4 BILLION HECTARES**
- **PER CAPITA ECOLOGICAL FOOTPRINT = 2.2 HECTARES**
- **OVERSHOOT  $\approx$  20%**

**Figure 1. The theoretical effect of economic development on environmental impact.**





## **Polynomial Form of Kuznets Curve:**

$$\mathbf{Ln(I) = a + bLn(P) + cLn(A) + dLn(A)^2 + f Ln(T) + e}$$

**Table 1. Summary of the dependent variable (D.V.) and independent variables (I.V.s).**

<b>D.V.</b>	Description	Transformation	Data Source
Ecological Footprint	Land area in hectares required to support consumption of nation-state (1996)	Logged. For five cases one or two of the six components of the total EF were imputed (because they were missing) based on the values of the other components.	Wackernagel et al. (2000)
<b>I.V.</b>			
Population	1996 Population (1000's)	Logged	UNPD (1998)
Non-dependent population	Percentage of population between the ages of 15 and 65 (1995)	Logged	WRI (1996)
Land, p.c.	Land area in hectares per capita	Logged	WRI (1998)
Latitude	Distance from equator as indicator of climate	Dummy coded into three categories based on the predominant latitude of nation: Arctic (>55 degrees), temperate (30-55 degrees), and tropical (<30 degrees). Tropical is reference category in models.	Espenshade (1993)

P.C. GDP	Per capita gross domestic product in purchasing power parity (1996)	Logged. Interpolated from 1995 and 1997 values	WRI (1998, 2000)
(P.C. GDP-mean) <sup>2</sup>	The log of per capita GDP centered by subtracting the mean of the log of per capita GDP and then squared to reduce collinearity with P.C. GDP		WRI (1998, 2000)
% non-service	Percentage of GDP not in service sector (1996)	Logged. Interpolated from 1995 and 1997 values. The values for three cases were imputed based on values of other independent variables	WRI (1998, 2000)
Capitalist	Dummy coded. A value of 1 indicates that a nation is reported as being “capitalist,” “mixed-capitalist,” or “capitalist-statist” (1996)		Freedom House (1997)
% urban	Percentage of population living in urban areas (1995)	Logged	WRI (1996)
(% urban-mean) <sup>2</sup>	The log of % urban centered by subtracting the mean of the log of % urban and then squared to reduce collinearity with % urban		WRI (1996)
W-S position	Position in the world-	Dummy coded into three	WRI (2000)

	<p>system estimated based on the amount of “official development assistance” and “official assistance” a nation gives or receives (1995-1997)</p>	<p>categories: core (nations that are not net recipients of assistance), semi-periphery (nation that are net recipients but the assistance is less than .5% of their GDP), and periphery (all other nations). Periphery is reference category in models</p>	
Political rights	<p>Reflects whether a nation is governed by democratically elected representatives and has fair, open, and inclusive elections (1996)</p>	<p>Dummy coded based on original 7-point scale into three categories: Free (1-2), partially free (3-5), or not free (6-7). Not free is reference category in models</p>	Freedom House (1997)
Civil liberties	<p>Reflects whether within a nation there is freedom of</p>	<p>Dummy coded based on original 7-point scale into three categories:</p>	Freedom House (1997)

	the press, freedom of assembly and demonstration, general personal freedoms, freedom of private organizations, including businesses, and property rights (1996)	Free (1-2), partially free (3-5), or not free (6-7). Not free is reference category in models	
State Environmentalism	Index based on state participation in 16 environmental treaties	Dummy coded based on dividing the index into equal thirds reflecting degree of environmentalism: high, medium, and low (reference category in models)	Roberts and Vásquez (2002)



**Table 2. Nations in sample (N=142) and the antilog of residuals for model 4.**

Albania	0.92	Greece	1.05	Pakistan	1.09
Algeria	0.62	Guatemala	0.97	Panama	0.88
Angola	0.82	Guinea	0.95	Papua New Guinea	0.96
Argentina	0.76	Guinea Bissau	0.87	Paraguay	1.48
Armenia	0.69	Haiti	0.81	Peru	0.56
Australia	0.95	Honduras	1.12	Philippines	0.90
Austria	0.80	Hungary	1.25	Poland	1.53
Azerbaijan	1.12	Iceland	0.52	Portugal	1.08
Bangladesh	0.69	India	1.02	Romania	1.13
Belarus	1.52	Indonesia	0.88	Russia	1.32
Belgium	0.68	Iran	0.98	Rwanda	1.07
Benin	1.00	Ireland	1.50	Saudi Arabia	1.86
Bhutan	0.75	Israel	0.87	Senegal	0.90
Bolivia	0.71	Italy	0.81	Sierra Leone	0.88
Botswana	0.77	Jamaica	1.29	Singapore	1.89
Brazil	0.91	Japan	0.78	Slovakia	1.15
Bulgaria	1.11	Jordan	0.74	Slovenia	0.98
Burkina Faso	1.04	Kazakhstan	1.52	Somalia	1.11
Burundi	1.00	Kenya	1.31	South Africa	1.35
Cambodia	0.89	Korea Republic	0.98	Spain	0.86
Cameroon	0.70	Kuwait	1.95	Sri Lanka	0.65
Canada	0.80	Kyrgyzstan	1.02	Sudan	1.17

