THE ECOLOGICAL CORRELATES OF ARMED CONFLICT: A GEOSPATIAL AND SPATIAL-STATISTICAL APPRAOCH TO CONFLICT MODELING

by

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of
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DEDICATION

Dedicated to my family for inspiring me, each in their own way, to pursue a more peaceful, generous, and compassionate world.

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I would like to thank my entire family for their encouragement, support, and patience throughout this process. Without them this work would not have been possible. My committee members each provided invaluable insight and support in this research. Dr. Paczynska's theoretical and intellectual insight inspired me to explore and pursue social, political, and economic development across the world. Dr. Simmons encouraged me to push myself intellectually and methodologically, and provided the support necessary for me to do so. Dr. Sklarew challenged me to bridge the ecological and social disciplines, and helped direct me through that process. I would like also to thank my colleagues at the Humanitarian Partnerships and Conservation Science Departments of the World Wildlife Fund, Inc. for their assistance and guidance in formulating the preliminary framework for this research. The Point of View Committee and other faculty and the administrative staff at the Institute for Conflict Analysis and Resolution made this research possible through fellowships, graduate funding, and administrative/technical support.

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ABSTRACT

Few studies of violent conflict focus explicitly on the environmental and ecological relationships that occur in locations that experience violence. Rather, traditional studies of focus on the political, economic, and social factors that affect conflict propensity, holding the state as the unit of analysis. This limits the ability of these studies to identify the geographic and biophysical factors that affect where violent conflict is physically located.

I employ a spatially explicit approach to studying the environmental and ecological correlates of conflict. Using a geographic information system (GIS) platform, I overlay a grid of 100 x 100 km cells across the entire terrestrial surface of the earth. I then overlay a series of raster data sets across the terrestrial surface and identify the biophysical and geographic characteristics of each cell. I use logistic regression to explore which ecological characteristics are most closely correlated with the occurrence of violent conflict. Among the characteristics I explore are land cover/land use, vegetative productivity (with controls in place for rain-use efficiency), human population density, infrastructure expansion, forest cover/type, climate and precipitation. I control for political and economic variables including democracy and economic prosperity.

I distinguish between conflicts over governance and conflicts over territory, and find that each type of conflict is associated with a distinct ecological, social, and political

profile. Armed conflicts fought over territory (succession, sovereignty, or independence) occur in cells that are marked by decreasing biomass productivity, high densities of crop and pasture lands, areas with higher incidence of distinct agricultural regimes and farming systems, open/fragmented land cover, and temperate climates. In contrast, armed conflicts fought over governance (control of the state, or right to rule) occur in areas with increasing populations and expanding infrastructure, in areas without much farming or grazing, in previously unconverted forest land, and in tropical climates.

Identifying the environmental and ecological conditions that affect local conflict propensity holds important implications for organizations working in conflict-prone states, offering a richer understanding of the precipitants of local violence, and offering a greater return on investment through better-informed planning. Further, this approach bridges the gap between biodiversity conservation and human/social/economic development by demonstrating the interconnection of human and natural systems.

Introduction. The earth as a complex system

That the world is a competitive place is one of only a few constants present throughout the dynamic biological history of the earth. In the natural world competition is evident in nearly every aspect of life, with organisms competing for sustenance, space, and the opportunity to reproduce. In some cases this competition is a passive struggle, where saplings in a grove vie for light, water, and nutrients. In other cases competition is expressed much more dramatically, as physical dominance and superiority determine (for some species) which individuals reproduce and which do not. In the most extreme, but not uncommon cases, competition is a grave undertaking, with winners surviving to continue competing, and losers becoming fodder for scavengers, decomposers, and other organisms all similarly engaged in a competitive bid to survive.

Fortunately for all, the earth is an incredibly dynamic system, and organisms (at least evolutionarily successful organisms) exist in dynamic relationships within that system. Competition is far from the only mode of interaction between organisms. Symbiotic relationships enable organisms across species lines to specialize in specific activities, and provide reciprocal services to each other in a biological division of labor. These complex interactions among individuals and elements in the system - cooperative, competitive, and parasitic relationships - combine to produce a stable dynamic system, where many individuals have at least their most basic needs met.

True equilibrium is rarely if ever reached, and is neither permanent nor sustained. The global ecosystem and component sub-systems (biomes, geographically or spatially explicit contained areas, even social groups and communities) are constantly changing. Populations, predator-prey relations, physical chemistry, etc. are in constant flux, each reacting to and simultaneously instigating changes in other elements in the system. As such, every part of the system or sub-system must constantly adapt to changes in the biotic (species introduction, extinction, and population fluctuations) and geophysical (chemical, climatic, geological and topographical) elements of the system.

Far from exempt, humankind exists within, and contributes to, this complex system just as any other type of biological organism. As such we are subject to the same rules and relationships that govern other actors in the system. Like our non-human counterparts, we are forced to compete for sustenance, space and reproduction. We form competitive, cooperative, and parasitic relationships with other species and organisms in the system, as well as amongst ourselves. Likewise, we must constantly adapt to changes in the biological and geophysical character of the system.

The work presented in the following pages explores the human connection to the natural world in an effort to better understand how societies react to ecological change. Specifically, this work asks: *what are the environmental and ecological correlates of violent conflict*, and *based on those correlations, which locations of the earth are most prone to conflict*?

To address these questions, chapters 1 & 2 discuss how changes in the physical and biological environment affect our social systems, potentially opening avenues for violent conflict. The theory laid out in those chapters is not deterministic, however. At no point is violent conflict a necessary response to environmental change or stress. Rather, changes in the natural world require societies and groups to adapt. The process of adaptation creates space for relationships to be renegotiated. Often, the changes to which people must adapt are so new or so different that they require the negotiation of entirely new relationships among people. It is the form that those negotiations take, and the relationships that they produce, that determine whether conflict, cooperation, or some mix of the two will arise from change.

Following that discussion chapter 3 reviews the state of the field of conflict modeling, and then describes the methods and design of empirical work that explores the ecological correlates of armed conflict. Chapters 4 & 5 discuss the results and implications of that empirical work. Finally, chapter 6 concludes this work by revisiting the locational aspects of the conflict, and combines statistical modeling with spatial analysis techniques to present maps of the locations across the globe that are most prone to violent conflict.

Social change as a response to perturbations in system stability

In order to uncover the connections between our human sub-systems and the global ecosystem, this work begins by exploring a body of theory that details how changes in the biological and physical world impact our human systems. While that body of work is elucidated in the following chapters, it is worthwhile to provide a cursory overview here.

Our political, social, and economic systems (hereafter social systems) are essentially sub-systems within the global ecosystem. The actions and interactions of our political, social, and economic behavior affect the character, quality, and distribution of many of the elements of the supra-system. Likewise, social systems are sensitive to changes in elements of the larger system. As the system is dynamic, we are constantly forced to adapt to changes in the distribution, quality, and availability of biological, chemical, and geophysical resources. Thus we hover in a delicate balance within a stable state defined by a particularly set of relationships and structures with other parts of the sub-systems, and the larger ecosystem

At times the system is disrupted. Abrupt changes in biological or geophysical aspects of the system, sustained incremental increase in demand for specific elements of the system, or changes in community or population dynamics can combine to affect the other elements of the system in both predicted and unpredicted ways. Subsystems - our social systems specifically - are also occasionally exposed to perturbations that drive them further away from stability. These perturbations can result from stress brought about by changes in the geophysical world. They can come from biological sources like epidemics or increases in birthrates. They can likewise be chemical, as pollution affects groundwater purity, or chemical fertilizer affects food and fuel costs. Perturbations can also be socially constructed, with political, economic, or social dynamics affecting resource distribution and access, or with changes in political decisions disrupting the established order of the systems. In any of these cases our sub-systems are subjected to stress-induced perturbations away from stability, and we are forced to adapt to these changes. In the face of certain perturbations we rally together and develop cooperative adaptive strategies. Other perturbations generate passive competition, producing shifts in the modes or means of economic production, changes in political regimes and governance, or changes in social mores and rules. Still other perturbations have a more virulent impact on our social systems, generating intense social upheaval, resulting ultimately in violent conflict among individuals, groups, or nations.

The work at hand

It is the latter set of perturbations that the current work explores. It does so by asking several questions. Are there specific biological or geophysical elements or processes in the global environmental system with which humans interact that increase the vulnerability of our human systems? What are these elements, and where are they located? Knowing the location of specific biological and geophysical elements or processes, is it possible to ascertain the locations in which our subsystems are more likely to undergo periods of violence? Put differently, do specific aspects of the natural world help shape where violence among social and political groups occurs? For too long we have taken as granted the effects of the natural world on our social systems. In order to better understand our social systems, and social problems like conflict, we must explore exactly how and why the natural world affects us, and we it.

This work is forward-looking, premised in the notion that by uncovering the mechanisms that underlie violent conflict and that by identifying the locations most susceptible to violence we can prevent many instances of violence. Our evolutionary success as a species demonstrates that in most instances, cooperation is much more efficient and far more productive for us than violent conflict and competition. If, perhaps, violence is unavoidable in some situations, perhaps then the knowledge generated herein will be useful for limiting or mitigating the destructive force of violent competition within our social systems.

This work is also systemic in focus. Our success as a species has set us apart from much of the natural world. We have been so successful, come to see ourselves as separated (intellectually and to certain extents physically) from the processes that drive and govern the natural macro-system. This work seeks to challenge that view, and demonstrate that we as individuals and as a species are still directly tied into the natural system. We derive goods and services from the natural world that we employ in our needs-fulfillment. Our actions directly affect the system, and change the distribution, character, and availability of portions of it. As we are directly tied into the system, we are sensitive to its changes. Thus for our own sake we have should be obliged to more fully understand the system dynamics, and our role in those dynamics. With that understanding, our behavior as individuals and as a species should be better informed to limit our negative influence on the system, thus limiting the size and duration of systemic perturbation to which our human systems are in fact sensitive.

Chapter 1. Human integration with the natural world: implications for conflict

Since we emerged as a unique species, humans have existed in the natural world and interacted with the biological and geophysical elements that make up natural systems (Liu et al. 2007a). The epochs of our history - from the agricultural revolution, to the industrial revolution, to the green revolution - have witnessed the evolution of our interaction within those systems. Whereas our early interactions in natural systems were primarily subsistence-based activities (Redding 1988), seeking food and shelter and defending ourselves from natural hazards and predators, our role in these systems has evolved, and our ability to meet our needs inside these systems has progressively transitioned into our unique ability to adapt natural systems to meet our needs. Early examples of this transition include the development of swidden agriculture where humans transform ecological regimes through the use of fire (Pyne 2001), the domestication of ungulates (hoofed animals) to improve reliable access to protein stores (Meadow 1989), and the development of irrigation techniques providing larger agricultural yields from cultivated crops (Sherratt 1980). More recent developments include the use of carbon-based and nuclear resources for energy production, and genetic modification of floral and faunal food sources (Fernandez-Cornejo and Caswell 2006).

As early as Plato in the 4th century B.C. (Daily 1997) and continuing through the present day we have acknowledged our relationship with and our ability to modify natural systems (Liu et al. 2007a). Despite that acknowledgement, we continue to poorly understand the complexity of that relationship (Liu et al. 2007a; Liu et al. 2007b; Schneider and Londer 1984; Berkes et al. 2003). Liu et al. (2007a, 2007b) argue that our understanding of the dynamism and complexity of our relationship to the natural world is a product of the traditional divide among the social and ecological sciences. Traditional social science typically examines social action and interaction in the context of a static, unchanging natural environment. To the degree that environmental factors are incorporated in social research, it is typically in the context of constant environmental influences, or simple changes in one coarsely measure variable. Traditional ecological work is guilty of this same naiveté, examining ecological systems or processes in a vacuum outside of human influence, examining human influence in ecological processes as exogenous influencers, or from a resource management perspective. In either case, the human and natural realms are viewed at best as separate and reciprocally influencing systems, and at worst as mutually exclusive. Neither tradition has (historically) explored the endogenous and mutually influential aspects of human-environment interaction.

That scientific shortfall is, however, changing. There is a burgeoning tendency among interdisciplinary researchers to treat human and natural systems as nested, embedded, or otherwise connected, each exerting influence on and simultaneously being influenced by the other. *Figures 1.1* and 1.*2* demonstrate the traditional exogenous influence approach versus the emerging nested systems approach.

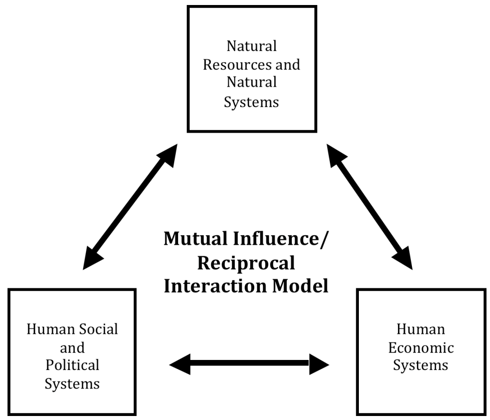

Figure 1.1. Reciprocal influence of natural, social, and economic systems. Adapted from Batabyal et al. (2003)

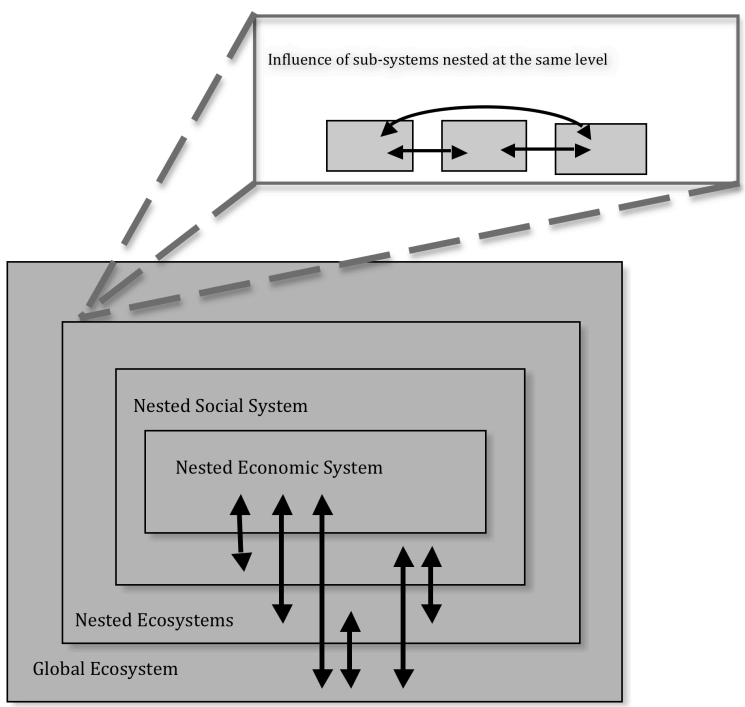

Figure 1.2. Nested systems model demonstrating the vertical and horizontal feedback pathways among nested systems. Adapted from Batabyal et al. 2003.

Within the social and natural scientific communities, sub-fields have emerged in recent years to examine these complex relationships. While still largely in their academic infancy, great strides have been made by these interdisciplinary efforts to uncover the complexity of the human-nature relationship. Some of the new work examines that relationship from the viewpoint of coupled human and natural systems (Liu et al 2007a; Liu et al 2007b; Monticino et al 2007; Pickett et al 2005), complex adaptive systems (Levin 1998; Hartvigsen et al. 1998) or social-ecological systems (SES) (Berkes et al. 2003; Walker et al. 2004; Olson et al. 2004). These and many other efforts are advancing compelling evidence that the intellectual divide between ecology and society is both arbitrary and artificial. Direct links do exist between the natural and the social realms, connecting them as sub-systems within a larger macro-system. Moreover, the reciprocal influence and feedback between them shape the character of, and define the relationships between, the constituent elements that comprise each sub-system.

Unfortunately conflict studies have been slow to acknowledge the dynamism of human-nature relations. Within the predominant academic traditions interested in conflict - political science, international relations, peace studies, conflict resolution, psychology, sociology, anthropology - conflict is explored in a strictly human context. Environmental factors are at times incorporated into conflict studies. Examples include Homer-Dixon 1991, 1994, 1999; Hague and Ellingsen 1998; Collier and Hoeffler 1998, 2001, 2002; Fearon 2005; Humphreys 2005; de Soysa and Neumayer 2007; LeBillon 2007, and several authors do explore human-nature interaction as it influences conflict dynamics (Galtung 1982; Renner et al. 1991; McNeely 2000; Kahl 2005; and LeBillon

2007. However, studies that incorporate environmental variables largely assume a static environment as the place where conflict occurs, and measure environmental variables coarsely as percentages of forest or mountainous terrain, distances from resources to ports or transportation corridors, or as potential value pools. Likewise, when interactional dynamics are included in conflict studies, that inclusion is equally coarse, with emphasis placed on the mechanisms through which access and exclusion to resources create absolute and relative scarcity (Homer-Dixon 1991), the political means through which certain groups control and allocate resources (Douma 2006; Galtung 1982), or the avenues through which resource abundance and resource quality create incentives to fight (Collier and Hoeffler 1998; LeBillon 2007; Kahl 2005; Reuveny 2007; Rustad et al. 2008).

Ecologists and conservation biologists have also made attempts to understand conflict, either through the lens of examining how human or social influences impact wildlife populations, habitat, and ecological regimes (Austin et al. 200; Dudley et al. 2001; Hatton et al. 2001; Blom and Yamindou 2001; Kalpers 2001 a, b; Hart and Mwinyihali 2001; Jacobs and Schloeder 2001; Squire 2001; Plumptre 2001; McNeely 2003), or by examining how social conditions and conflict affect resource governance and management (Shambaugh et al. 2001; De Merode et al. 2007; Fabricus et al 2001; Glew and Hudson 2007, McNeely 2003).

The fields of conflict studies and ecological studies each provide only cursory insight into human-nature dynamics. As such the mechanisms through which natural states and elements affect conflict dynamics remain obscured, and the reciprocal impacts and feedbacks of intra-human action/interaction and ecological processes continue to be arcane. In order to more fully understand these dynamic relationships a bridge must be built between ecology and conflict studies. The subsequent sections of this chapter examine human-nature interaction from a social-ecological systems (SES) approach to first examine how we as a species are connected to the natural world (with specific focus on the ways in which human conflict influences ecological states and systems), and next explore how biological diversity is important for maintaining and sustaining those connections. After demonstrating the interconnectedness of human and natural systems in this chapter, the following chapter presents a theoretical approach to understanding how changes in natural systems can influence social systems in such ways that social systems are prone to violent conflict.

