Militarization and the Environment: A Panel Study of Carbon Dioxide Emissions and the Ecological Footprints of Nations, 1970–2000

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Introduction

The detonation of Trinity—the first atomic explosion—in the New Mexico desert on July 16, 1945, simultaneously ushered in the nuclear era and the contemporary age of ecology.[2] This atomic test, as well as those that followed, introduced radioactive fallout into the environment that was distributed around the globe by wind, water, and living creatures.[3] This is one—highly visible—example of military actions that have repercussions for the global environment. Indeed, throughout history, military operations and war have involved the degradation of land and ecosystems, but increasingly such processes generate greater environmental impacts. These society/nature relationships are, in part, a function of emergent military technologies and the capability to transport weapons and growing numbers of soldiers to distant regions, both in times of peace and war. In the name of national security military establishments in wealthy and poor countries alike have developed large-scale built and social infrastructures to sustain and support the coercive power of nations.

These military establishments are clearly resource consumptive and waste generating endeavors. However, comparative research in the social sciences on the environmental impacts of militarization is greatly lacking. Given their potential consequences for the natural environment and well-being of human

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2. Davis 2002; Hagen 1992; and Worster 1998.
3. Commoner 1971, 49–53.

Global Environmental Politics 10:1, February 2010

populations throughout the world, we contend that the inattention to such human/environment relationships should be addressed. We begin to consider these issues by examining the impact of military personnel and equipment on multiple environmental outcomes. More broadly considered, though, our work expands recent theorization concerning the environmental impacts of militarization. In this article, we engage with a particular perspective—known as treadmill of destruction theory[4]—and situate it within an international comparative orientation. Our empirical findings indicate that military equipment and personnel both contribute to increases in the scale and intensity of anthropogenic carbon dioxide emissions as well as the consumption-based environmental impacts of nations, which strongly supports the proposed theorization.

We begin with a discussion of treadmill of destruction theory and the potential environmental consequences of militarization. We detail how military personnel and equipment (especially high-tech equipment) consume vast amounts of natural resources, including fossil fuels that contribute to climate change. We then describe the samples, variables, data sources, and panel regression techniques employed in the quantitative analyses. Next, we present and summarize the findings for the analyses, focusing on the impacts of the two key military measures. We conclude by highlighting the theoretical relevance of our findings for future comparative research on the human dimensions of global environmental change.

The Military, Treadmill of Destruction Theory and Environmental Degradation

Recent comparative investigations in the social sciences address how different aspects of the military influence economic development, domestic income inequality, and other social outcomes.[5] However, with few exceptions,[6] theorization and macro-comparative research on the environmental impacts of militarism are non-existent in the social sciences.[7] The general inattention to the environment is indeed highly problematic. As Kenneth Gould—an environmental sociologist—poignantly asserts, "militarization is the single most ecologically destructive human endeavor."[8] Without doubt, national security interests have increasingly guided technological change, with the latter being capital

4. Hooks and Smith 2004, 2005.
5. Jenkins and Scanlan 2001; Kentor and Kick 2008; Kick et al. 1998; Kick, Davis, and Kentor 2006; and Levy 1998.
6. Hastings 2000; Jorgenson 2005; Hooks and Smith 2004, 2005; Singer and Keating 1999; and York 2008.
7. Of the few extant macro-comparative studies on military and environment relationships, most are descriptive and atheoretical (e.g. Hastings 2000; and Singer and Keating 1999) or focus on only one aspect of the military (e.g. Jorgenson 2005; and York 2008). In the current study we consider multiple aspects of national militaries and situate the research in a focused theoretical orientation.
8. Gould 2007, 331.

and labor intensive, requiring an enormous amount of resources—including oil—to meet military demand.[9] Randall Collins notes that the technological innovations associated with national militaries enhance the ability to move massive amounts of equipment and large numbers of soldiers throughout the world, which increases the ancillary infrastructure and resources required to support such global movements.[10]

A notable theoretical exception comes from Hooks and Smith,[11] who characterize the expansionary dynamics and profound environmental impacts associated with militarism as the "treadmill of destruction." Treadmill of destruction theory is, in part, inspired by the treadmill of production perspective, which argues that an economic system predicated on constant growth generates ever increasing environmental degradation.[12] However, Hooks and Smith[13] note that the military is not simply a derivative of the economic system but has its own expansionary dynamics with unique environmental impacts. Drawing from various perspectives within political sociology,[14] Hooks and Smith[15] argue that, primarily for geopolitical reasons, states—not classes or firms—declare and wage wars. At the same time, military development—influenced by geopolitics and domestic pressures—generates various forms of environmental degradation. Thus, the fundamental logic of the treadmill of destruction undermines environmental protection concerns. This was clearly articulated by a US military base commander during a community hearing in Virginia: "We are in the business of protecting the nation, not the environment."[16]