Central African Rep.	0.95	Laos	0.88	Sweden	0.93
Chad	0.79	Latvia	1.03	Switzerland	0.87
Chile	0.61	Lebanon	0.79	Syria	1.28
China	0.89	Lesotho	1.22	Tajikistan	0.73
Colombia	0.60	Lithuania	1.28	Tanzania	1.32
Congo Dem Rep	0.92	Macedonia	1.09	Thailand	1.17
Congo Rep	0.80	Madagascar	1.11	Togo	0.86
Costa Rica	1.17	Malawi	1.17	Trinidad and Tobago	0.78
Côte d'Ivoire	0.91	Malaysia	1.37	Tunisia	0.75
Croatia	0.65	Mali	1.05	Turkey	0.84
Czech Republic	1.30	Mauritania	0.81	Turkmenistan	1.59
Denmark	1.16	Mauritius	0.71	Uganda	1.09
Dominican Republic	0.64	Mexico	0.93	Ukraine	1.89
Ecuador	1.03	Moldova Republic	1.07	United Arab Emirates	2.76
Egypt	1.05	Mongolia	1.87	United Kingdom	0.90
El Salvador	1.12	Morocco	0.68	U.S.A.	1.46
Eritea	0.82	Mozambique	0.85	Uruguay	0.99
Estonia	1.72	Myanmar	1.16	Uzbekistan	1.50
Ethiopia	1.24	Nepal	1.14	Venezuela	0.82
Finland	1.08	Netherlands	0.79	Vietnam	0.92
France	1.05	New Zealand	1.26	Yemen	0.80
Gabon	0.88	Nicaragua	0.90	Yugoslavia	1.14
Gambia	0.97	Niger	1.18	Zambia	1.20

Georgia	0.73	Nigeria	1.44	Zimbabwe	1.18
Germany	0.83	Norway	0.69		
Ghana	1.05	Oman	1.61		

**Table 3. Factors influencing national ecological footprint. OLS regression results. All continuous variables in log form.**

Independent Var.	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	B	S.E.	b	S.E.	B	S.E.	B	S.E.	b	S.E.	b	S.E.
Population	.992***	.023	.987***	.023	.964***	.022	.980***	.018	.977***	.022	.977***	.022
Non-dep. pop.	1.302**	.467	1.594***	.425	1.431***	.390	1.387***	.426	-	-	-	-
Land, p.c.	.045*	.022	-	-	-	-	.045*	.022	-	-	-	-
Latitude <sup>a</sup>												
Arctic	.435**	.136	-	-	-	-	.339**	.124	-	-	-	-
Temperate	.283***	.081	-	-	-	-	.260***	.070	-	-	-	-
P.C. GDP	.455***	.064	.443***	.056	.430***	.065	.396***	.042	.658***	.028	.660***	.028
(P.C. GDP-mean) <sup>2</sup>	.088**	.032	.050	.027	.066*	.031	.049*	.023	.028	.026	-	-
% non-service	.005	.150	.061	.158	-	-	-	-	-	-	-	-
Capitalist	-.022	.072	-.124	.072	-.165*	.065	-	-	-	-	-	-
% urban	.247*	.095	.405***	.095	.353***	.093	.280**	.089	-	-	-	-
(% urban-mean) <sup>2</sup>	.104	.064	.139*	.067	.125	.066	.139*	.062	-	-	-	-
W-S position <sup>b</sup>												
Core	-.110	.166	-	-	.062	.163	-	-	-	-	-	-
Semi-periphery	.117	.084	-	-	.120	.084	-	-	-	-	-	-
Political rights <sup>c</sup>												
Free	-.002	.106	-.023	.113	-	-	-	-	-	-	-	-
Partially free	-.018	.089	-.074	.094	-	-	-	-	-	-	-	-
Civil liberties <sup>d</sup>												
Free	-.013	.147	.022	.157	-	-	-	-	-	-	-	-
Partially free	-.020	.101	-.045	.107	-	-	-	-	-	-	-	-
State. Env. <sup>e</sup>												
High	-.177	.096	-.130	.101	-	-	-	-	-	-	-	-
Medium	-.069	.070	-.073	.074	-	-	-	-	-	-	-	-
Constant	-8.958***	1.863	-10.786***	1.631	-9.362***	1.448	-8.780***	1.510	-4.246***	.422	-4.233***	.422
R <sup>2</sup>	.972		.966		.965		.969		.949		.949	
Mean/highest VIF	3.63/8.55		3.33/6.76		3.32/7.74		2.36/4.54		1.00/1.00		1.00/1.00	