Natural goods and ecosystem services: human reliance on natural systems

Mooney and Ehrlich (1997) adeptly argue, "… natural ecosystems help to support society…" (p. 11), providing the goods that humans consume, and the services upon which humans depend. Since at least the 1960s scholars have debated the value of natural systems and natural processes for human social, economic, and political systems (de Groot 2006; King 1966; Helliwell 1969; Hueting 1970). As de Groot (2006) demonstrates, there has been substantial growth in academic interest in the value of natural systems for human society over the last two decades. Among the many notable studies are Daily 1997, Pearce 1993, Turner 1993, de Groot 1992, Costanza et al. 1997, Balmford et al. 2002, and Batabyal 2003. These are but of few of the myriad studies that acknowledge and explore the connection of humans and their natural environment. This section explores that connection first by reviewing human reliance on natural *goods* - the products derived from natural sources that are used for consumption by humans - and next by discussing human dependence on *ecosystem services* - system functions that perform essential roles in human and social well-being (including the production of natural goods).

As early as the writings of Thomas Malthus (1829) scholars have acknowledged that human life depends directly on a great many primary products and natural goods harvested from ecosystems to meet our basic physical requirements of space, shelter, and nutrition (Daily et al. 1997). These include water, food in the form protein, glucose, cellulose, and minerals compounds in biotic and abiotic stores; fuels from biological stores (fuelwood and fossil fuels); timber and non-timber forest products, and medicinal and pharmaceutical products extracted directly from plant and animal sources. Natural goods and primary products also sustain human life and meet human and social needs in indirect ways, providing virtually every raw material which is processed, refined, or otherwise transformed into a good which is consumed, traded, or utilized by humans. These are indirect goods derived from natural sources in the sense that they form the constituent parts of products that humans use, but must be modified from their original state before they can be utilized. Examples of such indirect good are pharmaceutical products, paper products, soy-based inks, plastics, food products, petrochemicals - virtually every product that humans consume can ultimately be traced back to natural sources. Thus all human consumption depends on the natural world as the point of origin for the goods and products used to meet human needs, sustain human civilization, and supply human markets.

The degree of directness between a natural good and final human consumption is simply a function of the modification required to transform a natural primary product into a final product used in human consumption. Because the supply chain for virtually all human consumed goods is ultimately traced back to natural sources, human systems are sensitive to changes in the availability of natural products. In economic terms, the cost of specific consumables is a function of the supply of their constituent elements, the collection costs (related to the supply, but also dependent on the state of the good as found in nature - fuelwood, for example has a low collection cost, whereas iron ore has a much higher cost) the amount of modification required to transform primary products into consumable ones, the transportation cost involved with moving goods from supply source to refinement, production, consumption, and ultimately disposal sources, and the number of individual agents involved in the production process. Thus human life, economic systems, and the social and political systems to which they are tied, are directly sensitive to the state, amount, availability, and distribution of natural goods.

Those goods, whether useful as primary products or requiring refinement or modification, do not exist in a vacuum, however. Rather, they occur in, and form constituent elements of, natural ecosystems. Because they connected to systems, the state, availability, and distribution of any resource is a function of the system dynamics with which it is connected. In this way, the human systems that any particular resource affects are sensitive not only to that resource, but also to the state of the system in which the resource exists. While there are various ways of defining an ecosystem, the definition advanced by Odum (1971) is particularly useful as it is scale-independent. According to that definition an ecosystem is a unit that includes biotic organisms and abiotic elements interacting to create energy flow such that defined trophic structures, biologic diversity, and material cycles exist within the unit. According to this definition the entire global system can be considered an ecosystem, as biological and abiotic elements interact in specific ways, forming identifiable trophic relationships and resulting in material cycling throughout the system. Within that global system, sub-systems exist at more localized scales (such as biomes) with similar trophic and material relationships and cycles. Within those sub-systems further subsystems exist, such as freshwater systems, marine ecosystems, etc., and within those yet further sub-systems exist. Each system is composed of smaller semi-autonomous systems nested within it, and within each of those, more nested systems. Ecosystems thus exist at scales ranging from the cellular to the global levels. At each scale systems are simultaneously influenced in cross-scale feedback mechanisms (Raffa et al. 2008) by the trophic relationships and material cycles at its own level, as well as by its constituent ecosystems, and the systems of which it is part.

Human consumption of natural goods is well acknowledged. However, this is not our only connection to the natural world. Ecosystems provide a range of services and functions that are essential to human somatic, psychological, social, and economic wellbeing. There are multiple definitions of ecosystem services, differing in the range of services and functions considered, the level at which the services are applicable, and the scale on which they operate. Competing definitions describe the internal functioning of ecosystems versus the benefits derived by humans and human systems (de Groot et al. 2002). Daily (1997) states that they are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (p. 3). De Groot et al. (1992; 2002) offer a slightly different definition under which "ecosystem functions [are] the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (2002, p. 394).

Both definitions suggest that the condition and interaction of parts of the natural world produce goods and services that humans value. However, de Groot et al. include two additional elements in the definition. Describing them as 'functions' suggests that it is not simply natural processes, but the *functioning* of those processes, that produce the services that humans value. Building on that idea, the *capacity* of ecosystems to deliver those services is a contingent on functionality. Marginalized ecosystems have lower productive capacity, whereas better functioning ecosystems have a larger capacity. For the purposes here, unless otherwise stated the term ecosystem services refers to the functional definition of de Groot et al. (1998, 2002). To distill the concept, de Groot et al. conceive of ecosystem services as being a subset of ecological processes and structures, and each function or service is the product of "the natural processes of the total ecological sub-system of which it is a part" (2002, p. 394). These processes are driven and produced by the interaction of abiotic and biotic components of ecosystems, the trophic relationships that these interactions drive, and the material cycling that results.

These ecosystem functions can be grouped into four meta-categories related to the types of process and services that ecosystems produce. Adapted from de Groot et al. (2002) these are:

Regulation Functions: the ability of ecosystems to regulate ecological process and life-support systems for all biotic components. This regulation occurs through bio-geochemical and biospheric processes.

Habitat Functions: the provision of refuge and reproduction habitat to flora and fauna. This preserves biological as well as genetic diversity for associated species.

Production Functions: the trophic systems and functions through which energy and nutrients are converted into biomass by primary consumers, the conversion of biomass into a larger variety of biomass by secondary consumers, and the conversion of biomass back into energy and nutrients by all consumers.

Information Functions: as the site of life and living relationships, ecosystems serve a reference function which allows exploration of the nature of geological, biophysical, and geochemical relationships. Further, human spiritual, cognitive, recreational, and aesthetic development are in many ways tied to natural ecosystems. Thus ecosystems provide for the cultivation and sustenance of certain psychological, emotional, and otherwise intangible human needs.

In a seminal study Costanza et al. (1997) describe many ecosystem services and the functions with which they are associated. They group renewable ecosystem functions into 17 categories, and provide examples of these. They are careful to note, however, the integrated and interdependent nature of ecosystems and ecosystem functions. Because these are systems, any division of the functions and interplay between constituent elements is necessarily arbitrary. Below are examples of many of these services, adapted from Costanza et al. (1997) and de Groot et al. (2002):

Regulation of atmospheric composition: CO_2/O_2 balance, SO levels, Ozone levels and distribution

Regulation of climate: global and local temperature, precipitation, and other biologically mediated processes (via evapotranspiration influence on local humidity, etc.)

Control and mitigation of environmental disturbance: flood prevention and mitigation, storm protection, drought recovery and mitigation

Hydrological regulation: water cycling (seasonal, local, global)

Water provision: capture and storage in watersheds, aquifers, lakes, ice, etc.

Soil formation: conversion of mineral and organic structures into soil

Soil retention and recycling: erosion control, siltation

Nutrient cycling: conversion of atmospheric and mineral chemical sources of nutrients into bio-available stores, chemical fixation and storage

Waste treatment: pollution control, detoxification, waste recycling

Pollination: transfer of reproductive material between reproductive partners of floral organisms

Biological control: trophic transfer of energy between interconnected organisms, predator/prey relationships

Refugia: provision of habitat for survival, genetic storage, and reproduction

Food production: primary production of carbohydrate and protein stores for use as energy by organisms

Raw materials: primary production useful for transformation into other forms

Genetic and medicinal resources: provide information, primary products, and raw materials used to further scientific knowledge; primary products used for treatment of disease and injury; biological diversity

Recreation: provide opportunities for activity valued by humans, but not necessary to meet fundamental needs

Cultural: provide connection with historical, spiritual, intellectual/educational, and artistic aspects of human experience

One danger in imposing an arbitrary delineation onto ecosystem services is the reduction of incredibly complex processes and the simplification of the dynamic feedback mechanisms between constituent parts and associated processes that combine to produce the observed processes. Further, most ecosystem services are so complex that there is as yet no coherent understanding of the multiple processes and pathways through which inputs are transformed into products. As a simple example of this Costanza et al. (1997) argue, "some of the net primary production in an ecosystem ends up as food, the consumption of which generates respiratory products necessary for primary production" (p. 253). As such, something can simultaneously be an input and a product in the same function for different constituent parts of the system. Segmenting these functions and processes, then, imposes an artificial simplification on the structure and composition of ecosystems and their functions.

Explicit in the concept of ecosystem services is the value that humans place on natural goods and process. Indeed, without the imposition of the human artifact of 'value', ecosystems remain sets of constituent elements and processes, interconnected through the functions and feedbacks that sustain or define relationships in the system. Multiple methods for assessing the value of ecosystem services have been previously advanced in academic literature, and there is as yet much work to do to construct effective valuation mechanisms and methods (Mitchell and Carson 1989; Costanza et al 1989; Dixon and Sherman 1990; bard and Pearce 1991; Aylward and Barbier 1992; Pearce 1993; Goulder and Kennedy 1997; Costanza et al 1997; Wilson and Carpenter 1999; Batabyal 2003).

De Groot et al. (2002) and others suggest that the value of ecosystems and their associated services to humans can be divided into three basic categories: ecological, socio-cultural, and economic (see also Farber et al. 2002; Howarth and Farber 2002; Wilson and Howarth 2002, Limburg et al. 2002). Under such conceptualization, *ecological value* is the overall importance of ecosystems and ecosystem services for providing regulation and habitat functions - their ability to harbor and sustain life. In other words, ecosystem services have ecological value in that they provide and maintain critical life-support functions for humans. *Socio-cultural* value relates to the non-material value that humans assign to natural systems and processes. This value takes many forms, but includes among others, physical and mental health, cultural and historical ties, identity formation, spiritual and religious value, and scientific/educational opportunity (de Groot et al. 2002, p. 403). Humans also value ecosystem services for their *economic value*. This category of value includes direct value (the value of goods and services traded in markets), and indirect value (value for goods and services for which there are no markets - which usually involves assessing the cost of replacement or substitution of these goods, or the theoretical economic value that people and societies assign to specific goods and services).

Costanza et al. (1997) advance an alternate (but related) conceptualization of valuating ecosystem services, by discussing their *natural capital*. Natural capital, under their interpretation, is the supply or stock of natural materials and information at a specified point in time and in specific spatial arrangements/locational distributions (p. 254). The supplies of various capital stocks combine through natural processes and functions to produce flows of services that enhance human wellbeing, and to produce goods that humans can collect, transport, transform, and distribute to enhance their wellbeing. Ecosystem services can thus be described as the flow of natural goods, energy, and information, from their sources to final consumption by humans.

Under this framework the value of specific services can be assessed by considering the cost of living in the absence of them. As natural capital pools are the fundamental sources of energy, material, and information in the world, they are essential to human wellbeing. The value of these services that natural capital pools produce, then, can be thought of as the cost of either foregoing, or artificially replicating their functions.

The utility of attempting to quantify the value of natural systems and services in this way is perhaps limited to assessing the cost to specific groups, or at local scales. In other words, the value (in an economic sense) is associated with the cost of transferring and transforming stocks of capital from one area, system, or state to another to meet local demand. However, as valuation is expanded beyond the local scale to larger groups or systems, quantifying value in this way quickly loses its viability. As Costanza et al.

highlight, it is not feasible to substitute ‘natural’ capital for ‘manufactured’ capital, as manufactured goods require natural input. Fundamentally, the supply chain of all good originates ultimately in natural capital. Further, while specific services might by substitutable or replicable on limited scales, others are inherently not. The atmosphere, for example, is so massive on one hand (continuously distributed and integrated at the global scale), and composed of specific constituent gases in specific forms (for which there is no substitute), that it would be impossible for humans to replicate it on a similar scale or in the absence of specific constituent elements. Likewise, the geophysical and biophysical processes that drive the global hydrological cycling of water from evaporation to catchment to dispersion are so vast and so complex that it would be impossible for humans to replicate at a large scale. As certain services are neither substitutable nor replicable, and as certain services are fundamentally essential for life and thus unable to be foregone, their value to humans is fundamentally infinite and absolute.

While natural capital and ecosystem services are valuable to humans, their distribution, quality, and availability is neither static nor homogenous in spatial or temporal terms. Thus value of services can be associated with their scarcity. Water provides a good example of this. At the same exact point in time a drought can exist in east Sudan while flooding occurs in Brazil. On a smaller geographic scale, floods can inundate portions of provinces in Mozambique, while adjacent lands crack and dry from a lack of water. This scarcity occurs temporally as well, with precipitation fluctuating wildly inter-annually and inter-seasonally for the same location. Distributional dynamics are particularly evident when considering biological endemism. The concept of endemism refers to species naturally occurring in specific areas. While a given species may (or may not) be suited to a variety of habitats or alternative locations, it may be endemic in that it naturally occurs in only a given location or set of locations. Recent estimates suggest that endemism among vascular plants in Madagascar, for example, may be as high as 92% (Goodman and Benstead 2005). In other words 92% of the vascular plants found in Madagascar (fern species excluded) occur naturally only on the island, producing scarcity in these plants in every other location on the earth. This distributional scarcity (temporal and spatial) can be regarded as relative scarcity, as it refers to the amount of a good or service available in a given location at a given time, relative to the entire stock of that service. Relative scarcity is particularly evident through extirpation of species, or the interruption of natural cycles and processes at the local level.

Natural and anthropocentric disturbance at the local scale can affect stocks of natural capital and ecosystem services, exacerbating relative scarcity at the global level, and introducing scarcity at the local level. Thus while capital sources are subject to spatial and temporal relative scarcity, they are also subject to absolute scarcity, or scarcity regarding total stocks of certain capital. Absolute scarcity is experienced through extinctions of biotic species, significant and sustained interruption of natural processes or ecosystem functions, or conversion of capital stores in irreversible or difficult-to-reverse ways, like the conversion of land cover from natural states to urban areas.

Whether relative or absolute, humans as individuals and humans as societies are sensitive to scarcity of ecosystem services. These services perform a range of functions that are essential to human wellbeing. Further, our social, political, and economic institutions have developed in the context of these systems. As the provision of these services fluctuates, we are forced to adapt - like our non-human counterparts - to these changes. At a local level we can often substitute manufactured or natural goods and services for increasingly scarce ones. However, other services are non-substitutable. At the global level most services have no replacement. As our survival as a species fundamentally relies on these services we must concern ourselves with their maintenance.

Conflict influence on natural systems

Changes in any system or phenomenon have direct and indirect drivers. Direct drivers can be understood as variation (sudden or cumulative) in one or more element of a system that are most causally proximate to changes in the system state (UNU, ICSU, UNESCO 2008). In contrast, indirect drivers are farther down the causal chain in system change (WHO 2005, Chapter 7; (UNU, ICSU, UNESCO 2008, Chapter 2). Indirect drivers can be conceptualized as the elements, interactions, or changing dynamics that shape the value or character that direct drivers assume at any given point in time or space. Academic work has long recognized that human influence can act as both direct and indirect drivers of ecosystem change. In recent decades there is also popular and political acknowledgement that human influence affects the nature, character, and stability of natural systems (WHO 2005). This popular acknowledgement is evidenced most notably by the myriad global political environmental summits that convene to address anthropogenic drivers of environmental change, beginning with the Earth Summit in Rio de Janeiro 1992, and continuing with subsequent annual meetings around the world, the most recent of which was the Copenhagen Climate Summit in 2009.

What is clear in both academic literature and popular debate is that human action is inexorably tied to the natural world in direct and indirect ways. Further, human action is changing the biotic and abiotic structure of many natural ecosystems in complex, costly, and often-irreversible ways (Hooper et al. 2005). These changes are brought about through a variety of mechanisms, including the introduction of non-native, invasive, or genetically modified species; through changes in the flow of energy and materials in these systems; and by altering their geophysical and geochemical composition. While there is significant debate as to the nature or extent of specific relationships and feedback mechanisms within the macro-system, it is apparent that humans due in fact affect the character and stability of natural systems (Moran 2006; Millennium Assessment 2005).

For the purposes of this work, the sheer scope and complexity of human action precludes substantive exploration of the myriad relationships and multiple feedback processes that exist between all aspects of human/social action and the natural world. It is perhaps more effective - and indeed more plausible - to focus on only one aspect of human action/interaction and its impact on natural systems. As the purpose of this work is to explore the environmental and ecological precipitants of violent conflict, discussion of human influence on the natural world will revolve largely around the effects of violent conflict.

The impacts of conflict on the environment are highly variable. These impacts vary according to their spatial and temporal scales, the nature and degree of effect they have on the environment, and the range of actors/sectors that are affected (Shambaugh 2001). When conflict erupts its ecological impacts can include (but are not limited to) such events as species extirpation and extinction, pollution of marine and freshwater ecosystems, pollution and disruption of soil, land cover conversion leading to increased erosion, increased human dependence on natural resources, habitat destruction and fragmentation, diversion of government resources away from natural resource and protected area management, and increased resource extraction to fund military and opposition efforts.