Warfare causes significant environmental harms, including the chemical contamination of ecosystems and devastation of landscapes that result directly from military weaponry. Moreover, military campaigns consume enormous amounts of fossil and nuclear fuels in planes, ships, and tanks.[17] Michael T. Klare[18] notes that the US military consumes at least 1.3 billion gallons of oil annually in the Middle East alone—more than the annual consumption of Bangladesh.[19] Such levels of fossil fuel use are a major source of carbon dioxide emissions that contribute to climate change.[20]

Treadmill of destruction theory contends that the expansionary dynamics of militarism are not limited to periods of war. Vested geopolitical and military

9. Shaw 1988.
10. Collins 1981.
11. Hooks and Smith 2004, 2005.
12. Gould, Pellow, and Schnaiberg 2008; and Schnaiberg and Gould 1994.
13. Hooks and Smith 2004.
14. Mann 1988; Tilly 1990.
15. Hooks and Smith 2005.
16. Renner 1991, 152.
17. Davis 2002; Grimes 1999; Klare 2002; Lanier-Graham 1993; Marshall 2005; Pellow 2007; and Thomas 1995.
18. Klare 2007.
19. This figure does not include all those soldiers in training and transit or the vast military infrastructure that surrounds the world.
20. Intergovernmental Panel on Climate Change 2007.

interests as well as constant preparation for future conflicts escalate the scale and operations of militaries. As a result, even in the absence of armed conflict military institutions and their activities consume vast amounts of nonrenewable energy and other resources for research and development, maintenance, and operation of the overall infrastructure.[21] At the same time, they generate large amounts of toxic substances and waste, which contribute to the contamination of land and water. While some contamination occurs through the testing of weapons,[22] militaries also use a broad range of thinners, solvents, lubricants, degreasers, fuels, pesticides, and propellants as part of the everyday operation and maintenance of military equipment. As a result, militaries "produce the greatest amount of hazardous waste in the world."[23] Further, "the most ecologically devastated locations on Earth" are found wherever "military production facilities" operate, given that they are often "exempt from environmental protection legislation in the name of national security."[24]

According to the United Nations' Centre for Disarmament,[25] armed forces have used a steadily increasing amount of land for bases, other installations, and training exercises over the last century. Even the end of the Cold War has not reduced the use of public lands for military operations, training, testing, and exercises.[26] The United States alone has hundreds of military bases in almost sixty countries.[27] A network of military bases encompasses the globe, requiring a vast amount of resources—especially fossil fuels—to staff, operate, and transport equipment and personnel between destinations. Collins[28] notes that even with advanced technologies, military operations require bases close to theaters of action to supply energy and personnel needs. To a significant extent military power remains dependent upon access to land.

In order to support operations and personnel, militaries must have ready supplies of raw materials and energy as well as the infrastructure to meet specific needs. Consequently, military-oriented resource use involves strategic stockpiling of fuels and other materials, with resource consumption further increased by industries that produce marginal equipment for the armed forces and their support economies. The production of such marginal equipment and stockpiling of fuels places greater demands upon the environment. The populations of armed forces also use large quantities of materials for uniforms and specialized forms of clothing that would not otherwise be consumed. Further, the labor intensity of militaries increases the resources required for training, armaments, transportation, and the housing of troops and support personnel.

21. Dycus 1996; Jorgenson 2005; Sidel and Shahi 1997; and York 2008.
22. Hastings 2000; LaDuke 1999; Shulman 1992; and Ward 1999.
23. Singer and Keating 1999, 338.
24. Gould 2007, 331.
25. United Nations' Centre for Disarmament 1982.
26. Singer and Keating 1999.
27. Blaker 1990; and Foster 2006.
28. Collins 1981.

The peacetime activities of the military generate different forms of waste. During regular operations, the armed forces consume large amounts of fossil fuels.[29] Renner[30] estimates that the petroleum products used for land vehicles, aircrafts, sea vessels, and other military machinery account for approximately 75 percent of all energy use by the armed forces worldwide. Further, the US Pentagon operates "the world's largest fleet of modern aircraft, helicopters, ships, tanks, armored vehicles, and support systems," which is almost entirely fueled by oil.[31] As a result, the Department of Defense is "the world's leading consumer of petroleum."[32]

We argue that treadmill of destruction theory provides a useful avenue for understanding the relationships between the military and environment. While developing this perspective, Hooks and Smith[33] focused on the US military and domestic environmental conditions. Here we situate the theoretical orientation in an international comparative perspective, thereby extending the logic of the theory to the overall environmental impacts of the world's national militaries. Geopolitical competition often drives arms races as well as concomitant technological advances, infrastructural development, and growth in troop size. Especially for developed nations, the environmentally damaging capabilities of their militaries are partly a function of technological developments with weaponry and other machinery. These capital-intensive militaries employ advanced weaponry and utilize state of the art transportation systems to facilitate the rapid movement of troops and to enhance their strike capabilities, including an extensive system of vehicles and infrastructure to aid in the deployment of equipment and personnel. Further, capital-intensive militaries are likely to increase their material infrastructure or become more spatially dispersed.[34] The logic of treadmill of destruction theory suggests that as nations develop more capital-intensive militaries, their environmental impacts will increase. In a related vein, political-economic sociologists and international relations scholars have emphasized that nations with relatively large and more technologically advanced militaries utilize their global military reach to gain disproportionate access to natural resources.[35]