\* p<.05 \*\* p<.01 \*\*\* p<.001



## **GENERAL FINDINGS:**

### **FOR EVERY IMPACT EXAMINED:**

- **SUPPORT FOR CONTINUED IMPACT THEORIES (CURVE b)**
- **REJECTION OF NEO-LIBERAL /MODERNIZATION THEORIES (CURVE a)**

# STIRPAT RESEARCH PROGRAM: EMPIRICAL STUDIES

Publication Date	Publication Outlet	Dependent Variables	Number of Nations	Data Year	Kuznets Curve	Noteworthy Features
1997	PNAS	CO <sub>2</sub> Emissions	111	1989	>\$10K	GDP/PC < \$5K for 75% of Nations
2003	International Journal of Sociology & social Policy	1. CO <sub>2</sub> 2. CH <sub>4</sub> 3. GWP*	1. 137 2. 137 3. 137	1. 1991 2. 1991 3. 1991	n.s. n.s. + Quadratic	
2003	American Sociological Review	Total Ecological Footprint (EF)	142	circa 1996	+ Quadratic	No support for neo-liberal modernization theories
2003	Ecological Economics	1. CO <sub>2</sub> Emissions 2. Energy Footprint	1. 146 2. 138	1. 1996 2. 1999	>\$61K <sup>1</sup> + Quadratic	<sup>1</sup> Turning point is well beyond the range of observations
2004	AMBIO	1. ODS** 2. CO <sub>2</sub> 3. CH <sub>4</sub> 4. Total EF 5. Forest EF 6. Grazing EF 7. Arable EF 8. Fishing EF 9. Built-up EF	1. 131 2. 146 3. 147 4. 142 5. 142 6. 142 7. 142 8. 142 9. 142	1. 1997 2. 1996 3. 1991 4. 1996 5. 1996 6. 1996 7. 1996 8. 1996 9. 1996	>\$13K <sup>1</sup> >\$34.8 <sup>2</sup> n.s. + Quadratic + Quadratic n.s. n.s. n.s. n.s.	<sup>1</sup> Beyond the range of a vast majority of nations <sup>2</sup> Beyond the range of observations
2004	JIE	EF/GDP/Md***	139	1998-9	N.A.	Sensitivity analyses reveal the need for extraordinary gain in efficiency to counter footprint effects
2005	Globalization & The Environment	1. SO <sub>2</sub> 2. NO <sub>x</sub>	1. 138 2. 138	1. 1995 2. 1995	>\$14.4K <sup>1</sup> >\$23.3K <sup>2</sup>	<sup>1</sup> 85% of nations are below this <sup>2</sup> 99% of nations are below this

\* GWP = Global Warming Potential (A combination CO<sub>2</sub> and CH<sub>4</sub>)

\*\* ODS = Ozone Depleting Substances (Chlorofluorocarbons (CFCs), halons, other fully halogenated CFCs, carbon tetrachloride, methyl, chloroform, HCFCs, and methyl bromide)

\*\*\* Md = The median of the EF/GDP Ratio

## **SPECIFIC FINDINGS:**

### **FOR EVERY IMPACT EXAMINED:**

- **POPULATION IS ALWAYS THE LEADING DRIVER OF IMPACTS**
  - (1) **CONSISTENTLY A PROPORTIONAL RELATIONSHIP (UNIT ELASTICITY)**
- **AFFLUENCE IS ALWAYS A DRIVER OF IMPACTS**
  - (1) **FOR CO<sub>2</sub> THE RELATIONSHIP IS ALWAYS ELASTIC (COEFICIENT  $\approx 1.5$ )**
  - (2) **FOR OTHER IMPACTS THE RELATIONSHIP IS INELASTIC (COEFICIENTS OF .26 TO .94)**
- **OTHER CONTRIBUTING FACTORS: (1) POPULATION COMPOSITION, (2) LATTITUDE, AND (3) URBANIZATION**

## **DIRECTIONS IN STIRPAT RESEARCH PROGRAM:**

### **□ WORK IN PROGRESS:**

- REFINEMENTS IN PROJECTIONS OF THE EF TO 2020 AND 2030**
- REASONS FOR SHIFTING TURNING POINTS WHEN KUZNETS CURVES APPEAR**
- PANEL ANALYSES**

### **□ FUTURE WORK:**

- TIME SERIES ANALYSES OF EF**
- INTEGRATING SOCIETAL WELL-BEING (QUALITY OF LIFE) WITH EF ANALYSES**



**“TO MAKE SUSTAINABILITY HAPPEN WE NEED TO BALANCE THE BASIC CONFLICT BETWEEN THE TWO COMPETING GOALS OF ENSURING QUALITY OF LIFE AND LIVING WITHIN THE LIMITS OF NATURE” (P. 3).**

**“THE FOOTPRINT INTENTIONALLY SAYS NOTHING ABOUT PEOPLE’S QUALITY OF LIFE. QUALITY OF LIFE HAS TO BE LOOKED AT SEPARATELY...” (P. 31).**

**Chambers, Nicky, Craig Simmons, and Mathis Wackernagel. 2000, *Sharing Nature’s Interest: Ecological Footprints as an Indicator of Sustainability*.**