While conflict can impact ecological systems and their constituent elements in these and other ways, the impacts incurred at any given location vary in different conflicts, depending on the scale of violence, the range of tactics employed, the nature and type of fighting, and the disruptions to local human communities and livelihoods. There is limited evidence that certain effects of conflict are environmentally beneficial (Hanson 2009), owed largely to the exclusion of human settlement and incursion into disputed territories, thus creating a *no-man's land* where floral and faunal communities are safe from over-exploitation (Kim 1997). This phenomenon has been referred to as the war zone/game source phenomenon (Martin and Szuter 1999). There is, however, little evidence that these positive impacts are wide-ranging or long lasting (Dudley 2002). For example, the Demilitarized Zone that separates North and South Korea is sometimes touted as a haven for biodiversity (Martin and Szuter 1999). The success of conservation in this zone is owed directly to the exclusion of humans, made possible by the presence of razor wire and extensive minefields. Behre (2007) however, presents an extensive review of the literature that documents significant long-term environmental degradation resulting from the presence of landmines, including morbidity and mortality among primates and ungulates, heavy metal contamination of topsoil and groundwater, and soil disturbance leading to uncontrolled erosion of topsoil. This raises doubt as to the viability of biological richness in these areas. Further, Dudley et al. (2002) posit that the majority of conflicts occurring after the middle of the twentieth century failed to provide a buffer for biodiversity, but rather had overwhelmingly negative environmental impacts.

The variability and specificity of each conflict occurrence and its implications for natural systems preclude an exhaustive review of every possible impact that conflict has on the natural world. Further, the dynamism of natural systems - the constant interplay between elements of the system and the reverberation of changes in a single element throughout the entire system - prevent a thorough exploration of the full range of environmental implications resulting from violent conflict. However, myriad case studies document the impacts of violent conflict on specific species, ecosystems, and resource pools. Fjeldsa et al. (2005) for example document rates of forest conversion in the Columbian Andes in response to shifting migration and production of coca resulting from conflict between the Columbian government, Marxist revolutionary forces, and networks of illicit drug producers and traffickers. They use rates of change in bird populations as a proxy for overall levels of biodiversity and suggest that armed conflict in the region is significantly reducing biodiversity through ecosystem regime change. Davalos (2000), however, highlights the complexity of the relationship between armed conflict and biodiversity in the Colombian Andes. She demonstrates that conflict affects land tenure and settlement patterns; and that the political agenda of groups controlling particular tracts of land largely determine the types of land use present in various areas. Specifically, she demonstrates that armed rebel groups strictly prohibit the conversion of forest to agricultural land, coincidentally preserving biodiversity in rebel-controlled forests. However, this often displaces conversion to areas outside of rebel control, intensifying the impact of conversion in adjacent areas. One problem with displacement of impacts in this way is the fragmentation of species' populations leading to diminished genetic diversity, which threatens the viability of isolated populations. Such is the case of large mammals in conflict-affected areas in Uganda (Muwanika et al. 2005; Hamilton et al. 2000).

Bloom and Yamindou (2001) analyze cycles of conflict in the Central African Republic (CAR) and draw correlations between conflict in remote areas of the CAR and the loss of biodiversity including the extinction or extirpation of wildlife including mega-fauna such as the rhinoceros. Similar impacts to biodiversity have been documented in Sri Lanka, with specific links drawn between conflict and habitat loss, increases in poaching, and increased trade in bushmeat (Santiapillai and Wijeyamohan 2003). Loucks et al. (2008) also describe the correlation between small arms availability and poaching in Cambodia. McNeeley (2000) similarly reports habitat loss and subsequent biodiversity loss from tactical defoliation through the widespread application of Agent Orange herbicide during the Vietnam War resulting in a regime shift from mangrove and terrestrial forests to mudflats and low-density grasslands. Mishra and Fitzherbert (2004) assess the status of mega-fauna and threatened and endangered species in Afghanistan and report significant threats to these specific species due to the economic activities of conflict affected people.

Hart and Mwinyihali (2001) highlight the mutli-scalar and multi-system impact of conflict for the natural world. They track conflict across the Democratic Republic of the Congo (DRC) and show that at local levels conflict-displaced populations increase pressure on natural systems for protein sources and caloric needs resulting in local biodiversity loss through bushmeat trades. Also, these displaced populations increase local pressure on habitat extent and connectivity through increased deforestation rates due to human reliance on charcoal for fuelwood. At the landscape level the cumulative impact of many localized pressures results in dramatic ecosystem regime transitions, species extinctions and extirpations, and general loss of biodiversity. A further problem highlighted by the case of the DRC is marginalization of conservation strategies and programs through direct engagement of park and protected area staff with armed rebels; through increases in poaching of sensitive, threatened or endangered species; and through the diversion of government funding for resource management and protection. Like the DRC, the case of conflict in Ethiopia demonstrates the difficulty of establishing and maintaining conservation strategies and government-run resource management and protected areas (Jacobs and Schloeder 2001)

The direct impacts of conflict on the natural world are not limited to the temporal period when fighting occurs. Rather, the post-conflict phase holds a diverse set of potential impacts for natural systems, and can in some cases be more dramatic than the impacts incurred during outright violent phases. Kanyamibwa (2001) examines the scope of environmental impacts for biodiversity conservation in post-conflict Rwanda and finds that the main sustained impacts both during and following the Rwandan civil war include destruction of wildlife and habitat, pollution of rivers and freshwater aquatic systems, marginalization of parks, protected areas, and resource management, and the isolation of populations of various species due to habitat conversion.

Shambaugh et al. (2001) advance a method for conceptualizing the impacts of conflict on biodiversity and on ecosystems more generally. They suggest several broad categories of direct negative impacts: habitat destruction and loss of wildlife; over-exploitation and degradation of natural resources; pollution; marginalization of the conservation and natural resource sectors; the mutually reinforcing effects of conflict environmental degradation and poverty; and fundamental shifts in social, political, and economic structures. Underlying these umbrella categories are series of other impacts of conflict that have indirect effects, often channeled through one of the primary categories. These include: negative impacts to conservation staff and programs; erosion of governmental funding for resource management/enforcement; resource demands by government and rebel groups to generate funds; expansion of illicit trade networks, proliferation of arms, and the post-conflict rush for resources.

Summary

Discussion here suggests that humans are intrinsically tied to natural systems. Rather than existing in conjunction with the natural world, we are an integral part of it.

Our human sub-systems form integral parts of local and global systems. As such we are sensitive to changes in those systems. Likewise, human action has a direct and impressive impact on the state of natural systems, and on the flow of services they provide us. While review of the whole of human-nature interaction falls outside the scope of the present work, a review of the impacts of just one aspect of human action has been discussed. From this brief and non-comprehensive review it is apparent that violent conflict directly affects natural systems in a variety of ways and at multiple temporal and spatial scales. While limited evidence exists of the positive influence that conflict can have on ecosystems generally, and biodiversity specifically, it is clear that these limited benefits are greatly overshadowed by the myriad negative impacts that human conflict can have on natural systems.

The question of why humans ought to be concerned with changes in the state and character of ecosystems has been addressed by discussing our reliance on the services we derive from them. Many of these services are so complex or so vast and interrelated that there is no technological replacement for them. Many are so fundamentally essential for human health and wellbeing that they cannot be foregone. On a local scale, scarcities in these services are perhaps manageable, but as we scale up, scarcity ultimately becomes a major problem for our continued survival.

Critics of this line of reasoning will be quick to argue that the idea of adaptability and adaptation has been left out of the equation. After all, throughout the entirety of our evolutionary history we as a species have constantly adapted to changes in the natural world, and surprisingly well. In the face of further environmental or ecological change then, will humans not simply continue to adapt to changing ecological regimes, resource availability, and other ecosystem dynamics?

The short answer to that question is, certainly humans and social systems will continue to adapt to changes in the natural system, regardless of the cause (either anthropocentric, natural, or both). However, adaptation comes neither freely nor easily. Changing supplies of various ecosystem services can *stress* social sub-systems and force them to adjust to changes in service delivery by altering their consumption of that service, finding substitutions for it, or foregoing it. Further, as systems and ecological processes are interconnected in complex ways, changes in one service will alter the flow of other services, stressing social systems from multiple angles. As discussed in the next chapter, this readjustment process can disrupt well-established patterns of action and interaction, lowering a society's resilience to stress. Further, in the specific context of adaption by conflict-affected populations and human systems, adaptation to a changing environment or ecology places further pressure on already disrupted systems, increasing the overall cost of the conflict and exacerbating the return to social, political, and economic stability. The following chapter discusses the specific pathways through which changes in the natural world - either natural or anthropogenic - can drive conflict processes.

Chapter 2. Resilience: pathways to conflict

A common theme throughout much of the work on conflict and the environment is the search for direct or primary causal pathways through which resources, topology, and topography generate conflict between social actors; or sustain, fund, or harbor groups engaged in conflict. In some cases there may in fact be direct links where rents generated from mineral or timber resources are used to fund insurgency (Collier and Hoeffler 2005). Likewise, distance from the capitol or harshness of terrain may affect the ease with which rebellions can be suppressed by governments (Buhaug and Rod 2006). However, while much statistical work has demonstrated strong correlations between conflict and particular environmental and topological variables, the pathways through which these variables produce, drive, or otherwise affect conflict processes remain underdeveloped. In specific cases the links between the natural resources and violent conflict may be direct, and the causal processes transparent. More often, however, the effect of the natural world on social systems is much more subtle and much more complex than the traditional views allow. This chapter presents a theoretical mechanism based on social resilience theory (Holling 1973, 2001; Walker 2004; Adger 2000; Kinzig et al. 2006) through which changes in natural world alter the trajectories of social systems, pushing them toward fundamental changes in their function and structure. This approach differs dramatically from mainstream approaches to conflict, in that environmental influences are far removed from the expression of violence. Rather than the environment or natural resources being a cause of violence or social tension *per se*, changes in the relationships between and among interconnected natural and social systems combine to produce fundamental shifts in the states of those systems.

Scholars have long debated the role of environmental processes and natural resources in conflict dynamics. Social science interested in that role typically falls into one of three veins. Scholars in the first vein explore a wide array of avenues through which certain resources and certain institutions (formal or informal) that regulate access to resources produce mechanisms that drive or sustain violence. Among the volumes of work in this vein, Homer-Dixon (1991, 1994, 1999) and Kahl (2005) discuss absolute and relative scarcity as driving deprived groups toward violence. Collier and Hoeffler (2002, 2004, 2005) explore greed and grievance mechanisms. Alston et al. (1997, 1999, 2000) as well as Simmons (2002, 2004, 2006, 2007) explore land tenure regimes and land conflict in the Brazilian Amazon. De Soysa (1997) Lebillon (2007) and Humphreys (2005) examine resource wealth as a precipitant to civil war. Douma (2006) examines relative deprivation in sub-Saharan Africa. Fearon (2005) examines primary commodity export dependence as a driver of conflict, and Urdal (2008) examines population pressure combined with environmental degradation as a precipitant of violence.

A second vein of research into conflict and the environment, geographic and topologic studies (i.e. studies that examine relative location and physical characteristics that promote violent conflict), have become increasingly popular over the last two decades as advances in geospatial computing and remote sensing have refined our ability observe and measure environmental variables. Among the studies in this vein, Buhaug et al. (2002, 2005, 2006) examine the geographic determinants of civil wars, in a variety of studies. Cederman et al. (2007) discuss possibilities for geo-referencing or geographically locating and defining ethnic groups. Gleditsch et al. (2006) examine shared river boundaries as sources of tension between states. Gulden (2002) examines georeferenced incidents of violence in Guatemala. O'Loughlin (2007) discusses using spatial analysis in the study of civil war. Rustad et al. (2009) examine forest cover and terrain as influencing the location of civil war, and Ward (2005) examines conflict in the context of geographic neighborhoods.

A third vein of research has emerged in response to the legitimization of climate change and the resulting pressure on human systems. Scholars in this third vein study climate-induced migration and population pressures, as well as resource degradation (Barnett and Adger 2007; Nordas and Gleditsch 2007; Reuveny 2007), and large climatic changes generating scarcity (Hendrix et al. 2007; Meyers 2007; Levy et al. 2005; Raleigh et al. 2007).

Common to all of these veins of study is the search for the shortest causal pathways through which environmental factors or natural resources drive or influence conflict processes. While in some instances those direct correlations may exist, in most cases ideas such as scarcity of a particular resource leading to grievance and ultimately to conflict may be too coarse to capture the mechanisms through which environmental influences affect social systems. An alternative approach would be to forgo the shortest-path approach, and explore conflict and the environment from a nested-systems perspective. The latter approach provides much more room than the former for reciprocal feedback, mutual influence, and complex adaptability among interrelated social and environmental systems. Whereas the former approach seeks to reduce complex interactions into simplified relationships, the latter embraces that complexity and builds theory around it.

Resilience theory is one of several intellectual trends that explore the complexity of social and natural interaction. The concept emerged in ecology in the early 1970s with the publication of Holling's (1973) innovative paper *Resilience and Stability of Ecological Systems*. This paper challenged the mainstream view of the time that ecosystems tend toward single static equilibrium points by demonstrating the existence of multiple stability domains in natural systems. By exploring predator/prey dynamics Hollings demonstrates that natural systems are composed of many variables simultaneously acting and interacting in complex ways. Among these variables there are multiple potential relationships that can be formed, depending on the values of each variable at a given time. The nature and functioning of an observed system at a given point in time is only one of the multiple potential expressions of the system.

A simple analogy to this is could be a system composed of heat, pressure, and carbon atoms. With certain values for each variable, the system functions to produce a specific molecular arrangement of the carbon atoms, observable as a diamond. This is only one stable state, however. Alternate values of each variable produce a system that functions to produce an alternate stable state where the carbon atoms are spatially arranged to form coal.

Hollings explored multiple potential stable states in natural systems, and examined the ways in which disturbance, natural and anthropogenic processes, and cross-scale feedback mechanisms affect system states (Holling 1973; Folke 2006). The multiple potential stable states are referred to *as basins of attraction*, and *resilience* is the capacity of a system to remain in a single basin despite exogenous and endogenous changes in the components of the system, and the relationships among those components. For Holling, the resilience of a system is the degree to which it can “absorb changes of state variables, driving variables, and parameters, and still persist” (Holling 1973 p.17, cited in Folke 2006 p. 254).

Since that seminal work the resilience concept has been refined and revisited so much that it is now a mainstay in much contemporary ecological study. It is also perhaps one of the dominant paradigms in the study of social-ecological systems. As noted by Adger (2000, 2006), Kinzig et al. (2006), and Holling (2001), resilience as a framework has gained momentum in the social sciences as well. Folke (2006) provides an excellent review of the development of resilience study in multiple applications and disciplines. Despite the widespread adoption of the concept, there is little consistency among scholars on the use of the term (and associated terms), particularly across discipline divides (Walker et al. 2004). To understand the resilience framework and apply it to examine social systems in violent conflict, it is necessary to first define several concepts.

Socio-ecological systems

From a nested systems perspective, and following Gallopin (2006), natural systems and human systems exist in tandem. They are not merely interactional, but rather are integrally coupled in what can be called socio-ecological systems (hereafter SES). Gallopin defines an SES as " a system that includes societal (human) and ecological (biophysical) subsystems in mutual interaction" (2006; 1991). This definition is scale independent, as systems can be defined from the very micro to the macro levels. Specific systems can be observed at specific scales, and can thus be studied according to their scale-specific characteristics, structures, and relationships. For example, a social system can be identified and observed at the state/country level. That system will have certain scale-dependent variables (i.e. political parties, racial and ethic groups, etc.). Each of those variables, however, can be isolated and studied as systems at a finer scale, and each will be comprised of variables that can be further isolated and studied at even finer scales. Thus any system identified for study must simultaneously be understood in the context it's scale-dependent variables, in the context of the larger systems of which it is part, and in the context of the subsystems which comprise it.

A forest, for example, can be defined according to its spatial extent and dominant vegetative types. However, that forest does not exist in a vacuum, and is as much a product of the climatic processes that drive temperature and precipitation in the entire region as it is a product of the trophic structures within the forest that ultimately provide soil nutrients which are consumed by the dominant vegetation. Likewise, a human population living in the forested area can be defined as a social system. However, there are sub-groupings within that population (villages, families, business interests, ethno-linguistic groups, etc), and that system is part of larger national, regional and global systems. The social dynamics at forest community level are influenced by internal as well as exogenous influences at these other scales. Adding another degree of complexity, the natural sub-systems in this case are influenced by the actions of the human community in a variety of ways including human collection of biomass for fuel, grazing or other pastoral enterprises, agricultural practices, economic dependence on forest resources, waste management, etc. So too, the human community is directly affected by the natural sub-systems for production of air, food, cultural/spiritual ties, etc. The forest system, then, is an SES that includes both biotic and abiotic components that all exert influence on each other, and all exist within larger and smaller sub-systems. That system can be reduced down with its component human or natural systems as the focus of analysis, however those sub-systems must be considered in relation to other nested systems with which they are connected.

Ecological resilience

While Holling's original definition provides a good starting point for understanding the concept of resilience, a variation of that definition is preferred here that emphasizes not only the capacity of the system to absorb change, but also the ability of a system to adapt while still maintaining the same fundamental character. Resilience, according to Walker et al., "is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks…" (2006, p. 10). This definition reflects the dynamism of systems and their components by allowing space for reorganization without loss of function. Holling's definition emphasizes maintenance of relationships among variables, which is appropriate given that the original focus for Holling was on predation systems and predator/prey relations. Since that original work, the concept of resilience has been expanded to a more holistic systems view. In light of this, the expanded definition of resilience allows for reorganization of the relationships among variables without losing essential system functioning or character.

There is no normative value attached to the resilience of a system. Rather, resilience is simply the capacity of a system to retain essential characteristics and perform specific functions, or the resistance of a system to change. We can think of systems where such stability is considered positive by the human component, such as the maintenance of a democratic social system, or negative like the maintenance of oppressive structures like slavery. The same holds for the natural world, where humans may assign positive value to the maintenance of a biologically diverse and productive fishery, or negative value to the sustained succession of a riverbank by invasive plant species. Likewise, the vulnerability of a system (the lack of resilience, or its capacity to change states) is normatively neutral. Change in a system may be regarded as positive when that change brings about lower infant mortality rates or increased biological productivity, or negative when it signals diminished human well-being or extinctions. There is no inherent value in a system remaining in one or another stable state. Rather, that value is imposed by the human element in a SES, assigned based on the utility that they derive from one versus another stable state and the services they derive from specific system functions (Gallopin 2006, Walker et al. 2004).