Overall, we posit that military personnel and high-tech equipment require extensive infrastructures that are highly resource consumptive and waste generating. While prior cross-national research investigates the environmental impacts of capital-intensive, high-tech militarization in the form of either *military*

29. Roberts, Grimes, and Manale 2003.
30. Renner 1991.
31. Klare 2007.
32. Klare 2007; also see Hynes 1999; and Santana 2002.
33. Hooks and Smith 2004, 2005.
34. Kentor and Kick 2008.
35. Chase-Dunn 1998; Dalby 2004; Conca 2004; Kentor 2000; Magdoff 1978; McNeill 1982; and Podobnik 2006.

expenditures per soldier[36] or *number of military personnel*,[37] we consider it crucial to consider both simultaneously. Doing so allows for a more thorough assessment of treadmill of destruction theory in a comparative perspective. Thus, in the subsequent panel analyses we assess the effects of military expenditures per soldier and military personnel on multiple environmental outcomes: total and per capita carbon dioxide emissions, and the per capita ecological footprints of nations.[38] Treadmill of destruction theory would propose that both of these military factors contribute to increases in the per capita consumption-based environmental impacts of nations (i.e. their ecological footprints) as well as increases in both the scale (i.e. total) and intensity (i.e. per capita) of their anthropogenic carbon dioxide emissions.

Empirical Analyses

We conduct cross-national empirical analyses to investigate the impacts of national militaries on carbon dioxide emissions and the ecological footprints of nations. Two aspects of the military establishment are considered: *military participation* (the number of military personnel per 1000 population) and *military expenditures per soldier*. We use these findings to assess the validity of treadmill of destruction theory.

Methods and Data

We use a pooled time series of cross-sections (TSCS) panel dataset design to estimate fixed effects (FE) models with the within estimator, which amounts to using ordinary least squares (OLS) to perform the estimations. This is one of the most commonly used methods in the comparative social sciences because it addresses the problem of heterogeneity bias.[39] Heterogeneity bias in this context refers to the confounding effect of unmeasured time-invariant variables that are omitted from the regression models. To correct for heterogeneity bias, FE models control for omitted variables that are time invariant but that do vary across cases. This is done by estimating unit-specific intercepts, which are the fixed-effects for each case. FE models are quite appropriate for this type of cross-national panel research because time invariant unmeasured factors such as natural resource endowments and geographic region could affect environmental outcomes. The FE approach also provides a stringent assessment of the relation-

36. Jorgenson 2005.
37. York 2008.
38. At the time of the study, panel data on the total ecological footprints of nations were unavailable. Assessing per capita resource consumption removes the effects of population, assuming consumption is scaled proportionally by population size. However, prior cross-sectional research on the total ecological footprints of nations reveals that the population elasticity of the total ecological footprints of nations is very close to 1.0 (Dietz, Rosa, and York 2007; and York, Rosa, and Dietz 2003), which justifies the use of per capita footprint measures.
39. Halaby 2004.

Table 1
Countries Included in the Analyses

Algeria*	El Salvador	Kuwait*	Portugal*
Argentina*	Finland*	Luxembourg	Rwanda*
Australia	France*	Madagascar	Senegal*
Austria*	Ghana	Malawi	South Africa*
Bangladesh	Greece	Malaysia	Spain
Belgium*	Guatemala	Mexico*	Sri Lanka
Bolivia	Hungary*	Morocco	Sweden*
Brazil*	India*	Nepal*	Syrian Arab Republic*
Burundi	Indonesia*	Netherlands*	Thailand*
Cameroon*	Iran*	New Zealand	Togo
Canada*	Ireland*	Nicaragua	Tunisia*
Chile	Israel	Nigeria	Turkey*
Colombia*	Italy*	Norway	United Kingdom*
Cyprus	Jamaica	Oman	United States*
Denmark	Japan*	Pakistan*	Uruguay
Dominican Republic	Jordan	Panama*	Venezuela*
Ecuador	Kenya*	Peru	Zambia
Egypt*	Korea	Philippines	Zimbabwe

* denotes countries included in the Ecological Footprint per capita analyses

ships between military characteristics and all three outcomes, given that the associations between them are estimated net of unmeasured between-country effects. Overall, this modeling approach is quite robust against missing control variables and closely approximates experimental conditions.[40] Results of Hausman tests also indicate that FE models are more appropriate than random effects (RE) models for the current analyses. In all OLS FE models we include a correction for first-order autocorrelation (i.e. AR[1] correction). Not correcting for autocorrelation can often lead to biased standard error estimates.[41]

We analyze two balanced cross-national panel datasets consisting of five year increments from 1970 to 2000. The first dataset, which is for the carbon dioxide emissions analyses, includes seven observations on seventy-two nations with a total of 504 observations. The second dataset, for the analyses of per capita ecological footprints,[42] consists of seven observations on thirty-seven nations totaling 259 observations. The countries in each dataset consist of those where observations of the dependent variable(s) and all independent variables

40. Hsiao 2003.
41. Greene 2000; and Wooldridge 2002.
42. These analyses are restricted to countries where the ecological footprints contain no temporal anomalies in their calculations as identified by Susannah Buchan, a research associate for the Global Footprint Network.

are available for the seven time points. Table 1 lists all countries included in each of the two datasets.