State space and basins of attraction

Two concepts essential to resilience are *state space* and *basins of attraction.* A system's state space is regarded as a theoretically *n* dimensional space, where *n = the number of component variables that comprise the system*. Walker et al. (2004) describe state space with the analogy of a rangeland system defined by the amounts of grass, shrubs, and livestock present in the system. Although an actual rangeland is exponentially more complex than this, Walker et al. describe a rangeland as a 3 dimensional state space with each dimension corresponding to one of the three variables. The position or state of the system inside that state is defined by the value of each variable at any given time, or the ratio of the variables to each other (Gallopin 2006).

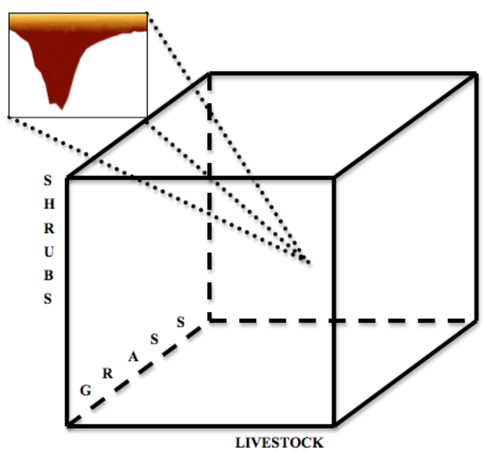

Figure 2.1 Simplified rangeland state space model with one basin of attraction

Regions in state space in which systems tend to remain are referred to as domains of attraction (Holling 1973) or basins of attraction (Walker et al. 2004). Gallopin conceptualizes basins of attraction as “the portion of the state space of a dynamic system that contains or “attractor” toward which the state of the system tends to go, and is therefore one region…where the system would tend to remain in the absence of strong perturbations.” (2006, p. 297) These *attractors* are theoretical stability points toward which the values of variables are attracted given values of all other variables in the system at a given point in time. The attraction toward these points is a product of the complex interactive relationships among interrelated variables. Were the variables to occur in a vacuum, these attractors could be conceptualized as equilibrium points. However, SES are incredibly complex systems, constantly subjected to stress from the interactions and processes of their individual components (biotic and abiotic), from exogenous stress or disturbance from systems in which they are nested, and from stochastic elements at each scale. Thus all elements of a SES are constantly fluctuating, adjusting to changes in other variables throughout the system.

Basins of attraction, then, are stable areas in state space within which the system behaves or functions in a specific way. Inside a particular basin the variables that comprise a system exist in predictable relationships with each other, given various levels or types of perturbations and specified parameters (interactional dynamics). Because of exogenous drivers and endogenous stressors, a system resides inside a particular basin on an orbit rather than at a stationary point. The trajectory of the orbit is defined by the values of component variables across time and their relationships, both of which are constantly fluctuating due to exogenous and endogenous stress. For systems with multiple attractors, resilience is regarded as the ability of the system to remain within one basin of attraction, or for the trajectory of that system to absorb changes in its variables and remain in orbit of that attractor.

Figure 2.2 Side view of state space with two basins of attraction: one deep and wide, the other shallow and narrow[1]

When a systems trajectory carries it out of one basin of attraction and into another, it can be considered a regime shift (Kinzig et al 2006; Scheffer and Carpenter 2003; Folke 2006). In the simplified example of the rangeland system, we can imagine two basins of attraction: one dominated by abundant grasses and sparse shrub, the other with abundant shrub and sparse grasses. The transition from a grassy regime to a shrub regime would signify the system shifting from one basin of attraction to another, each with corresponding levels of livestock that the system can support. Resilience in this

[1] Image generated in ArcScene, ARCGIS 9.3 using digital elevation data for Shiprock, NM. DEM data can be found online at: http://130.166.124.2/nm_index.html. Accessed 20 March 2010.

theoretical system is the degree to which it can handle fluctuating level of grasses, shrubs, and livestock, yet still retain its character as either a grass-dominated regime or a shrub-dominated regime.

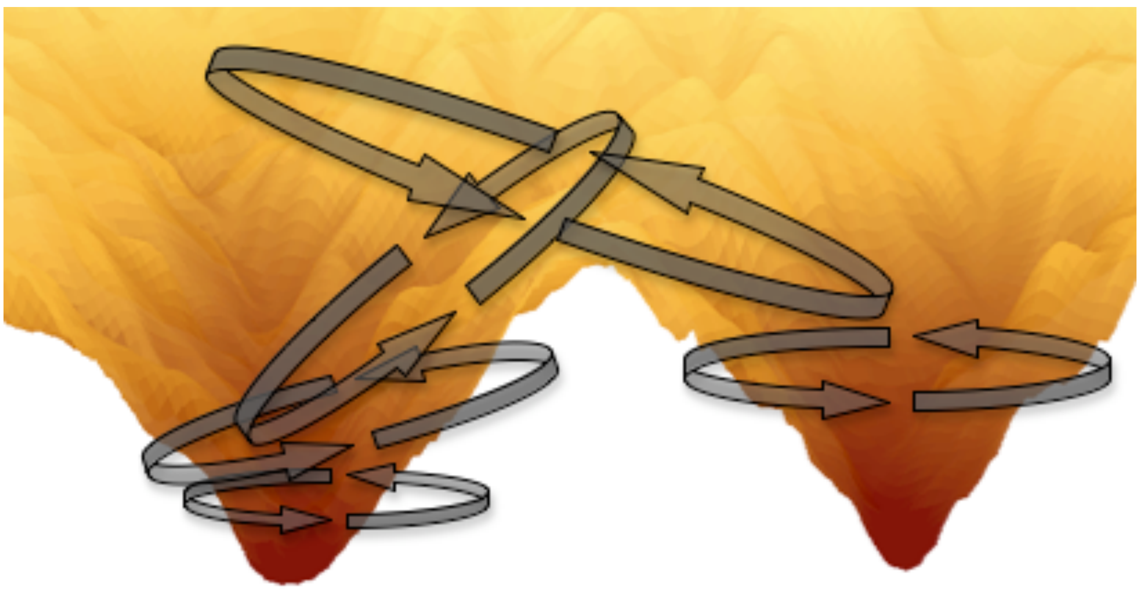

Figure 2.3 Shifting trajectory representing system regime shift

Of course the world is near infinitely more complex than this simplified model. Among the many variables omitted from it are climatic forces, soil stability, predation processes, decisions of livestock owners, other floral and faunal species, and land management institutions and practices. Each of these (and multiple other) omitted variables will interact among themselves and with the three original variables to produce the rangeland system in question. The system thus becomes incredibly more complex than the linear relationship among the variables assumed by the oversimplified model. It is this complexity and this non-linearity that gives rise to the potential for multiple stable states for the unit being observed. When we talk about the resilience of such a system, then, we are really describing the stability of system functioning or maintenance of system behavior, rather than stability of individual populations or static ecological states (Adger 2000; Gallopin 2006; Pimm 1984; Holling et al. 1995).

Stress, perturbation, and change

As noted earlier, a system occurs within a basin of attraction according to an orbit whose trajectory is defined by changes in variable values in response to endogenous and exogenous stress or perturbation. *Stress*, in this sense, refers to pressures exerted on variables (system elements and parameters) that disrupt (either suddenly or cumulatively) the value of those variables across time, and require that associated variables and the relationships among them readjust to new values. The response of the system to such stress during the readjustment phase defines its trajectory within a specific basin of attraction. This concept of cross-scale feedback causing shifts in values of system variables, and producing adaptation and readjustment across system variables and dynamics is referred to in the literature as *panarchy* (Hollings 2001). In the simplified rangeland example, stress could come endogenously from increased grazing pressure, or exogenously from a drought, each contributing to the character of the ecological regime (in this example, the ratio of grasses to shrubs, and the livestock that the system can support). *Perturbations* are a related concept. Gallopin defines perturbations as "major spikes in pressure (e.g. a tidal wave or hurricane) beyond the normal range in variability in which the system operates…" (2006, p. 295). In effect, these are significant increases in stress exerted on variables outside their normal tolerance range that dramatically alter the trajectory of the system orbit across a basin of attraction.

Social resilience

Discussion of resilience thus far has revolved largely around the ability of ecosystems to maintain their functionality without experiencing regime shifts. This is owed largely to the dominance of the concept in natural resource management, conservation biology, and sustainable development studies. Throughout much of the literature on the concept, it is applied to SES with a particular focus on human management of the natural world. Exceptions due of course exist, and are reviewed well by Folke (2006). As Adger (2000) points out, the concept of resilience has not been fully brought across the discipline gap and applied to the social aspect of social ecological systems. He attempts to bridge that gap by exploring the resilience of social institutions in SES, where institutions are regarded as both "habitualized behaviour and rules and norms that govern society… [and] formal institutions with memberships, constituencies, and stakeholders" (p. 348). According to this definition, social resilience is defined and observed at the community rather than the individual level.

Adger describes social resilience as conceptually related to ecological resilience, though applicability of the concept requires modification. According to him, employing the principles of ecological resilience directly to social systems in an SES assumes that no differences exist between the functioning, structure, and behavior of social versus ecological systems (Adger 2000). Holling (2001) discusses many of the differences between the two types of systems. Human systems are uniquely different from natural systems according to three traits: *foresight and intentionality* wherein humans anticipate events and adjust their behavior and their environment to counteract expected stresses; the human ability for *communication* of complex ideas and experiences; and *technology* as amplifying the scope of the human ability to influence the natural world and natural processes. Human systems are thus the product of intentioned action and interaction, though the order that emerges is beyond intentional design (Walker et al. 2004). The order that emerges in an SES, therefore, is influenced both by natural processes and natural interactive relationships among variables, as well as by the intentional manipulation of those variables and relationships by the social component of the SES. Whereas resilience in ecological terms refers to the ability of the ecological system to retain its functionality in the face of perturbation (either natural or anthropogenic), social resilience requires a modified definition (Adger 2000). Accordingly, social resilience is understood as "the ability of groups of communities to cope with external stresses and disturbances as a result of social, political, and environmental change." (Gallopin 2006, p. 297) Taking this a step further, social resilience can be thought of as the ability of social institutions (either formal or habitualized) to absorb exogenous and endogenous stress and perturbation while retaining the same essential character or maintain the fundamental relationships among social groups.

The latter definition allows the concept of basins of attraction to be applied to social systems in an SES. We can imagine for a given social unit several potential stable states in which variables within the system (social sub-groups, e.g. political parties, ethno-linguistic groups, clans and tribes, family units, etc.) take on different values and co-exist according to varied sets of behaviors and interactional dynamics according to specific political, social, and environmental conditions. Kuznar and Sedlmeyer (2005), for instance, discuss two stable states for social systems in Darfur, Sudan: conflict and cooperation. Their analysis of the Darfur conflict is both reductionist and deterministic, in part necessarily so, as they use it to develop an agent-based model of conflict dynamics. That modeling approach requires complex interactional dynamics to be reduced to a set of if/then rules. As such, those authors omit many of the most fundamental drivers of conflict in Darfur (i.e. religions, political maneuvering, etc.). Despite these glaring shortcomings, their analysis serves as a useful framework for demonstrating how environmental change can affect the stable states of social systems.

According to Kuznar and Sedlmeyer's analysis conflictive and cooperative stable states in Darfur are influenced heavily by environmental conditions (precipitation levels and associated biomass productivity), with high rainfall periods corresponding to a system state characterized by cooperation and inter-marriage among sedentary and pastoral groups and cooperation and trade among social sub-groups, and drought producing regime shifts to system state characterized by ethnic polarization and violent raiding between sub-groups. Citing multiple ethnographic and political studies Kuznar and Sedlmeyer argue that while traditional nomadic pastoralist and sedentary agriculturalist relationships in Darfur are complex and involve cycles of tension and cooperative interaction, in times of peace ethnic boundaries tend to be fluid, and partially determined by economic behavior and occupational choice. Beginning in 1982 severe drought affected Darfur, leading to decreasing ecological productivity. The plains where nomadic pastoralists traditionally graze were most affected, leading to the nomadic migration to other regions occupied by sedentary agriculturalists where rainfall is typically higher. This migration intensified ecological pressure and ethnic divisions began to solidify according to occupational choice. Increasing ecological pressure, declining productivity, and ethnic polarization combined to shift the system into a state of conflict. Throughout the next three decades, environmental degradation continued, and ethnic groups increasingly sought alliance with political groups and neighboring military groups. Complex ethno-political and intra-regional dynamics emerged and increasingly drove conflict processes so much so that the Darfur conflict is one of the most protracted conflicts on the globe. As the conflict intensified, the drivers of conflict thus became more complex, and now include Islamic fundamentalism, racial prejudice, and political opportunism all affect the situation in Darfur.

Given the reductionist methodological constraints under which those authors operate, it is right to be skeptical of the analysis advanced by Kuznar and Sedlemeyer. Indeed, from a practical perspective, their analysis serves limited utility for conflict prevention, mitigation, or resolution. However, from a strictly theoretical and hypothetic perspective, the conflict as they frame it provides an excellent analogy that is easily applied to a resilience framework. Translating this to a resilience perspective, prior to the shifts in climatic conditions, the SES in Darfur was characterized by different social sub-groups deriving different services from the natural systems in geographically distinct places. Nomads grazed their herds in low-lying plains, and sedentary farmers raised crops in the Jebel Marra region where rain is typically higher (Kuznar and Sedlmeyer

2005; Suliman 1996). Changes in one variable (rainfall), changed the relationship of social elements to geographic ones, as specific locations no longer provided specific services upon which social groups depended (e.g., declining ecological productivity led to diminished forage for livestock, and economically marginalized pastoralists while simultaneously diminishing their ability to meet subsistence needs). Nomads responded to the changing delivery of ecosystem services by migrating to higher rainfall areas. This migration had the dual affect of increasing ecological pressure on an increasingly marginalized environment, and changing the established relationships between sedentary farmers and migrating nomads by solidifying formerly fluid ethnic lines. Thus the initial change in precipitation initiated a string of perturbations in many variables in the SES, altering the trajectory of the entire system such that its orbit fell into the attraction of another stable state defined by conflict among the social component of the SES, with ramifications for many non-human components of the SES including crops, livestock, and environmental quality. We can describe this chain of events as lowering the resilience of the system to change, in that the stress accumulated in the system to such a point that the system exceeded its ability to absorb stress in its former state, leading to a regime shift (depicted in *figure 2.4)*.

While the political situations in Darfur specifically and Sudan more generally are infinitely more complex that the simplified synopsis offered by Kuznar and Sedlmeyer, what is clear is that the roots of the conflict are much more complex than either ethnic tension, or climatic variability alone. Rather, the conflict in Darfur demonstrates incredibly complex relationships and interactions between many variables precipitating conflict.

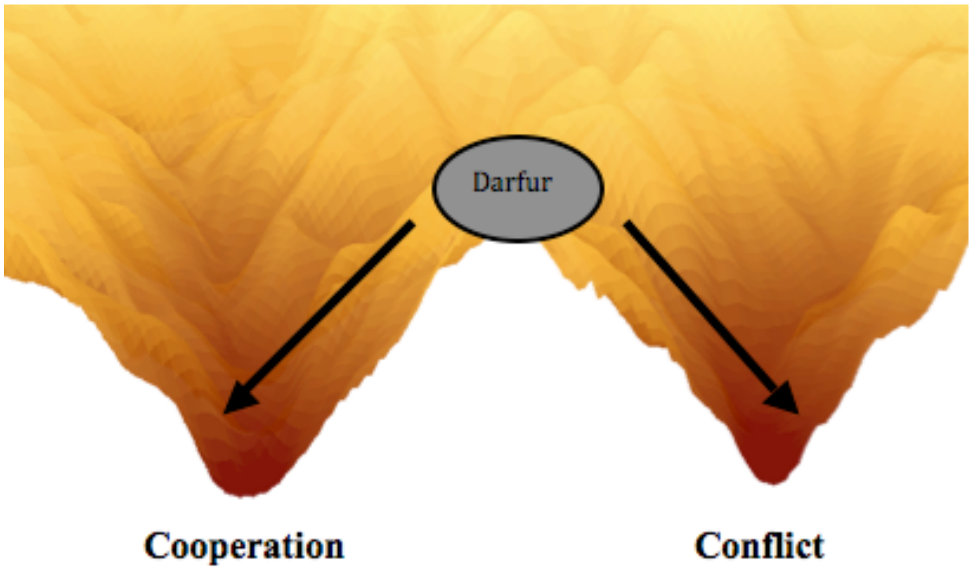

Figure 2.4 Darfur SES: changes in precipitation and associated levels of primary production of biomass alter the nature and function of relationships among social groups leading to a regime shift for the social subsystem from conflict to cooperation or vice versa

Among the few that were mentioned are climatic variability, primary biomass productivity, spatial distribution of precipitation, livelihood choice, economic productivity, ethnic fluidity/rigidity, intra-regional politics, population migration, and subsistence needs. In the Darfur example, change in one variable affected all the other variables, and change in each of those had reciprocal effects throughout the system. Environmental marginalization certainly played a role in the conflict dynamics, however that role is much more nuanced and much more complex than simple scarcity of rain and decreased biomass for consumption by livestock. Instead, changes in the delivery of ecosystem services introduced perturbations into the system, and the subsequent readjustments by corresponding variables altered the trajectory of the system such that it shifted into the basin of attraction for a SES characterized by human conflict.

Concepts revisited

A SES is any system composed of social and natural (biotic and abiotic) components acting in concert to produce a specific set of functions. A SES can be identified and observed at a variety of scales, however, regardless of the scale it is subject to endogenous processes and variables from its constituent units, as well as exogenous influence from components and processes in larger systems of which it is part - this notion is referred to as panarchy. Based on specific values of every variable in a system and the specific pressures being exerted on them from without and within, the variables naturally gravitate toward specific values. The points toward which variables are attracted are referred to as basins of attraction. For a given system, there are multiple potential stable states or multiple basins of attraction. That is, there are multiple sets of potential relationships among interconnected variables, and the relationships that are expressed are the product of specific values at specific times. The aggregation of all values at a specific time produces specific system functions and characteristics, called regimes. Because system dynamics are in constant flux, the system orbits through basins of attraction according to a trajectory. Changes in one or more variable from exogenous or endogenous stress force interconnected variables to readjust to the new values of each other, causing perturbations in the trajectory of the system orbit. These perturbations can be sufficiently dramatic or sufficiently sustained so as to cause fundamental changes in the structure, functions in the larger macro system, or fundamental character of the system, resulting in a regime shift wherein the system orbit is transferred from one basin of attraction to another, and values system variables gravitate toward alternative values, producing new system dynamics.

Applying this to the idea of conflict and the environment, a SES defined at a specific scale has a specific character defined by set (but flexible) relationships between and among the social and biophysical components of the system. The human component of the system derives ecosystem services from the natural world, and likewise human action affects the character of natural systems. Changes in a single variable in the system affect the relationships among all other variables, and the subsequent readjustment can significantly alter the natural or social components and the relationships among them sufficient to cause a regime shift wherein the structure or function of the SES fundamentally changes.

More specifically, changes in the natural components (caused by either ecological or anthropogenic sources) can lead to changes in the quantity, quality, or type of delivery of ecosystem services to the social components of the system. Such changes in ecosystem service delivery may be particularly prone to inciting a cascade of events that ultimately produce a regime shift in the social component of the system. Two aspects of these services account for such propensity. First, by their very nature, ecosystem services are produced through incredibly complex trophic structures, biological relationships and natural processes. A single service (or set of services), like pollination of flora in a system, is the product of countless interactions among interconnected variables, including the reproductive patterns of multiple insect species, the feeding habits of biological actors, climatic conditions, species populations, transportation and migration habits, and biomass productivity, to name just a few broad categories. Changes in one or many of these elements can affect relationships among interconnected elements, ultimately leading to decreased pollination of plants. This decreased pollination then further marginalizes biomass productivity, leading to increased pressure on human systems that depend on such productivity (grazing, farming, etc.). Further, these processes are not acting alone. Biomass productivity is likely changing due to changes in a host of climatic, biological, and geophysical processes all simultaneously occurring. The complexity of the system makes the pathways and interactions among variables opaque.

Because of that opacity it may not be possible to trace diminished biomass productivity to decreased pollination alone. Thus the human component may not be able to address the root cause of diminished productivity, and hence can only react to it. This introduces a sense of path-dependency to the problem. Because, in this example, humans cannot address the source of diminished productivity, they must either substitute certain natural goods for others that may be more available, find technological substitutions for the goods, change their livelihood and occupational strategies, or spatially relocate. Even if the social component could trace diminished productivity back to reduced pollination, that service is itself so complex and so vast that it is doubtful they could trace the source of diminished pollination back to its source, and equally doubtful that they could engineer sustainable technological alternative pollination methods.

The second aspect of ecosystem services that make them particularly prone to initiating regime change in a SES has to do with their valuation, and difficulty of signaling changes in their delivery. By definition, ecosystem services the natural processes produced by the interaction of abiotic and biotic elements of an ecosystem that sustain human life and wellbeing (Daily 1997). These services are produced at no cost to the humans they support. In other words, humans reap the benefits of these services without paying for them. Moreover, these are public or open-access goods. Because they are free and publicly accessible, ecosystem services are largely non-traded, or market independent (Batabyal et al. 2003). As such there is no direct means of measuring their value, such as a price point associated with the availability of a specific service (Costanza et al. 1997). Certainly the products of many ecosystem services are exploited by human agents and traded in a conventional market sense. However, the underlying processes that produce natural goods or natural capital are themselves market-independent. Measuring the value of a good or service plays an important role for societies by signaling the supply or scarcity of that good or service. Without a price mechanism in place for ecosystem services (or some other method of valuation), there is no readily available mechanism for signaling changes in the availability or delivery of such services. This makes it difficult to recognize or acknowledge marginal changes in service availability. More often, changes in service delivery are only acknowledged when the cumulative stress associated with altered services reaches a boiling point or becomes too painful to ignore. For example, marginal changes in fish stocks in an area may go largely unnoticed for years, until the fishery itself collapses. Likewise, soil productivity can diminish marginally for years. The decline in productivity can be offset with the use of fertilizers to a certain point. After that point, however, the soils are degraded to the point that they no longer support agricultural cultivation. In both cases the cost of production can signal marginal changes in the ecosystem. However, those price points do not accurately capture the changes in all aspects of the ecosystem that are combining to increase production costs. Thus such price points are ineffective at signaling ecosystem change until production either stops, or is too costly to pursue.

This has led to rigorous debate in environmental economics, and has spurred the creation of multiple metrics for valuating ecosystem services. Among the multiple methods advanced are willingness-to-pay schemes and similar hedonic pricing mechanisms, and various discourse-based valuation techniques (Batabyal et al. 2003; de Groot 2002; Costanza et al. 1997). In the absence of a price mechanism to signal scarcity, we must rely on proxies to identify changes in the quality, quantity, and delivery of ecosystem services. One proxy may be diminishing stocks of natural capital. These are directly measurable in an economic sense. However, due to the complexity of ecosystem functioning, and the time lag between harvest and sale of natural capital, measuring stocks of natural capital are inefficient measures of overall ecosystem service scarcity. Another proxy could be measuring the cost to communities incurred by foregoing the service, or the cost associated with substitution (either natural or technological). While there is no cost (except perhaps opportunity cost) associated with ecosystem service production for humans, there certainly is a cost associated with diminishing service delivery, and likewise with replacing the services. In the former case the complexity of the system and the subsequent opacity of pathways make it difficult to trace exactly which changes in the natural world produce the effect felt by humans. Thus relying on the cost of forgoing a service to signal scarcity may not actually reliably transmit specific service-scarcities to the end users. Further, as services and processes are interconnected, substitution of a particular service may mitigate the harm incurred by diminished delivery in one aspect of the service, but the substitute will likely not fulfill all of the functions of the service it replaces, and will thus contribute to changes in the availability or quality of other related services. Relying on chemical fertilizers to maintain agricultural yield is a good example of this. In the short term fertilizers can offset the effects of soil degradation on agricultural production. However, these fertilizers can be damaging to the biotic components of the soil. Rather than a substitute for the deteriorating soil processes, these chemical solutions can actually further marginalize the ecosystem services provided by soil processes.

Both aspects of ecosystem services, the lack of readily available scarcity indicators, and opacity of service generation and delivery processes, have important ramifications for social systems. As societies are dependent on service delivery for their wellbeing, they are sensitive to changes in the rate, quantity, and quality of service delivery. However, without a valuation mechanism in place, the increasing scarcity of particular services may go unnoticed until the effects of that scarcity are widely felt across a society, either via marginalization from lack of service delivery, or through the readjustment of social sub-groups to changing system dynamics. If and when the source of system stress is traced to scarcity of a particular set of services, it may be too late to adequately adjust to the change in service delivery. Further, due to the opacity of the system it may be impossible to fully identify the origins of the system change. The service itself is simply an expression of underlying processes and dynamics. Thus social systems are forced to adjust to the changing expression of system dynamics, without actually identifying the nature of the underlying change. Thus any mitigation measures that social actors employ - from personal behavior adjustment to large-scale social and environmental engineering - are likely to miss the source of system stress, and introduce additional stress into various other parts of the social-ecological system.

Limitations of the resilience framework

The discussion of resilience presented thus far serves as a good conceptual framework for exploring the ways in which changes in the natural world affect the social component of SES. As a framework, resilience is incredibly powerful for embracing the stochastic complexity and complexity of coupled human and natural systems. There are however several challenges in translating the concept from a conceptual framework to an operational, testable theory. One such challenge consists of the difficulties associated with observing and measuring system resilience on a practical level. Recall that the concept posits multiple basins of attraction for a given system. A regime shift consists of the system orbit escaping the attraction of one basin, and being captured in the attraction of another, producing fundamentally different system functions. While theoretically clear, this regime shift is difficult to observe, regardless of whether it happens quickly or over longer periods of time. Returning for a moment to the oversimplified rangeland example, as grazing pressure intensifies the ecological regime shifts from grass-dominated to a shrub-dominated regime. At what point, however, has the regime shift occurred? Further, at what point has the system orbit actually transferred basins such that its trajectory is consistently in the basin of attraction for shrub-dominated landcover? From a conflict perspective, and what point has a social regime transitioned from cooperation and non-violent competition to conflict? Is this threshold determined by numbers of people involved or killed in fighting, or by the occurrence of a single violent act? The literature on resilience discusses thresholds between basins, and various authors advance methods for measuring a system in relation to such thresholds. Walker et al. (2004) discuss four measureable aspects of resilience:

latitude: the theoretical width of the basin of attraction. Essentially this is the amount of change a system can endure before crossing undergoing a regime shift.

resistance: the theoretical depth of the basin of attraction. This is the ease with which the system can be change. According to Walker et al. this is a function of the ratio of resistance to change/ability to absorb change. Thus deep basins require greater or more sustained perturbation to undergo a regime shift.

precariousness: the location of the system and the direction of its trajectory in relation to the threshold separating two basins. In other words, how close the system is to a regime shift

panarchy: the ways in which each of these attributes of a system respond to exogenous and endogenous stress exerted on it. Each of the above attributes is related to the topology of the system's state space. That topology is defined by elements in the system and the ways in which they interact given specific values at specific points in time. As the component variables are constantly changing and readjusting, the topology of the state space is likewise changing.

Respective of these aspects of resilience, Walker et al. discuss the concept of adaptability as the capacity of human components of the system to affect or alter the resilience of the SES. As discussed by Hollings, humans have unique traits and abilities that set them apart from the other biotic and abiotic components of an SES. Among these are communication, foresight and intentionality, and technology. Given these traits, it then follows that by assessing a system according to its resistance, latitude, precariousness, and panarchy, the social component can introduce change in variables in order to alter the topography of the system state space. If the basin that the system is in is valued positively by humans, the can introduce change to make the basin wider and deeper, and to move the system farther into the basin. Similarly, if the current basin is undesirable, they can act to make the basin more narrow and shallow, and thus easier to escape.

There is perhaps limited applicability in this approach to measurement, however. The complexity of the system and the unpredictability or stochastic complexity inherent in dynamic relationships suggests that the ordering of a system is beyond the control of any individual agents within it. While humans may act intentionally, their actions cause unforeseen and unforeseeable reactions in interconnected variables and relationships across the system. Thus any order that emerges in the face of introduced change will likely be different than the one envisioned by SES engineers. Further, the concept of panarchy states that endogenous and exogenous stress on the system forces constituent components to constantly readjust to changing parameters and changing variables. Thus the topography of the state space is constantly shifting and transforming. To be measureable in any meaningful sense, the attributes of latitude, resistance, and precariousness would need to be applied to a very stable, nearly static system, where the topography of state space is slow-changing. Finally, while this approach does provide aspects that might be measured, the authors fail to advance a method of observing any of these aspects. Given the stochastic complexity of the system dynamics, it is unclear how these aspects could be measured on a practical level. In the context of the hypothetical rangeland, this approach to measurement does little to answer the question, what is the threshold between the two regimes, and how do we know when the system crosses it?

An alternative approach to the concept of regime shifts is advanced by Kinzig et al. (2006). They consider SES transition at a process level. Rather than regime shifts occurring in one large process, they see the transition from one stable regime to another as a series of cascading effects, "in which multiple thresholds across scales of space, time, and social organization, and across ecological, social, and economic domains my be breached" (p. 20). While a system's state space contains multiple stable states, the transition between these large basins consists of a procession through multiple interim unstable states at a range of temporal and spatial scales. A system's trajectory between basins thus takes the system through multiple cascading states, until it fully transitions into a separate regime. According to those authors, the regime that ultimately emerges from this transitional cascade is highly stable and resistant. Under this conceptualization, the transition of a rangeland from grass-dominated to shrub-dominated is thus a progression through a series of mixtures of vegetative mosaics until it fully transitions from one regime to the other. Likewise in a conflict situation, a single event can erode the relations between groups and begin a cascade of events that ultimately transitions a society from cooperation-dominated states to conflict. Conflict is not necessarily unavoidable at any time. A society can come to the brink of conflict and turn back at the last minute. At any stage the trajectory of transition may be altered by additional perturbation such that the end result is not predetermined in a fatalistic sense. Rather, the cascade trajectory is as much a product of the variables in the system adjusting and readjusting to new values and relationships as the overall regime shift is.

This approach perhaps holds more utility than the simpler views of regime shifts, in that it allows for progressive, successive, or marginal transitions rather than sudden abrupt changes. However, this approach too suffers from difficulty of application. Particularly since the end product of the regime shift is non-determinable, it is possible to retrospectively trace back the progression of cascading shifts. However, for a system undergoing a regime shift, it is unclear how to determine whether and when a stable state has been or will be reached.

A final limitation of the resilience approach lies in the question of what factors make a system more or less resilient? If resilience in a SES is the ability of the system to absorb change while still retaining the same essential character and functioning, what determines or affects that ability? There has been rich dialogue among scholars on this subject. When emphasis is placed on the ecological side of social-ecological systems, the debate largely revolves around the impact of biological diversity in preserving system multi-functioning and maintenance (Hector and Bagchi 2007), with various authors arguing that maintenance of keystone species and populations play an influential role in system resilience, and other arguing that it is the number and spatial arrangement of species that is most important (Balvanera et al. 2006; Hooper et al. 2005; Diaz et al 2006; Pimentel et al. 1997). There is similar inconsistency when the social components of SES are the focus of study. Among the many competing factors that may influence resilience are resource dependency, ecosystem dependency, livelihood stability, institutional structure and composition, integration with larger economic systems, economic diversification, environmental variability, etc. (Adger 2000).

Summary

While the concept of resilience as applied to social-ecological systems presents multiple operational challenges, it also provides a conceptual framework for exploring the complex interaction between social systems and ecological ones. This chapter has applied that framework to the concepts of conflict and the environment, in the hopes of exploring the complex interactions between environmental, ecological, and social interaction. It has been suggested here that changes in the delivery of ecosystem services introduce stress into social systems, causing them to readjust to the type, quantity, or quality of those services. That readjustment can be viewed as perturbation in the system trajectory, and those perturbations lower the social component's resilience, or ability to absorb change while retaining its essential structure and function. It is during this readjustment phase that a society is most prone to conflict, as the nature of the relationships are changing among social sub-groups, and among social and ecological components of the system. Conflict, however, is not inevitable during this readjustment. Indeed, history has demonstrated that humans are at least as prone to cooperation as they are to conflict. Thus conflict is only one of multiple potential stable states for the social component of the SES as it restructures in the face of change. The ultimate order that emerges is the product of complex interactions among all variables in the system throughout the transition phase. The following chapter builds on this approach, and asks if there are certain perturbations or certain ecological components of social-ecological systems that are more naturally prone to generate conflict among social groups.

Chapter 3. Searching for the ecological correlates of armed conflict

Since the end of the Second World War internal violence has been far more prevalent than interstate war (Sakrees et al. 2003). This has been widely documented in academic literature. In the search for the ecological correlates of violent conflict, then, it is prudent to focus on civil rather than interstate conflict. This is not, however, the first attempt to examine the correlations between civil war and the natural world. The last two decades have witnessed a surge of research so dedicated. That surge has given rise to the inclusion of many geographic variables into the study of violence (Buhaug and Lujula 2005). Rod and Buhaug (2007) argue that geographic factors are particularly salient issues in civil war, because the violence associated with this type of war rarely spans an entire country. Rather, fighting is typically concentrated in specific locations with geography favorable to insurgency or warfare (Rod and Buhaug 2007). Buhaug and Rod (2006) describe the unique spatially explicit aspects of many factors thought to affect the onset or duration of civil war. Because factors like ethnic diversity, economic prosperity, resource distribution, terrain and landcover, and productive capacity are not smoothly distributed across a country, but rather tend to cluster in specific spatial configurations and topologic relationships, it is imperative to account for that geographic heterogeneity when studying civil war. This chapter begins by reviewing burgeoning literature on application of geospatial techniques in study of civil war, highlighting various approaches and their limitations. Next this chapter describes the design of a statistical approach to explore the ecological correlates of armed conflict.

Traditional geographic covariates in the study of armed conflict

Across studies of armed conflict there is a tendency to examine the natural world according to two perspectives: natural resource dependence/exploitation, and the suitability of a region to host insurgency. Neither of these approaches is mutually exclusive, and most statistical work explores variables from each. The resource perspective explores the mechanisms through which natural resource endowment, scarcity, and location drives conflict dynamics (Collier and Hoeffler 1998, 2002, 2004; Lebillon 2007; de Soysa 2007; Ross 2004a, 2004b; Auty 2004; Hague 1998). Humphreys (2005) provides a good overview of the greed, grievance, and opportunity mechanisms advanced in the literature. The second perspective is less developed in traditional approaches. This perspective theorizes that terrain influences conflict dynamics by providing cover for rebel groups and making it difficult for governments to control specific areas, thus allowing rebels to establish bases of operation. Buhaug and Lujula (2005) note that among the more prominent researchers who explore this idea are Collier and Hoeffler (2004), De Rouen and Sobek (2004), and Fearon and Laitin (2003).

What is striking in each perspective is the lack of consistent and robust findings across studies. Collier and Hoeffler (2004) demonstrate a correlation between primary commodity export (as proxy for natural resource dependency) and risk of civil war, but other studies demonstrate that this correlation is either weak, or its significance is dependent on the sorts of resources being analyzed; whether agricultural, sub-surface mineral, timber, contraband, etc. (de Soysa 2002; Fearon and Laitin, 2003: Fearon 2005). There is similar inconsistency regarding terrain variables. Typically, terrain is operationalized as either the presence or the proportion of mountains and forests within a country, and these variables are correlated with the onset and duration of civil wars. The results of various analyses, however, are highly variable according to the subset of conflicts included in studies, the intervals at which cases are observed, and the temporal span of the analysis (Buhaug and Lujula 2005). Where certain studies find forest cover associated with protracted civil wars others find no relationship (De Rouen and Sobek 2004; Collier et al. 2004). Likewise, Fearon and Laitin (2003) demonstrate a correlation between mountains and conflict onset, contradicting the findings of Collier and Hoeffler (2004).