We do not restrict our sample based on economic development, as is sometimes done, as we find no pressing theoretical arguments to do so. However, in analyses not reported here, we tested the robustness of our findings with datasets limited to less-developed countries. Following the suggestion of an anonymous reviewer, we also re-estimated all models with the United States removed from the datasets. No substantive differences were found in any of these analyses, all of which are available from the authors upon request.

The Dependent Variables

Total carbon dioxide emissions (ln) (i.e. scale emissions) and *carbon dioxide emissions per capita (ln)* (i.e. intensity emissions) are the study's first two dependent variables. Both measures are obtained from the World Resources Institute (WRI).[43] Anthropogenic carbon dioxide emissions represent the mass of carbon dioxide produced during the combustion of solid, liquid, and gaseous fuels, as well as from gas flaring and the manufacture of cement. They do not include emissions from land use change or emissions from bunker fuels used in international transportation. More specifically, the data come from the World Resources Institute's Climate Analysis Indicators Tool (CAIT), which is an information and analysis tool on global climate change.[44] CAIT provides a comprehensive and comparable database of greenhouse gas emissions data (including all major sources and sinks) and other climate-relevant indicators.

Total carbon dioxide emissions are measured in thousands of metric tons. Carbon dioxide emissions per capita represent the mass of carbon dioxide emitted per person for a country in metric tons as a result of the same production and flaring processes as for the measures of total emissions. WRI calculates per capita emissions from total emissions divided by population estimates from the United Nations Population Division. Both measures of carbon dioxide emissions are logged (ln) to minimize skewness. Where appropriate, other variables are logged for analogous reasons.

The third dependent variable is the *ecological footprint per capita (ln)*, which we obtained directly from the Global Footprint Network. We treat this variable as a relatively comprehensive indicator of consumption-based environmental demand. The recently updated national footprint estimates measure the bioproductive area required to support consumption levels of a given population from cropland (food, animal feed, fiber, and oil); grassland and pasture (grazing of animals for meat, hides, wool, and milk); fishing grounds (fish and seafood); and forest (wood, wood fiber, pulp, and fuelwood). They also in-

43. World Resources Institute 2005.
44. For additional information on CAIT and the methodology used in calculating the carbon dioxide estimates, go to http://cait.wri.org/.

clude the area required to absorb the carbon dioxide released when fossil fuels are burned, and the amount of area required for built infrastructure (e.g. roads and buildings). Regarding the former, the carbon dioxide portion of the footprint deals explicitly with natural sequestration, which involves the biocapacity required to absorb and store emissions not sequestered by humans, less the amount absorbed by the oceans. A relatively new addition to the comprehensive footprint measure is the nuclear energy footprint subcomponent. In the absence of conclusive and available data, the nuclear energy portion of the footprint is estimated as the same as the equivalent amount of electricity from fossil fuels. However, this subcomponent accounts for less than 4 percent of the total global footprint in the year 2000, and this percentage is even lower for earlier years. The ecological footprint is measured and reported in global hectares, and is calculated by adding imports to, and subtracting exports from, domestic production. In mathematical terms, consumption = (production + imports)—exports. This balance is calculated for more than 600 products, including both primary resources and manufactured products that are derived from them.[45]

Key Independent Variables

To evaluate the proposed theorization, we employ two key military measures: *military expenditures per soldier* and *military participation.* Military expenditures data[46] include all current capital expenditures on the armed forces, including: peacekeeping forces, defense ministries and other government agencies engaged in defense projects, paramilitary forces that are trained and equipped for military operations, and military space activities. More specifically, such expenditures include operation and maintenance, procurement, military research and development, military and civil personnel (including retirement pensions of military personnel and social services for personnel), and military aid (in the military expenditures of the donor country).

Military expenditures per soldier (ln) is calculated by dividing total military expenditures by total military personnel. Total military personnel estimates are gathered from the World Bank[47] and total military expenditures are obtained

45. The footprint calculations also use (1) equivalence factors to take into account differences in world average productivity among different land types, and (2) yield factors to take into account national differences in biological productivity. The ecological footprint includes only those aspects of resource consumption and waste production for which the Earth has regenerative capacity and where data exist that allow this demand to be quantified in terms of bioproductive area. Thus, it does not include issues such as radioactive and toxic wastes, two components associated with the environmental impacts of militaries. The storage of nuclear waste and toxic contamination are important issues that deserve attention in future comparative research. For additional details on the ecological footprint, we refer readers to the Global Footprint Network's webpage (http://www.footprintnetwork.org).
46. SIPRI 2000.
47. World Bank 2007.

from the Stockholm International Peace Research Institute (SIPRI).[48] This variable measures the high-tech nature, or capital intensiveness, of national militaries.[49]