Traditional works on civil war produce more consistent findings for social variables, however again many works report spurious or contradicting results (Rod and Buhaug 2007) for many social and demographic variables. Examples of these variables include the influence of displaced populations, social fractionalization, ethnic, and religious diversity (Buhaug and Lujula 2005). Buhaug and Rod (2006) suggest that such inconsistency is related to a discontinuity between theory and analysis in traditional work. Most traditional work on civil war operates with the country or state as the unit of analysis. Because of this, any variable for which a correlation is hypothesized must be measured at the state level. This fundamentally omits important spatial relationships that may actually account for the hypothesized relationship. For example, many studies test for the effect of mountainous terrain on the incidence of civil war under the hypothesis that mountains provide cover to rebels. These studies test that hypothesis by measuring the percentage of a state covered by mountains. The use of a percentage in this way assumes a homogenous or smooth distribution of the variable across the state, thus imposing false attributes on the variable, and implicitly altering the hypothesis being tested. Rather than testing the hypothesis that mountains provide cover for rebel operations, a homogenized distributional assumption actually tests whether or not the abundance of mountains increases conflict propensity, and omits the relationship between mountains and rebels. Through careful model specification and creative variable construction and measurement it is perhaps possible to include spatial dynamics into studies aggregated at the state level. However, such proxies are poor substitutes for measures of specific spatial and geographic attributes.

There are several problems associated with aggregating local, or spatially explicit data at the state level. The first issue falls into a category of problems referred to as *ecological fallacies* (Gehlke and Biehl 1934; Stephenne et al. 2009; Buhaug and Lujula 2005; Buhaug and Rod 2006), wherein relationships observed at one scale of measurement do not hold at other scales. A second issue is that of *dilution* (Buhaug and Lujula 2005). Because civil wars are by definition sub-state events, and because they rarely occur homogenously across entire states, data aggregated at the state level can dilute the effect of important relationships. For example, if we hypothesize that terrain plays an important role in conflict dynamics in Chechnya, but we measure terrain for all of Russia, the sheer size of Russia can dilute any local terrain specific to the small area of Chechnya.

These problems of measurement and misspecification have led many to argue against employing the state as the unit of analysis in the study of civil war, preferring instead sub-state, disaggregated, or conflicts themselves as units of analysis (Buhaug and Rod 2006; Stephenne et al. 2009; Hague and Ellingsen 1998; O'Loughlin 2003; Starr 2003). Such approaches have to date been limited in the academic literature due to the paucity of sub-national data for most regions of the world. Where these data do exist, they are often inconsistently measured, preventing comparative statistical analysis on a *large N* scale. However, there is a growing body of work that augments state-level conflict studies by disaggregating from the state level to either sub-national or extra-state scales of observation.

Geospatial study of armed conflict

Stephenne et al. (2009) provide what is perhaps the most systematic review of the application of geographic and spatially explicit indicators in conflict studies. They argue that two elements of geography - space and distance - have been the predominant geographic elements incorporated into such studies. The concepts are typically operationalized as "[p]roximity, geographic opportunity… and the nature of borders between contiguous states…" (p. 504). Early studies examined the ways in which conflicts cluster in space, measuring states proximity (either contiguity or dyadic distances) to each other and the nature and length of borders between states (Richardson 1960; Wesley 1962; Boulding 1962; Vasquez 1993; Bueno de Mesquita and Lalman 1992; Lemke 1995; Sense 1999; Vanzo 1999; Gleditsch and Ward 2001). Stephenne et al. (2009) further note that throughout the 1990s and early-mid 2000s conflict scholars increasingly acknowledged and explored the role of more place specific geographic indicators in conflict dynamics. Among the variables that increased in popularity of study were population dynamics (Wils et al 1998; Hague and Ellingsen 1998; Urdal 2005), economic dynamics and inequality (de Soysa 2002; Fearon and Laitin 2003; Homer-Dixon 1999; Buhaug and Gates 2002; Collier and Hoeffler 2004; Murshed and Gates 2005), terrain and landcover (Bueno de Mesquita and Lalman 1992; Fearon and Laitin 2003; Lemke 1995), and natural resources (Collier and Hoeffler 2004; de Soysa 2002; Elbadawi and Sambanis 2002; Fearon and Laitin 2003; Ross 2004).

Recent technological innovations in geographic information systems (GIS) and computing ability have revolutionized the ways in which geographic and spatial variables can be applied to conflict studies. A GIS is a set of hardware and software used to collect, store, process, analyze, display, and manipulate spatial data. The process of georeferencing allows data to be assigned specific locations in space. Through georeferencing, social, political, environmental, and geographic data can be assigned to specific locations, allowing for analysis at a much finer scale than the state/country level. Star (2002) emphasizes, "that a GIS is a *tool*…that permits the integration of data about the spatiality of phenomena along with data about other characteristics of those phenomena" (p. 246). Thus a GIS can simultaneously store and analyze the data pertaining to the spatial aspects of a phenomenon like a state (the size, shape, and precise geographic location) as well as multiple other aspects of that phenomenon called attributes (population, ethnicity, languages, political system, etc.). Citing Cowen (1990), Star further argues that the real utility of a GIS is the ability to overlay multiple layers of data such that certain topological relationships among them became apparent, thus creating new data as opposed to simply storing and visualizing individual data layers. GIS systems thus offer conflict scholars a powerful tool for exploring local rather than state/national level variables in the study of civil war.

Despite the power of GIS, these systems are under-utilized in mainstream conflict studies. To date only a handful of studies have employed GIS to study the correlations among sub-national or non-state variables and civil war. Buhaug and Gates (2002) pioneered the use of GIS in conflict studies by georeferencing the location of all conflicts in the Prio/Uppsala Armed Conflict Dataset (hereafter ACD) (Gleditsch et al. 2002), and assigning attributes for size of the conflict zone. Using ordinary least squares (OLS) regression and three-stage least squares regression the authors explore the factors that affect the scope and location of conflict relative to the capital of the country. They find that its proximity to a neighboring country, the presence of certain natural resources inside the conflict zone, and the duration of conflict affect the scope of a conflict. Further, they find that distance of conflict from the capital is related to size of the country, scope of conflict, objective of rebels, and whether rebels profess religious/ethnic identity.

The measurement of several variables in this study was very coarse, and not spatially explicit. For example, the presence of natural resources was measured as a binary variable based on qualitative comparative review sources describing probable distributions of certain fossil, metal and mineral deposits. Likewise, conflict georeferencing was conducted by first identifying major battle zones for a given conflict, then creating a Euclidean centroid (the mid-point between all battle locations) to represent the center of the conflict zone. The size of the zone was calculated by measuring the maximum distance between battle zones for a conflict. The conflict zone, then, was calculated as a spheroid placed around the conflict center with radii equal to maximum distance from center to battle zones. Despite these coarse measures, this work paved the way for innovative approaches to studying the locational aspects of civil wars. This work also represents a pioneering approach to disaggregated study of civil war, by operationalizing conflicts as the unit of analysis, rather than states. The ACD dataset further served as the source data for O'Loughlin (2004) in a study examining the spatial coincidence of underdevelopment and conflict.

Star (2002) and Star and Thomas (2002) present a different approach. They employ a GIS to explore the ideas of willingness and opportunity in interstate conflict. They use the GIS to analyze various aspects of borders, and re-measure 301 contiguous land borders according to ease of interaction and salience/importance, thus creating a border dataset where borders become much more than simple lines of contiguity between adjacent states. These authors then use this dataset to explore opportunity and salience of specific border zones for the case of Israel.

Buhaug and Lujula (2005) employ a disaggregated approach to studying civil war that builds on the previously discussed approaches. These authors utilize ACD conflict location data, and construct a series of geographically specific, or spatially explicit indicators that they then test. Among these are conflict-capitol distance, mountainous terrain, forest cover, lootable resources (georeferenced data on gemstones, coca, cannabis, and opium poppy), population density, and rainfall. This study represents significant advancement in the creation of location-specific data and variables. They compare the effects of these variables on the duration of conflict at the country level against their effects at the conflict level, and find evidence to favor disaggregated approaches when examining spatially explicit variables. However, like Buhaug and Gates (2002), this model suffers from measurement problems. Specifically, the measure they employ for mountainous terrain is a simple percentage of mountainous cover for conflicts and countries based on a binary-coded gridded raster dataset indicating presence/absence of mountains (UNEP 2002). Since the publication date much higher resolution data have become publicly available. At the time of publication, this was one of the highest resolution datasets on global mountain distribution available. However, since that time digital elevation models (DEM) have made it possible to analyze slope, aspect, and attitude of mountains much more precisely, which could be used to further refine measurement of these data.

Several related studies build on Buhaug and Lujula (2005) by introducing several new datasets, each related to specific georeferenced natural resources. Gilmore et al. (2005) georeference the physical distribution of diamond deposits across the world. Lujula et al. (2006) introduce a similar dataset for petroleum reserves. Lujula et al. (2005) employ the diamond dataset to examine the effect of diamond distributions on conflict onset and duration. These datasets and studies have served as the foundation for several follow-up works on resources and conflict.

Buhaug and Rod (2006) further present a significantly refined disaggregated conflict model, based again on the ACD data. These authors generate a grid of 100 x 100 km cells, and overlay it on the African continent. Rather than conflicts or countries being the unit of analysis, these grid cells are the focus of the study. Using the overlay function in a GIS, each cell is assigned specific values for each of the variables the authors measure. This is not the only innovation made by these authors. They refine the spatial aspect of the ACD database by defining the conflict area according to a polygon[2] that encompasses all relevant battle sites for each conflict in the geographic coverage over the period 1946-2002 (updated from original). These authors generate several independent variables that are likewise spatially explicit and more precisely measured. They include a series of relative distance measures from cell centroids to specific lootable resources including diamonds and petroleum, georeferenced population density, level of infrastructure development (through the use of a proxy that measures the total length of roads per cell), percent of cell covered by forest and mountains, and ethnic heterogeneity (via a dummy variable indicating whether all populations in the cell belong to the same language family as the predominant language spoken in the capital). This model presents a serious innovation in disaggregated studies by allowing for study of local determinants at the resolution of 10,000 km^2. By focusing on a single geographic region these authors are able to access data on ethnic distribution (which is simply unavailable at the global scale). Likewise, they are able to effectively measure the amount of a specific element of

[2] Vector-based GIS data is based on three primary components: *Points* identify specific spatial locations; *lines* are comprised of two or more contiguous points; and *polygons* are comprised of lines that connect. Conflict polygons were developed by assigning points to specific conflict locations, then creating polygons around the periphery of all related conflict points.

infrastructure for the entire sample. This study, then, presents the first systematic spatially explicit attempt to identify the geographic/ecological variables that combine to produce conflict in specific places, and deter conflict in others.

Rustad et al. (2008) present yet a further refined approach to the geographic study of civil war. They test multiple hypotheses relating to the role of forests as drivers of conflict at the state level and at a disaggregated conflict zone level. Their approach is interesting for the multiple interaction effects it models between forests and other conflict-supporting resources like illicit drugs and mineral deposits. It is likewise innovative in that it introduces a new global georeferenced conflict dataset based on the ACD data, but with conflict polygons representing geographic extent for all conflicts in the world over the period 1946-2004. They note that the polygons they develop for African conflicts are similar to those generated by Buhaug and Rod (2006), but that discrepancies between the two datasets do exist.

This brief review of studies that employ spatially explicit approaches to conflict studies is not comprehensive. Rather it traces the progression of one of the dominant spatial conflict data streams as it has evolved over the past decade. The study described later in this chapter builds on the works described above to further refine the measurement and modeling approaches that have been advanced in the field.

A new empirical approach

Previous chapters discussed a theoretical pathway through which changes in the ecological character of a social-ecological system (SES) can produce readjustment in the other components of the system and cause renegotiation of the relationships among those components sufficient to generate a regime shift in the social component. That theory, however, does little to explain exactly which changes in which parts of the system are more or less likely to shift the social trajectory of a system toward conflict. Said differently, the present work has up to this point presented a theory under which biological and geophysical conditions and processes can combine to produce conflict, but has yet to explore what those conditions and precipitants might be.

Based on the discussion of resilience and human reliance on ecosystem services presented earlier, it is possible to conceptualize two mechanisms, which I call *consumption pressure* and *productive capacity,* through which changes in the natural world negatively affect social systems. Consumption pressure can be thought of as the level of consumption of natural goods and services by the human component of a SES at any given point in time. That pressure can be thought of as level of demand from the human population and the pressure on the system associated with the production/consumption cycles. Demand, however, is a concept loaded with economic associations such as price points, scarcity value, supply response curves, etc. For the purposes here, I discuss demand for goods and services not in the traditional economic sense, but rather in terms of the pressure that consumption of them places on the system as it readjusts to fluctuating values of various components. I thus refer to the concept as consumption pressure.

Different levels of consumption pressure for specific goods and services alter the values of the components that combine to produce them. Changes in the values of those variables produce changes in other processes and relationships to which they are connected in a sort of cascade effect. A change introduced in one variable ripples across the entire system, affecting all interconnected systems, processes, and components. Changes in consumptive pressure for various goods and services thus affect the local abundance of system components, and thus alter the quantity, quality and type of processes and interactions among system components. Ultimately this can affect the availability of specific goods and services for social consumption.

The second mechanism is related to the first. Productive capacity refers to the ability of the ecosystem to produce the goods and services upon which humans rely. This capacity is a product of biotic and abiotic relationships and natural processes within the system. Thus productive capacity is a function of biotic productivity and related geophysical conditions - in other words the flow of material and energy throughout the system. Changes in this productive capacity affect the delivery of goods and services to the human component, and require readjustment across the system to varying productivity. This concept is related to the supply of ecosystem services. Decreasing productive capacity of a specific service requires the human component to forgo the service, substitute something else for that service, or relocate to areas with higher productive capacity for the service in question.

Consumption pressure and productive capacity are interrelated concepts and processes. As discussed in previous chapters, changes in variable values affect the production of ecosystem services in a SES. Thus, increases in consumption pressure trigger readjustment in system variables, and alter the productive capacity of the system. Likewise, changes in productive capacity will alter consumption pressure through traditional scarcity functions. It follows from this that conflict should be spatially coincidental to areas that are undergoing intensification of consumption pressure for ecosystem services, and experiencing or susceptible to declining productive capacity. Whether or not these mechanisms hold up in the real world, however, has yet to be explored. If they do hold, we can expect to observe specific relationships between the occurrence of conflict and the state of the natural world. More specifically, if these mechanisms are valid, conflict is a product of changing relationships among social actors, and arises from changes in the relationships among human populations, biological productivity, and climatic and physical conditions in specific locations.

Hypotheses

Human population size is directly related to consumption pressure of ecosystem services; the larger the human population, the greater their need for natural goods and services to support themselves. Some services, like atmospheric production and maintenance, may be less sensitive than others to consumption pressure at a local scale. Others, however, may be incredibly sensitive, like production of food sources or waste processing, storage, and filtration. In general, though, it is possible to hypothesize that:

> *H_1: Human population density is positively correlated with the occurrence of armed conflict; as population density increases the consumption pressure on ecosystem services at the local scale.*

Consumption pressure is not the only effect that human population density has on natural systems. Land use and cover change (LUCC) can be thought of as anthropogenic modification of the biophysical environment to meet specific needs or to perform certain functions for human communities (Geist and Lambin 2002; Meyer and Turner 1992; Turner et al 2007; Deadman et al 2004; Robinson 2003). This is the imposition of artificial or non-native vegetative and biophysical structures, relationships, and processes on natural ecosystems. By definition LUCC modifies the natural world, and as a result should affect the type, quantity, and quality of ecosystem services available at the local level; in other words, the productive capacity of the system. From this we can expect:

> *H_2: Human encroachment into natural areas is positively correlated with the occurrence of armed conflict as it simultaneously increases consumption pressure on ecosystem services and decreases productive capacity by altering relationships among the biotic and abiotic components of those areas; and*
>
> *H_3: Human modification of natural land cover and land use is positively correlated with the occurrence of armed conflict; as it disrupts productive capacity at the local scale; and*
>
> *H_4: Ceteris paribus, land cover regimes characterized by high biomass productivity (closed canopy forests, grasslands, and similarly biologically rich regions) are negatively correlated with the occurrence of armed conflict, as these areas are likely comprised of intact ecosystems.*

By definition ecosystem services are complex sets of interconnected biotic and abiotic components and processes. As such, we can expect productive capacity to be directly related to biological productivity. Changes (either naturally occurring or anthropogenic) in the levels, composition, and structure of biotic communities in a system will force readjustment of other components in the system, and thus alter the type, quality, and rate of ecosystem service delivery. From this it follows that:

> *H_5: Changes in biological productivity (either increases or decreases) are positively correlated with the occurrence of armed conflict, as these are likely to be the locations where social-social and social-ecological relationships are being renegotiated based on changing productive capacity.*

Ecosystem services are as much a product of the geophysical and climatic conditions at the local scale as they are the relationships among biotic components of a system. Indeed, the character of the biological components of a SES is directly related to abiotic conditions and processes. Thus we can expect conflict in those areas where ecological productivity is constrained by climatic and geophysical properties. Specifically:

H_6: Physical conditions that promote biological productivity are negatively correlated with the occurrence of armed conflict; and

H_7: Climatic conditions that promote biological productivity are negatively correlated with the occurrence of armed conflict.

Covariates

The global scope of the present research limits the number of variables available for inclusion in this study, as there is a paucity of consistent data on most ecological variables for the entire terrestrial surface of the earth. The incorporation of time series into the study further constrains the sets of data available, as it is costly (in terms of time, money, and resources) to collect and process data at the global scale for a single time-period, let alone multiple observations across time. As such the ability to rigorously test many variables is constrained by data availability. Thus this research is more an exploration of variables that may affect ecosystem service delivery than it is rigorous hypothesis testing. That said I have been able to collect several global data sets for variables that can serve as effective indicators for the hypothesis advanced above. They are described presently.