Military participation (ln) is the ratio of military personnel per 1000 population. Military personnel data (from the World Bank)[50] counts active duty military personnel and paramilitary forces if the training, organization, and equipment suggest they may be used to support or replace regular military forces. Like others, we treat this variable as an indicator of the relative labor intensity of nations' militaries.[51]

Additional Independent Variables

Military expenditures as percentage of gross domestic product (GDP) (ln) are obtained from the World Bank[52] based on SIPRI's military expenditures data and total GDP data in constant US dollars. Prior cross-national research on carbon dioxide emissions includes these data as a measure of nations' relative military investments and expenditures.[53] More importantly, controlling for military expenditures as percentage of GDP allows for more rigorous assessments of the effects of military expenditures per soldier and military participation in particular, and treadmill of destruction theory in general.

GDP per capita (ln) is included as a control for level of economic development. These data, which we gather from the World Bank,[54] are measured in constant 2000 US dollars. Data for all other variables described below are obtained from the same source. Political-economic approaches, including treadmill of production theory, the metabolic rift, and world-systems analysis, as well as structural human ecology, all argue that development is a key driver of environmental degradation measured by scale and intensity.[55] Indeed, prior research on carbon dioxide emissions and ecological footprints (total and per capita for both) consistently shows a positive association between these outcomes and level of economic development.[56]

Total population (ln), measured in thousands, is included only in the analyses of total carbon dioxide emissions. Social scientists working in the structural human ecology tradition argue that population is a key driver of scale-level environmental outcomes.[57]

48. SIPRI 1977, 1984, 1987, 1991, 2000, 2008.
49. Kentor and Kick 2008; and Jorgenson 2005.
50. World Bank 2007.
51. Kick, Davis, and Kentor 2006; Weede 1993; and York 2008.
52. World Bank 2007.
53. Roberts, Grimes, and Manale 2003.
54. World Bank 2007.
55. Clark and York 2005; Gould, Pellow, and Schnaiberg 2008; Roberts and Grimes 2002; and York, Rosa, and Dietz 2003.
56. Jorgenson 2005, 2007, 2009; Jorgenson and Burns 2007; Özler and Obach 2009; Roberts and Parks 2007; York 2008; and York, Rosa, and Dietz 2003.
57. Rosa, York, and Dietz 2004; and Shi 2003.

Manufacturing as percentage of total GDP controls for the extent to which a domestic economy is manufacturing-based. Most perspectives in the social sciences posit that all else being equal, nations with larger manufacturing sectors will consume larger and more intensive amounts of fossil fuels and other resources, which contribute to increases in both carbon dioxide emissions and overall consumption-based environmental impacts.

Urban population as percentage of total population controls for a country's level of urbanization. Prior cross-sectional and panel analyses reveal positive associations between urbanization and a variety of environmental outcomes, including the total and per capita ecological footprints of nations,[58] as well as the emission of carbon dioxide and other noxious gases.[59] While perhaps the most common measure of urbanization for cross-national research in the environmental social sciences, we acknowledge its relative limitations.

Percentage of population aged 15–64 controls for the extent to which a nation's population is adult and non-dependent. Structural human ecology[60] posits that all else being equal, nations with relatively larger non-dependent adult populations will consume more fuels and natural resources, which increases both the intensity and scale of carbon dioxide emissions, as well as per capita ecological footprints.

Exports as percentage of total GDP (ln) controls for the extent to which a country is integrated into the international trading system. While the potential environmental impacts of trade are not the focus of the current study, recent analyses show a positive association between exports and carbon dioxide emissions.[61] A partial explanation for these findings is that in order to be relatively competitive in the world-economy, trade and other forms of economic globalization create added pressures for less-developed countries to lower environmental standards for export-oriented production. Since levels of exports are used in the ecological footprint calculations, we exclude this predictor from the per capita footprint analyses.

Table 2 provides descriptive statistics and correlations for all variables in both of our datasets. We note that all three outcomes have moderate to strong positive bi-variate associations with military expenditures per soldier and military participation. Military expenditures per soldier and GDP per capita are highly correlated in both datasets, a problem we address below.[62]

58. Jorgenson and Burns 2007; and York, Rosa, and Dietz 2003.
59. Jorgenson 2007; and York and Rosa 2006.
60. Dietz and Rosa 1994.
61. Jorgenson 2007; Schofer and Hironaka 2005; and York 2008.
62. Additional moderate correlations exist between couplings of other predictors as well, most notably between GDP per capita and urban population as well as between GDP per capita and percentage of population aged 15 to 64. While these statistical controls are not the focus of the current study, in sensitivity analyses (available upon request), we estimated the models with regular OLS regression and assessed the variance inflation factors (VIFs) for all coefficients. VIFs are all well below an acceptable threshold (i.e. all below 4.0), suggesting that the reported FE models are not unstable due to multicollinearity.

Table 2
Descriptive Statistics and Bi-Variate Correlations

	Mean	*S.D.*		*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*	*8.*	*9.*	*10.*
Total CO_2 Emissions (ln)	10.12	2.08	**1.**										
Per Capita CO_2 Emissions (ln)	8.29	1.63	**2.**	.74									
Military Expenditures Per Soldier (ln)	9.47	1.33	**3.**	.58	.80								
Military Participation (ln)	1.79	.75	**4.**	.27	.48	.20							
Military Expenditures as % GDP (ln)	1.29	.59	**5.**	.06	.12	.21	.62						
GDP Per Capita (ln)	7.81	1.57	**6.**	.62	.92	.87	.45	.05					
Total Population (ln)	9.51	1.40	**7.**	.63	−.05	−.06	−.16	−.04	−.14				
Manufacturing as % GDP	17.25	6.28	**8.**	.45	.36	.26	.11	−.12	.35	.25			
Urban Population as % Total Population	53.57	23.72	**9.**	.59	.85	.71	.46	.09	.85	−.11	.34		
Percent Population Aged 15 to 64	58.31	6.37	**10.**	.62	.72	.63	.32	−.09	.78	.09	.37	.66	
Exports as % GDP (ln)	3.20	.64	**11.**	−.07	.38	.27	.14	.01	.32	−.55	−.06	.29	.21

Note: N=504

	Mean	*S.D.*		*1.*	*2.*	*3.*	*4.*	*5.*	*6.*	*7.*
Ecological Footprint Per Capita	1.23	.50	1.							
Military Expenditures Per Soldier (ln)	9.71	1.35	**2.**	.85						
Military Participation (ln)	1.78	.65	**3.**	.35	.08					
Military Expenditures as % GDP (ln)	1.28	.52	**4.**	.01	.09	.54				
GDP Per Capita (ln)	8.08	1.56	**5.**	.93	.89	.34	−.07			
Manufacturing as % GDP	18.42	6.52	**6.**	.35	.37	.09	−.12	.43		
Urban Population as % Total Population	55.52	23.28	**7.**	.78	.75	.35	.03	.84	.34	
Percent Population Aged 15 to 64	59.37	6.41	**8.**	.64	.65	.26	−.10	.76	.43	.61

Note: N=259

Results and Discussion

The findings for the panel analyses are reported in Table 3. For all predictors we provide unstandardized coefficients, the absolute values of t-statistics, and standardized coefficients. For each tested model, we report values for R-square within, R-square between, and R-square overall. Two models are tested for all three dependent variables.[63] For both per capita dependent variables, the first model—labeled as Model A—consists of military expenditures per soldier, military participation, military expenditures as a percentage of GDP, and GDP per capita. For total carbon dioxide emissions, Model A also consists of total population. The second model—labeled as Model B—includes all Model A predictors plus manufacturing as a percentage of GDP, urban population, percentage of population aged 15 to 64, and exports as a percentage of GDP.[64] For reasons noted above, the latter predictor is excluded from the ecological footprint per capita analyses.

Before discussing the results of interest, we briefly summarize the associations between the outcomes and the additional predictors. As expected, the effect of total population on total emissions is positive and relatively strong in magnitude, which corresponds with prior research on scale-level emissions and assertions of structural human ecology. For all three outcomes, we find that the effect of level of economic development is positive and slightly reduces in magnitude with the introduction of other controls in Model B. For the footprint analyses, the relative magnitude of GDP per capita's effect is small to moderate, and its statistical significance is at a marginal level in Model B (p value = .095). Since most past research on ecological footprints reveals strong positive effects of level of development, we speculate that these findings are largely a function of high collinearity between GDP per capita and military expenditures per soldier. Further, the reduced sample size of the footprint analyses may enhance the collinearity between GDP per capita and military expenditures per soldier. While the effects of economic development are not the focus of the current study, we return to this issue below. However, the positive effect of economic development on all three outcomes is consistent with various political economy orientations in the environmental social sciences as well as structural human ecology. In analyses not reported here (but available upon request), inclusion of the centered quadratic for GDP per capita produced positive correlations with all of our dependent variables, contradicting the curvilinear associations predicted by environmental Kuznets curve theory.[65]

63. We exclude carbon dioxide emissions per GDP as a dependent variable since our focus is the impact of nations' militaries.
64. Elsewhere we include measures of democratization, state strength (government expenditures as a percentage of GDP), services as a percentage of GDP, environmental international nongovernmental organization presence (both weighted and un-weighted by population size), and environmental treaty ratifications (Roberts, Parks, and Vasquez 2004). The effects of the additional predictors on the three outcomes are all non-significant and their inclusion does not substantively alter the reported findings.
65. Grossman and Krueger 1995.