Population- In order to test the effect of population density on conflict propensity I measure population density for each grid cell on annual intervals. These data were generated by CIESIN and CIAT (2005), and are publicly available in raster data format at the resolution of 2.5 arc minute grids (approximately 5 km at the equator) on five-year intervals for unadjusted totals, and for totals adjusted to match UN totals. I apply linear interpolation assuming a smooth growth curve for the years between observations. Using the zonal statistics tool in ArcGIS 9.3 I calculate the sum of all 2.5 minute cells for each target grid cell to generate a total population count for each cell. I then divide total population by size of the grid cell to generate a kilometer-squared population density measure. Finally, the population density data are logged to reduce outlier bias (Rustad et al. 2009; Buhaug and Rod 2006).

Encroachment- Testing H_2 presents a challenge, as there is no global time series dataset on human expansion into the natural world. I thus employ a proxy indicator to measure human encroachment on natural systems. I measure the amount of light emitted at night from every point on the terrestrial surface of the earth, and assume that increases in the amount of nighttime light signal expansion of the human population into previously natural areas. This could also be seen as a proxy measure of development, as increased light is likely to follow increased infrastructure and increased economic productivity.

Data for nighttime lights are provided by the National Geophysical Data Center (NOAA 2010), and consist of 30 arc second raster grids at annual observations for the years 1992-2003[3]. The grids are cloud-free composites, corrected for edge effects, sunlight, glare, moonlight, and light features from the aurora band. Thus the light that is recorded in these data consists of the light emitted from cities and other areas with persistent lighting. As noted by the metadata for the raster layers, ephemeral or short

[3] At the time of analysis, data were only available for the years 1992-2004. However, the source dataset was recently updated to include the years 2004-2008. FAO. (2001, 07 01). The World's Forests 2000. Rome: FAO.

duration events such as fires are omitted. The 30 arc second rasters range in value from 0-63, and are coded 255 areas with 0 cloud-free observations in a calendar year.

Before computing zonal statistics, I reclassified each annual raster such that values of *255* were coded as *NoData*. For each grid cell in my analysis, I measure the average amount of light at annual observations using the *Mean* statistic generated by the zonal statistics tool in ArcGIS 9.3. For the years 1991 and 2004 I apply linear interpolation by determining the slope of light growth at annual intervals for each cell across the entire time series, and applying it to generate values for the two missing years. Thus each grid cell receives a score ranging from *0* to *63* based on the average amount of light in all the constituent 30 arc second raster pixels. Following H_2 I expect increased light to be positively correlated to the occurrence of armed conflict.

Land use and land cover- I include four covariates to explore the affect of human land use strategies and land cover regimes. Van Velthuizen et al. (2007) measure the density of cropland and the density of pasture as the percent of 5 arc minute raster pixels comprised by these lands. I employ both variables as covariates, and code grid cells according to the mode of underlying raster pixels. An alternative approach would be to measure the mean of all underlying raster pixels, and assign cell values based on that mean. However, employing the mean in reclassifying the raster pixels (which measure percentage of pixel covered) to the coarser cell resolution would imply that the grid cell is *x*% cropland or pasture. As I did not measure pixel coverage at the cell resolution, but rather calculated statistics based on pixel values, I cannot reasonably make that claim. I chose instead the modal statistics, as it measures the most commonly occurring proportion of cropland and pasture in grid cells rather than the mean. A potential problem with this measurement is that cells where pixel values are not normally distributed may not be accurately measured. That is to say that the most common value may not accurately describe the distribution of cropland and pasture in a cell.

Neither the mode nor the mean are perfect measures of cropland and pasture density. A preferred measurement strategy would be to reclassify the original raster data to the cell resolution prior to statistic calculation. However, since the grid cells are not homogenous, it is not possible to perform that reclassification.

In addition to the occurrence of cropland and pasture, I code each grid cell for the dominant farming system found in the cell. These data are provided by the FAO (2007) and are taken from Dixon et al. (2001). The original data code 5 arc minute raster pixels according to one of 7 farming systems for developing/transitioning countries[4], and include categories for *water* and *not applicable*. I recode the original raster data such that *coastal/artisanal fishing* and *water* are included in the *not applicable* category, as these cells do not include landscape modification. Again I assign modal values based on underlying raster pixel values. I further divide the data into *j-1* categorical binary variables and employ the *not applicable/not farmed* category as a reference.

Finally, I categorize grid cells according to the dominant land cover found in each cell. The data I use to code land cover are derived from 1992-1993 and 1995-1996 remotely sensed AVHRR data, and estimate land cover according to the standard FAO four-category classification: *closed forest, open/fragmented forest, other wooded land,*

[4] Western Europe, North America, Australia, New Zealand, and Japan are coded as 'other lands' in the dataset

and other land. The data also code *water* and *not classified* lands. Data are provided by the FAO (2001) in raster format at a 1 km resolution. The original data were created at the EROS Data Center. I recode *water* and *not classified* as *missing*, and code each cell according to the mode of all raster pixels. I then create *j-1* categorical binary variables and employ *other land cover* as a reference category.

Biological Productivity- For the purposes here, biological productivity is measured by proxy through 4 measures of net primary productivity (NPP) calculated in kilograms of Carbon produced per hectare per year; or C, kg/ha/year (Bai et al. 2008, p. 10). The first proxy is unadjusted NDVI data. This is a measure of the total amount of green light radiated from the earth's surface. Increasing green radiation signals increasing biomass production, which in turn can signal NPP. The second proxy is rain use efficiency (RUE) adjusted NPP. This measure adjusts NPP for precipitation variability, and signals changes in vegetative production resulting from ecological integrity, not climatic variability. The third proxy, net primary productivity is a composite variable made by subtracting negative NDVI from Positive NDVI for a given location over time. The final proxy is climate adjusted positive NDVI. This is a measure of the net increase in NPP over time, adjusted to filter out increases due to climatic variability. Together these proxies measure increasing and declining biomass productivity that results from biological and geophysical conditions, rather than changes resulting from climatic conditions.

NPP data were estimated from normalized difference vegetative indexing (NDVI) reported by the Global Inventory Modeling and Mapping Studies (GIMMS) group and measured by US National Oceanic and Atmospheric Administration satellites, in a joint report on global land degradation issued by World Soil Information and the Food and Agriculture Organization of the United Nations (Bai et al. 2008). NDVI is a ratio measure of photosynthetically active green biomass (Bai et al. 2008). High NDVI values correspond to high productivity of biomass. Bai et al. estimate the total change in NPP from NDVI for the period 1981-2003, and present total change in raster data at a resolution of 8km.

Using zonal statistics, I calculate average change per grid cell using the *Mean* statistic in the ArcGIS output. This value is measured only once, as the data are based on change over time for a period covering all but one year of the panel data used in my analysis. The measure I employ, then, is an indicator of locations with general increasing and decreasing trends in biological productivity throughout the panel years.

Physical and climatic conditions- Biological productivity, measured by biomass production, depends directly on water availability. At the local level water availability is affected by the ability of the soil to retain water. I include a covariate that measures the capacity of soil to retain water (FAO 2007). Soil drainage data are provided publicly in the "Derived Soil Properties" section of the FAO-UNESCO *Soil Map of the World* at a resolution of 5*5 arc minutes. The original raster data code raster pixels according to one of 7 soil drainage classes, ranging from *excessively drained* to *very poorly drained*, and two non-soil categories, *not applicable* and *water bodies*. I reclassified the original data such that *not applicable* and *water bodies* are classified as missing, and are thus omitted from analysis. I assign grid cells the modal statistics of all 5*5 raster pixels, and code grid cells according to the dominant soil class where low scores indicate excessively drained soils and high scores correspond to poorly drained soils. I expect lower soil moisture to correlate positively with conflict, as biomass productivity in areas with low water retention should be more sensitive to climatic variability.

Water availability at the local level is also affected by climatic conditions. The United Nations Environmental Programme (UNEP) has developed an index of aridity, measured as average yearly precipitation divided by potential evapotranspiration. The FAO (2009) provides aridity data in a 10 arc minute raster grid. The aridity data are measured such that low values correspond with high aridity. According to the FAO low values likely negatively affect agricultural productivity and livestock do to dryness of climate. I assign each grid cell the mean value of all constituent aridity raster pixels. I expect aridity to be positively correlated to the incidence of armed conflict, as biomass productivity is constrained in these areas, and thus ecosystem service delivery should be sensitive to climate variation. I expect these areas to be more sensitive than semi-humid and humid areas, as marginal changes in water availability correspond to larger changes in biomass productivity in dry areas versus wetter areas.

Ideally climatic conditions would be modeled using precise point-specific measures of rainfall, temperature, levels of solar radiation, etc. Such factors are highly variable both at the local scale and across fine temporal scales. As such I was unable to find data that adequately captured climatic dynamics at scales and scopes pertinent to this research. I thus employ a coarser measure of climate, based on climatic zone. The data were generated by the Food and Agriculture Organization (FAO) and UNESCO in van

Velthuizen et al. (2007) and contribute to the Soil Map of the World; a database containing raster-based information on soil properties. The data include a 5*5 arc minute raster grid, based on thermal climatic conditions generated by classifying mean monthly temperature corrected to sea level. The original raster data contain 10 climatic zones and inland water bodies. I collapsed these zones into 3 categories; *tropical and subtropical*, *temperate*, and *boreal/arctic*, and assigned ordinal values from low to high - tropical to boreal. I also recoded *inland water bodies* to *missing*.

I expect cells in higher temperature climate zones to be more prone to armed conflict for two reasons. The first reason is an artifact of human settlement patterns. While I expect biological productivity to be more sensitive to temperature extremes, human settlement is concentrated in higher temperature areas. Thus biological disruption due to temperature extreme is more likely to affect human populations in high temperature zones than it is in low temperature zones, simply because that is where people live and depend on ecosystem services. Thus the argument that higher temperature climate zones are more prone to conflict than lower temperature climate zones thus is effectively a question of odds. The odds of conflict are higher where people live. The second reason I expect hotter climate zones to be more prone to armed conflict deals with biological sensitivity to other climatic conditions near temperature extremes. While biological productivity is likely to be higher hotter temperatures zones, the biological communities in these zones are likely to be sensitive to changes in other climatic variables, like rainfall. Without local time-series data on precipitation and temperature I am not able to accurately model this interaction. However, by including the net primary productivity variable (NPP), as well as the rain-use efficiency (RUE) adjusted NPP variable, I am able to determine the general trends among biological productivity, climate-adjusted productivity, and conflict. A preferred approach would be to measure temperature, precipitation, and biomass production at the local level on annual or monthly intervals and explore the occurrence of conflict at varying levels of each variable. That approach is indeed possible at a finer spatial resolution. However, given the scope of the current research, those data do not exist in global and uniform coverage over time. I am thus constrained to coarser measures and general trends.

I include a final variable to assess the affect of climatic conditions on the occurrence of armed conflict. The FAO (2007) presents a 5 arc minute raster data layer of climatic constraints on agricultural productivity. Agricultural productivity is a salient issue for conflict, particularly in developing and emerging countries for two reasons. First, the majority of the world's population depends on local agriculture to meet caloric and nutritional requirements. Second, local economies throughout the world are in part dependent on agricultural productivity. I am thus interested in the ways that different climatic conditions affect agriculture, as it nuances our understanding of the ways that climatic conditions matter for societies and economies. This is particularly salient in the face of climate change and climate variability. If certain types of climatic constraints on agriculture affect the likelihood of conflict, in the future we can expect to see conflict as certain areas undergo climatic change.

The data for this variable are classed according to one of five categories: *no constraints, wetness constraints (seasonal water surplus), moisture constraints (water* *deficit), severe moisture constraints, temperature constraints, and severe temperature constraints*. I assign grid cells the mode of all constituent raster pixels, and code according to dominant constraint present in a grid cell. In multivariate analyses, I divide this variable into *j-1* categorical binary variables and use *no constraints* as a reference category. These measures are designed to examine the effect on armed conflict of various climate constraints to agricultural productivity.

Table 3.1: Covariates

	format	scale
Population density	continuous	low density to high density
Nighttime light	continuous	low density to high density
Gross change in NPP	continuous	negative to positive
RUE adjusted change in NPP	continuous	negative to positive
RUE adj. NPP (net)	continuous	negative to positive
Climate adj. positive NPP	continuous	low to high
Cropland	continuous	low density to high density
Pasture	continuous	low density to high density
Farming system	categorical	7 classes
Land cover	categorical	4 classes
Aridity	continuous	dry to wet
Soil drainage	ordinal	dry to wet
Climate zone	ordinal	hot to cold
Climate constraints on agriculture	categorical	6 classes

Research design

In order to discover which local ecological conditions are most closely associated with the occurrence of conflict the present work undertakes a disaggregated statistical approach to the study of armed conflict. As has been previously noted, armed conflicts rarely span entire countries, but instead have a unique spatial character. Biological and geophysical elements likewise have unique spatial characteristics according to their size, distribution, and topological relationships. Disaggregating conflict from the state level, then, allows access to the local conditions that affect conflict propensity. The disaggregated approach undertaken here loosely follows the methodological approach of Buhaug and Rod (2006). Like those authors I create a fishnet grid, and employ grid cells as my unit of analysis. Using ARCGIS 9.2 with ArcInfo licensing I overlay datasets for each covariate on the grid using Mollewiede equal area projection, and assign values to each grid cell based on the attributes that each cell intersects. I measure each covariate using the *Zonal Statistics as Table* tool in the *Spatial Analyst* toolbox in ARCGIS. Through a panel time-series approach, I then statistically test the correlation among the covariates and the onset of conflict.

This approach is readily applicable for examining SES. Recall that Gallopin (2006) defines a SES as any system containing human/societal and ecological/biophysical components in mutual interaction. These can be defined at any scale, from cellular to global. Folke (2006) highlights that due to the continuous (rather than segregated) nature of the global system and the nested character of its sub-systems, any delineation of the subsystems is necessarily artificial and arbitrary. For the purpose of this study, the fishnet grid artificially delineates the global system into arbitrary sub-systems, which are assumed to represent SES.

However, my approach diverges from its predecessors in two non-trivial ways. First, where Buhaug and Rod limit their analysis to the African continent, I overlay a fishnet grid over the entire terrestrial surface of the earth, and with only a few areas omitted (discussed below), I analyze the correlations between local conditions and conflict for the entire globe. To my knowledge, the present research is the most comprehensive attempt to employ geospatial analysis to the local ecological determinants of armed conflict at the global scale. Previous studies have undertaken global-scale studies. However, these largely measure only a few variables pertaining to natural resources or terrain, and coarsely measured. My analysis creates ecological profiles for each cell that include data on land use, ecological productivity, soil type, water availability, agricultural productivity, several political and social controls, and multiple other ecological variables (described below).

A second deviation from Buhaug and Rod's methodological approach concerns the size and shape of the fishnet I employ. Where those authors employ a fishnet of uniform 100 x 100 km^2 cells, and assign to each cell values for each variable based its distribution inside the cell, I employ a heterogeneous grid, where cells that span international borders are divided into their constituent political entities. *Figure 3.1* demonstrates the division of Mozambique into grid cells.

Figure 3.1 Disaggregation of Mozambique into grid cells

There is utility in so doing. To understand that utility, examine the method of assigning value to a cell. For their mountainous terrain variable, Buhaug and Rod measure the amount of each grid cell covered by mountains, and assign the cell a percentage value. This approach works well for biophysical variables, as they can be generalized to the resolution of the cell. However, for social variables this approach holds a fundamental measurement issue. The uniform grid cells are overlaid across a study area that contains multiple political borders, which are not uniform and do not match the grid cells. Each cell is assigned political and social values associated with the country it overlaps. When a cell intersects two or more countries, the authors assign values based on the country with the largest area inside the cell. Thus specific geographic locations are incorrectly assigned values for social and political variables. This is perhaps not a substantial issue when the proportion of one state accounts for most of the area in a particular cell. However, when the ratio of coincidental states in a cell is closer to equal, the issue becomes a larger problem. The implicit assumption that this approach imposes is that the presence or absence of conflict in a grid cell is directly attributable to the political and social conditions of the larger country (larger in terms of proportion of the cell covered). This same problem exists for conflicts that do not span international borders. Large portion of the cell may be wrongly assigned presence or absence of conflict, based on conflict occurring in only a fraction of the cell, and confined to specific international borders.

Unit of analysis

To avoid incorrectly specifying the political and social characteristics of cells that intersect multiple countries, I relax the uniformity of the grid. Using the GIS I created a fishnet of polygons using the open source FISHNET tool (Nicholas 2003). I overlaid the fishnet grid on the world political boundaries for 2006 (ESRI 2006). For cells that do not cross international borders I retain the 100 x 100 km^2 grid cells, and assign these cells to the country they intersect. For cells that span international borders, I use the intersect analysis function in the GIS, to divide the cells into their component political units. Thus I employ non-homogenous grid cells as my units of analysis ranging in size from 0.001 km^2 to 10,000 km^2. As with any global study, I am constrained by data availability, particularly pertaining to certain social and political variables. Due to the lack of data for several areas of the world (discussed below), those areas are omitted from the study. With those omitted, the non-homogenous fishnet grid is composed of a total of 18,382 grid cells.

The decision to opt for a non-homogenous grid carries important tradeoffs. While it allows me to more precisely assign political and social data to specific locations, it complicates the measurement of spatially explicit data. The literature on spatial analysis discusses the *modifiable areal unit problem* (MAUP) (Wrigley et al. 1996). This problem describes the ways in which different spatial resolutions capture different spatial relationships. Since there is not a 1:1 relationship between the unit of observation and the associated geographic data, those data must be rescaled to match the resolution of the unit under consideration. Rescaling can be done through multiple processes, but for simplicity sake here I discuss rescaling by assigning the mean of all values in a unit. As different resolutions cover different areas, they contain different sets of data. Thus the mean of the set of data at a 50 km^2 resolution will likely be different from the mean of the data in a 100 km^2 coverage. The value of a cell for any set of data, then, depends on the scale or resolution of the cell. With a homogenous resolution among the units being observed, they are likely to capture the same sets of relationships among the data being rescaled. A heterogeneous resolution is likely to capture different relationships at different resolutions, which could potentially affect the measurement of certain variables.

Rod and Buhaug (2007) demonstrate that this problem may not affect disaggregated studies as much as once thought, by comparing models measured at 4 separate resolutions, 50 km^2, 100 km^2, 150 km^2, and 200 km^2. To test for the effect of the MAUP in the present research, I run full models of all covariates with three different samples; one with the entire sample, one with a sample restricted to cells larger than 100 km^2, and one restricted to cells larger than 1000 km^2. If different grid cells are in fact measuring different relationships, I expect the coefficients and standard errors of each covariate to vary dramatically with the exclusion of specific sets of cells.