Table 3
Coefficients for the Regression of Total CO_2 Emissions, Per Capita CO_2 Emissions, and Per Capita Ecological Footprints on Selected Independent Variables: Fixed Effects Model Estimates with AR[1] Correction for 7 Observations on 72 Countries and 37 Countries, 1970–2000

	Total CO_2		*CO_2 Per Capita*		*Footprint Per Capita*	
	Model A	*Model B*	*Model A*	*Model B*	*Model A*	*Model B*
Military Expenditures per soldier (ln)	.22***	.25***	.13*	.23***	.12***	.11***
	(3.31)	(4.02)	(1.77)	(3.67)	(5.19)	(4.64)
	[.14]	[.16]	[.10]	[.19]	[.32]	[.29]
Military Participation (ln)	.41***	.44***	.37***	.43***	.16***	.15***
	(4.80)	(5.52)	(3.89)	(5.22)	(5.61)	(5.19)
	[.11]	[.12]	[.13]	[.15]	[.19]	[.17]
Military Expenditures as % of GDP (ln)	−.02	−.03	−.05	−.03	−.02	−.02
	(.40)	(.60)	(.95)	(.58)	(.89)	(.91)
	[−.01]	[−.01]	[−.02]	[−.01]	[−.01]	[−.02]
GDP per capita (ln)	.50***	.37***	.72***	.36***	.05*	.05
	(5.34)	(4.07)	(7.20)	(3.84)	(1.70)	(1.32)
	[.36]	[.28]	[.69]	[.35]	[.16]	[.15]
Total Population (ln)	1.62***	1.30***				
	(22.52)	(12.13)				
	[.94]	[.88]				
Manufacturing as % of GDP		.02***		.02***		−.01
		(5.79)		(5.54)		(1.30)
		[.07]		[.08]		[−.02]

Urban Population as % of Total Population		.02***		.03***		.01
		(4.60)		(8.02)		(1.32)
		[.21]		[.38]		[.09]
% of Population Aged 15 to 64		−.01		−.01		.01*
		(1.28)		(.62)		(2.15)
		[−.03]		[−.01]		[.06]
Exports as % of GDP (ln)		−.02		−.01		
		(.42)		(.22)		
		[−.01]		[−.01]		
Constant	−11.22***	−8.39***	1.58**	1.80***	−.35*	−.37*
	(14.57)	(8.24)	(2.92)	(3.70)	(1.70)	(1.83)
R-square within	.75	.79	.40	.57	.35	.38
R-square between	.82	.91	.86	.87	.89	.88
R-square overall	.81	.90	.85	.86	.87	.87
Overall Sample Size	504	504	504	504	259	259
Number of Countries	72	72	72	72	37	37

Notes: *p<.05 **p<.01 ***p<.001 (one-tailed tests); unstandardized coefficients flagged for significance; absolute value of t statistics in parentheses; standardized coefficients in brackets; p value for GDP per capita in footprint Model B is .095

The effects of manufacturing as a percentage of GDP and urban population on total emissions and per capita emissions are positive, indicating the importance in controlling for both when investigating anthropogenic emissions measured by scale and intensity. However, their effects on per capita ecological footprints are non-significant. The effects of population age structure in the context of the percentage of population aged 15 to 24 and world-economic integration in the form of exports as a percentage of GDP are non-significant for total carbon dioxide emissions and per capita carbon dioxide emissions. Conversely, per capita footprints are positively associated with relative levels of non-dependent populations. While not the focus of the current study, these differing effects highlight the importance of assessing how the impacts of various political economic and human ecological drivers differ across environmental outcomes. Lastly, the effect of military expenditures as a percentage of GDP is non-significant in all reported models. Considering the weak bi-variate associations between this predictor and both total and per capita carbon dioxide emissions as well as the per capita footprints of nations, the non-significant effects are not surprising. We now turn to the results of interest: the effects of military expenditures per soldier and military participation.

As indicated in Table 3, military expenditures per soldier and military participation positively affect both total and per capita carbon dioxide emissions. Thus, it appears that, all else being equal, nations with more high-tech and labor intensive militaries emit relatively higher overall levels and greater intensities of anthropogenic carbon dioxide gas. Further, the magnitudes of their effects on total and per capita emissions are certainly not trivial. Likewise, the per capita ecological footprints of nations are positively associated with both military participation and military expenditures per soldier, with moderate magnitudes. Thus, we find substantial support for treadmill of destruction theory from a comparative perspective. As articulated by the theory, countries with technologically advanced and labor-intensive militaries require enormous amounts of resources for their infrastructures and research and development, as well as to maintain their relative size and power. The amount of land used by armed forces for bases and other forms of installations has increased steadily in spite of changes in the overall geopolitical structure of the world, which partly accounts for the positive associations between both aspects of militaries and the consumption-based environmental demands of nations. Even during peacetime, the armed forces consume large amounts of fossil fuels, a trend that is likely to continue as high-tech militaries develop and deploy new vehicles and machinery. This equipment must be constantly maintained and tested, increasing the environmental demands of militarization. While these continual changes contribute to the use of fossil fuels and subsequent anthropogenic carbon dioxide emissions, the scale and intensity of the latter are both influenced by labor intensive militaries, given the volume of fuels used for the movement, training, and protection of troops and support personnel.

As noted above, military expenditures per soldier and GDP per capita are highly correlated. Thus, to minimize collinearity and to better assess the independent effects of both on carbon dioxide emissions and the per capita ecological footprints of nations, we regressed military expenditures per soldier on GDP per capita and used the residuals as measures of the former in additional analyses of all three outcomes. This "residualizing" technique is common in prior research on the economic and environmental impacts of military expenditures per soldier.[66] With the residuals we test the most saturated model for all three outcomes. The results are reported in Table 4.

For both total and per capita carbon dioxide emissions as well as the per capita ecological footprints of nations, the standardized coefficients for military expenditures per soldier decrease with the use of residuals. However, the associations remain positive and statistically significant, further validating the results in Table 3 as well as the proposed theorization concerning the environmental impacts of technologically advanced militaries, net of other factors. The unstandardized and standardized coefficients for GDP per capita increase when employing the residuals for military expenditures per soldier. With the exception of the constants, all other findings in each model are identical to those reported for both outcomes in the preceding analyses (Table 3). Overall, these findings further support treadmill of destruction theory, and indicate that the treadmill of destruction in the mode of high-tech militarization has unique environmental impacts, independent of economic development and the treadmill of production.

Conclusion

This research broadens our collective understanding of the human dimensions of global environmental change by considering the impact of military institutions on carbon dioxide emissions and the ecological footprints of nations. Cross-national panel analyses indicate that both the number of soldiers and technological sophistication of militaries have significant impacts on the environment. We draw on treadmill of destruction theory with an international comparative orientation to explain these findings. The expansion of militarism—influenced by both geopolitics and domestic interests—has involved the development of high-tech weaponry and vehicles that consume massive quantities of fossil fuels and emit large quantities of carbon dioxide. Transportation equipment allows for the effective movement of soldiers throughout the world and helps connect a web of military bases. Increases in the scale and intensity of national militaries, whether in terms of soldiers or technology, increase their environmental demands and impacts. Equipment and weapons must be tested, and soldiers must be trained, outfitted, housed and fed. As a result, ecological degradation is a concomitant of militarism, given constant resource demands to sustain and support military operations and troops.

66. Jorgenson 2005; and Kentor and Kick 2008.

Table 4

Coefficients for the Regression of Total CO_2 Emissions, Per Capita CO_2 Emissions, and Per Capita Ecological Footprints on Selected Independent Variables Where Military Expenditures Per Soldier is Residualized on GDP Per Capita: Fixed Effects Model Estimates With AR[1] Correction for 7 Observations on 72 Countries and 37 Countries, 1970–2000

	Total CO_2	*CO_2 Per Capita*	*Footprint Per Capita*
Residualized Military Expenditures per soldier (ln)	.25***	.23***	.11***
	(4.02)	(3.67)	(4.64)
	[.08]	[.09]	[.15]
Military Participation (ln)	.44***	.43***	.15***
	(5.52)	(5.22)	(5.19)
	[.12]	[.15]	[.17]
Military Expenditures as % of GDP (ln)	−.03	−.03	−.02
	(.60)	(.58)	(.91)
	[−.01]	[−.01]	[−.02]
GDP per capita (ln)	.56***	.53***	.13***
	(8.15)	(7.70)	(4.83)
	[.42]	[.51]	[.41]
Total Population (ln)	1.31***		
	(12.13)		
	[.88]		

Manufacturing as % of GDP	.02***	.02***	−.01
	(5.79)	(5.54)	(1.30)
	[.07]	[.08]	[−.02]
Urban Population as % of Total Population	.02***	.03***	.01
	(4.60)	(8.02)	(1.32)
	[.21]	[.38]	[.09]
% of Population aged 15 to 64	−.01	−.01	.01*
	(1.28)	(.62)	(2.15)
	[−.03]	[−.01]	[.06]
Exports as % of GDP (ln)	−.02	−.01	
	(.42)	(.22)	
	[−.01]	[−.01]	
Constant	−7.49***	2.63***	.03
	(7.44)	(5.18)	(.17)
R-square within	.79	.57	.38
R-square between	.91	.87	.88
R-square overall	.90	.86	.87
Overall Sample Size	504	504	259
Number of Countries	72	72	37

Notes: *p<.05 **p<.01 ***p<.001 (one-tailed tests); unstandardized coefficients flagged for significance; absolute value of t statistics in parentheses; standardized coefficients in brackets

Historically, research in the environmental social sciences has focused on economic and demographic processes. The robust findings of this study highlight the importance of considering the environmental impacts of militaries as well. Thus, we echo the call by other society/nature scholars[67] to incorporate the military into future theorizing and analyses of environmental degradation.[68] This broader perspective is imperative given that global climate change and unsustainable resource consumption are among the most serious challenges currently facing the world.[69] While it is well understood that military institutions focus on protecting their respective nation-states and not the environment, their continual technological development, expansionary practices, and overall infrastructure are highly resource consumptive and waste generating endeavors that exacerbate ecological problems at multiple scales, thereby threatening the environmental security of humanity and all other living species.

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67. Gould 2007; Hooks and Smith 2005; Jorgenson 2005; and York 2008.
68. The failure to include military dimensions is not limited to the environmental social sciences. Kentor and Kick (2008) note that military power has been largely excluded from sociological studies for over forty years, and argue for "bringing the military back in" to social science research.
69. Hansen 2008.

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