Dependant variable

The dependant variable in my study is the presence or absence of armed conflict in a grid cell, observed at annual intervals for the period 1991-2004 (referred to as grid years) and coded as *0= no conflict* and *1= conflict.* The lower bound of the time range is set according to the earliest availability of multiple spatial datasets for covariates, and the upper boundary is set according to the latest observed spatial conflict data. The total observations for the entire population in this study are 257, 348 grid years. This panel approach to observing conflict in the same cell over time analyzes change in conflict over time, as opposed to simple incidence of conflict. The dependent variable observed this way explores what conditions affect change in the unit from one stable state to another (no-conflict to conflict) over time.

Following Buhaug and Rod (2006), I further dichotomize armed conflicts into two sub-categories: conflicts over governance, and conflicts over territory. The ACD dataset codes each conflict on this dichotomy based on the predominant incompatibility identified by conflicting parties. In some instances, a conflict can be coded as both being waged over governance and territory. I run separate models for three dependent variables: all armed conflicts, territorial conflicts, and governance conflicts. These three variables are defined by Gleditsch et al. (2002, p.619):

> *Armed conflict*: "A contested incompatibility that concerns government or territory or both where the use of armed force between two parties results in at least 25 battle-related deaths. Of these two parties, at least one is the government of a state."
>
> *Territorial conflict:* Conflicts in which the incompatibility concerns "a change from one state to another in the control of territory in an interstate conflict or demands for secession or autonomy in an internal conflict."
>
> *Governance conflict:* Conflicts in which the incompatibility concerns "the type of political system, the replacement of the central government, or the change of its composition."

The spatial conflict data are taken from the conflict polygon dataset created by Rustad et al. (2008). *Figure 3.2* displays the conflict polygons used for this study. Rustad et al. georeferenced the ACD data based by creating polygons that encompass all relevant battle sites for a conflict, based on narrative information from various volumes of Keesing's reference publications and archival data held at the conflict data archive in the Department of Peace and Conflict Research at Uppsala University. Since the conflict polygons are general approximations of areas that experienced conflict, and since the location of the fishnet grid is arbitrary, there exists the potential for inconsistencies between the shape of conflict polygons and the overlap with fishnet grid cells. I thus set a minimum overlap threshold of 5 km^2 when measuring grid cells for conflict. The dependent variable is thus coded *1* for cells with at least 5km^s overlap of a conflict polygon, and *0* for less than 5 km^2, or no intersection.

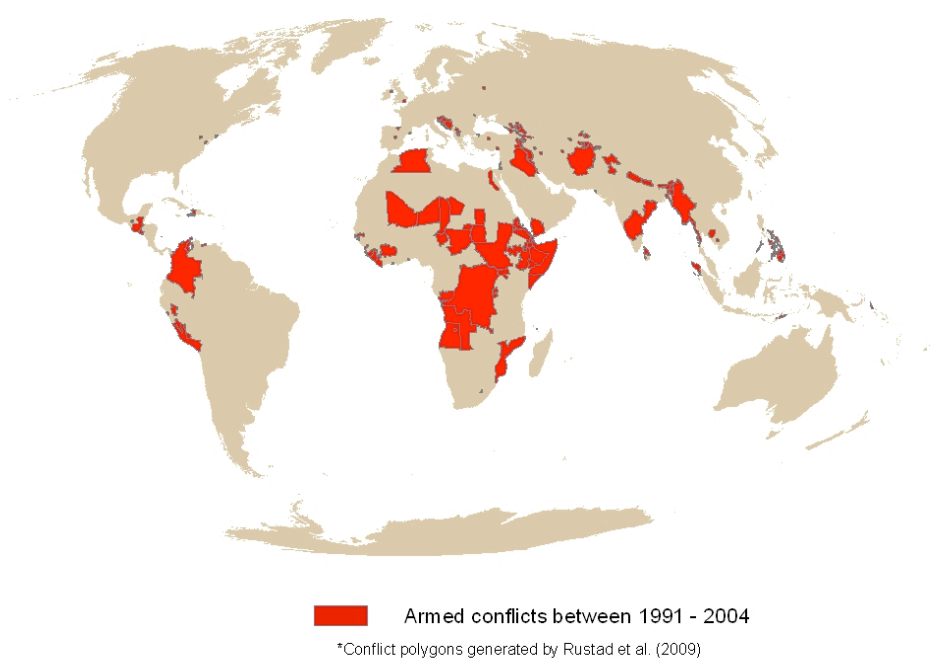

Figure 3.2 Conflict polygons 1991-2004

Spatial and temporal lags

A basic assumption of traditional regression is that the data consist of independent observations (Rod and Buhaug 2007). Spatial panel models violate this assumption on two fronts, through spatial and temporal autocorrelation. Temporal autocorrelation refers to the fact that observations for variable *X* of a case at time *t+1* are partially dependent on the state *X* at time *t*, or rather that value of *X* at *t* is correlated to value of *X* at *t+1*. One method of controlling for temporal autocorrelation involves including a lagged dependent variable as a covariate. I follow that approach by including conflict at *t-1* as a covariate in my models. This assumes that the value of the dependent variable at each annual observation is partially dependent on the value of the dependent variable in the previous year.

Spatial autocorrelation is a similar artifact, and relates to the way that phenomena cluster in space. In conflict studies, this is sometimes referred to as the neighborhood effect (Hewitt 2008), where conflict in country *X* is partially dependent on conflict in neighboring country *Y*. There are multiple methods of addressing spatial autocorrelation (Ward and Gleditsch 2008). Many country level conflict analyses include a simple binary variable for conflict in a neighboring country (Hewitt 2008). Disaggregated approaches are more complex, as neighborhoods can be defined in multiple ways, and spatial autocorrelation can be modeled in various ways. Buhaug and Rod (2006) control for spatial autocorrelation by constructing a country-level spatially lagged dependent variable which they measure as total number of years a country experiences conflict divided by the total number of years observed for each cell. Their spatial lag then takes a value between *0* and *1* for each cell. This, they claim, controls for the influence of conflict in other areas of a country affecting conflict in a cell. The assumption underlying this lag (intended or not) is that conflict in one region of a country affects the likelihood of conflict in all other regions of that country. This may be the case, as local conflicts will change the behavior and the capacity of the state to manage conflict in other areas. However, conflicts in various regions of states may in fact be independent, and there is little reason to assume a strong autocorrelating effect. Indeed, Tobler's first law of geography states that, "everything is related to everything else, but near things are more related than distant things" (Tobler 1970, cited by Rod and Buhaug 2007, p. 218). Building on this idea, conflicts within a country may in fact affect each other. However, in particularly large states, or for conflicts that are geographically distant from each other, their reciprocal influence on each other may be quite small. For instance, it is unlikely that the likelihood of conflict in a village in Siberia is affected much by the occurrence of conflict in Chechnya. A lag that controls for conflict anywhere in the Russia, however, would suggest that local conflict in Siberia is in fact partially a product of conflict in Chechnya. While it may be true that conflict in one part of a state affects the likelihood of conflict in all other parts of the state, that relationship is not necessarily true for all states and all conflicts, but rather likely exists on a case-by-case basis.

I employ two alternative controls for spatial autocorrelation that model the impact of contiguity, rather than a state-level contagion (see *figure 3.3*). The first lag controls for the geographic coincidence of conflict by creating a measure of the proportion of geographic neighbors in conflict at time *t* to the total number of neighbors in conflict.

The second spatial lag controls for the geographic spread of conflict, or the contagion of conflict, across time by temporally lagging the spatial lag. In other words, the second lag is defined as the proportion of neighboring cells in conflict at time *t-1* to the total number of neighbors. I used the *Enumerate Intersecting Features* tool included in Hawth's Analysis tools for ecological GIS (Beyer 2004) to measure the spatial lags according to the number of cells in conflict that each target cell touches.

Finally, while I assume that individual units are independent outside of first-order neighborhoods, I assume that individual units will have differing variances across time. I control for panel or cross-sectional heteroscedasticity by clustering units on their individual grid cell identification number using robust clustering in Stata 10.

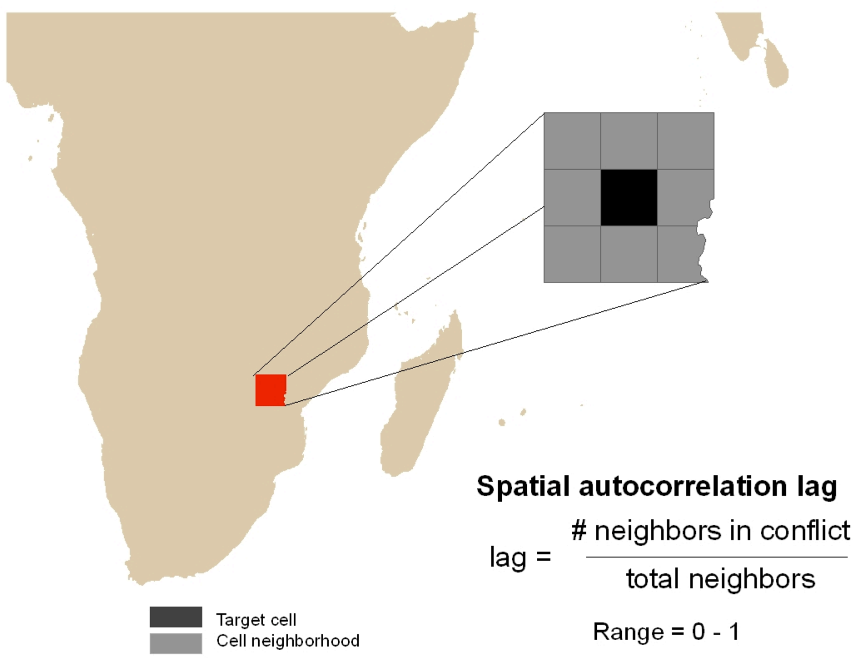

Figure 3.3 Spatial lag

Political and social controls

Two categories of factors are widely regarded as influencing the likelihood of conflict at the state level. These are *political/regime consistency* (Hewitt 2008; Gates et al 2006; Hegre et al. 2001) and *economic/human development* (Goldstone et al. 2005; Collier and Hoeffler 2004; Fearon and Laitin 2003; de Soysa 2002). When measured at the country level, there is an implicit assumption that the value of a variable representing either category is smoothly distributed across the entire country area. With political variables this assumption may hold better than economic variables. Certainly local corruption will affect the level of institutional transparency, or the effective level of democracy. However, generally a political system governing a country is more or less equally distributed across that territory. The same does not hold, however, for poverty and prosperity. These are likely to be extremely variable across space. Thus indicators like GDP per capita or infant mortality measured at the state level do little to explain the distribution of wealth or well-being at local levels. Unfortunately, it is not possible to collect local indicators for political and economic variables at the global range. I am thus forced to control for these influences by using country-level data. I control for political regime consistency by coding each cell according to the country data coded in the 2008 Peace and Conflict Ledger (Hewitt 2008). That study consists of a dataset that records among other variables each country's polity score and its squared term, and binary measures of full democracy and full autocracy. Together, Hewitt argues that these variables measure whether a country's political system is uniformly democratic, autocratic, or inconsistent. He and others argue that inconsistent institutions are more prone to instability (Hewitt 2008; Goldstone et al 2005). The general argument is that highly consistent regimes possess sufficient institutional, economic, and military/policing strength to manage tension and instability. This is particularly true as consistent regimes monopolize the legitimate (at least legally) use of force. Inconsistent regimes, in contrast, are marked by social, political, and economic transition. In those systems there may not be a single or accepted authority, and there may be multiple state, sub-state, and extra-state actors competing for monopoly over use of force.

I control for democracy and regime consistency by assigning each grid cell the annual polity IV score and the absolute value of the polity score. Polity scores range in integer values from *-10 (full autocracy)* to *+10 (full democracy)* on annual observations. The polity score thus measures the effect of democracy on the occurrence of armed conflict in my study. By including the absolute value of the polity score, I am able to test for the effect of regime consistency on the occurrence of conflict. Hewitt (2008) argues that it is not the type of regime that accounts for its conflict propensity, but rather the consistency of the regime. Regimes with scores approaching either *-10* or *10* on the polity scale are considered consistent. Middle range values, or values approaching *0*, are considered inconsistent. Absolute value of the polity score thus measures deviation from *0*, or progression toward regime consistency. Other models including Hewitt (2008), Rustad et al. (2009), and the Political Instability Task Force (Goldstone et al. 2005) employ polity squared in their analyses. This alternative measure examines deviation from zero, but assumes a fundamentally different relationship between the polity score and the dependent variable and the polity squared score and the dependant variable.

Absolute value polity assumes that the statistical relationship between polity score and dependent variable is the same as the relationship between the extremes of the polity score and the dependent variable. Including the squared term rather than absolute value, however, assumes a linear relationship between polity score and the dependent variable, and a non-linear relationship between the extremes and the dependent variable. I assume that the statistical relationship is the same between both polity and absolute value polity, and thus employ the absolute value polity score to assess whether civil conflict is most likely to occur in the democratic, non-democratic, or inconsistent regimes.

I employ the polity scores recorded in the Peace and Conflict Ledger replication data (Hewitt 2008). That study is limited to countries with a population greater than 500,000 in 2005, thus many areas of the world (particularly small countries and island countries) are omitted from the study. I deviate slightly from this on two counts. In an effort to expand the sample to include more geographic areas, I include data for the Solomon Islands for the period 1991-2004. Next, I assign the annual scores of the sovereign to any cell defined as belonging to a territory, protectorate, or other non-autonomous collective of a larger state. This pertains primarily to island nations in the Pacific, Caribbean, and Indian Oceans. *Figure 3.4* displays the relevant study area used in this study.

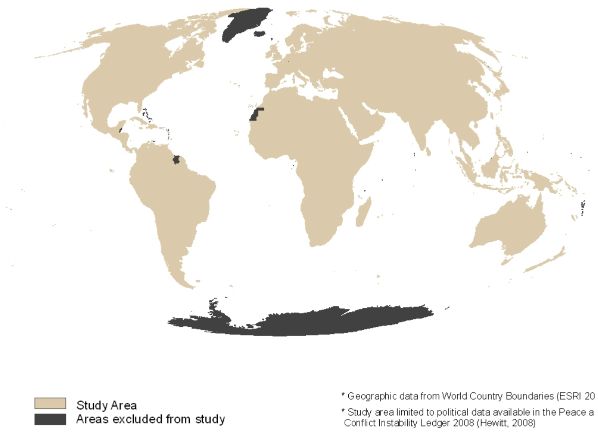

Figure 3.4 Study area

Regarding economic controls, I assign a coarse measure that indicates whether a cell belongs to a high, medium, or low-income country. Since poverty is more prone to have a more explicit spatial distribution, assigning state level infant mortality or GDP per capita scores to each cell assumes a false level of precision, and may not accurately capture the effect of poverty on the occurrence of conflict. To control for that influence, I employ a coarse control where each country is coded as belonging to one of three World Bank income groups based on 2008 GNI per capita. These are: *1- High income $11,906; 2- upper middle income $3,856-$11,905; and 3- low income/developing <= $3855.*[5]

Summary

This chapter has traced the state of the art in disaggregated approaches to investigating the local/geographic determinants of armed conflict, and has described a statistical research design to further identifying the local conditions and processes that

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[5] This classification scheme can be found online at http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html. Accessed 26 February 2010.

affect the likelihood of conflict for disaggregated grid cells. The methodology outlined here builds on the framework of Buhaug and Rod (2006), but incorporates several methodological advancements, including refined measures of forest and mountain cover, locally specific spatial lags, more locally accurate measures of political variables, and expansion of the disaggregated approach to the global scope. The research as described is designed to identify the local biotic, social, and geophysical conditions and relationships that combine to increase the propensity of armed conflict at the local level. The following chapter reports the results of this research design.

Chapter 4. Models of conflict

Disaggregated exploration of conflict reveals that armed conflict is a rare occurrence, affecting only 7% of all disaggregated grid cells across the period 1991-2004. Dichotomizing armed conflicts into those over territory and those over governance, territorial wars affect only ~2% of grid cells, while governance conflicts affect more than twice that number. Some conflicts are fought over both territory and governance, and are thus coded for each dichotomized dependant variable. In exploring the correlations between ecological characteristics and conflict, I estimate three sets of models, each corresponding to one dependent variable listed in *Table 4.1*.

Table 4.1 Descriptive statistics of dependent variables

All Armed Conflict			Territory Conflict			Governance Conflict		
	Frequency	Percent		Frequency	Percent		Frequency	Percent
no	239,485	93.06	no	251,463	97.71	no	244,693	95.08
yes	17,863	6.94	yes	5,885	2.29	yes	12,655	4.92
Total	257,348	100	Total	257,348	100	Total	257,348	100

Multivariate analyses of global ecological and biophysical data for these dependent variables reveal that the different types of conflict are each strongly correlated to unique ecological and biophysical conditions. *Table 4.2* reports the results of full logistic models for each specification of the dependent variable.[6] When measured to include all armed conflicts (*model 1*), virtually none of the ecological variables appear to be significantly associated with conflict. Instead, only the social, political, and demographic variables correlate significantly. However, when the dependent variable is split into the distinct types of armed conflict, the ecological variables demonstrate strong and significant correlations with conflict. Moreover, the inverse signs for many of the ecological covariates the two types of conflict (*models 2&3*) suggest that these two types of conflicts have nearly opposite relationships with the natural world, or at least with the variables included in this study.

Armed conflicts fought over territory (groups seeking succession or sovereignty) occur in cells from middle-income countries that are transitioning away from democracy. Inside those countries, the areas more prone to armed conflict are marked by decreasing biomass productivity, high densities of crop and pasture lands, areas with higher incidence of distinct agricultural regimes and farming systems, open/fragmented land cover, and temperate climates. In contrast, armed conflicts fought over governance (control of the state, or right to rule) occur in low-income countries with unstable and non-democratic political systems. Inside those countries armed conflict is more likely to occur in areas with increasing populations and expanding infrastructure, in areas without much farming or grazing, in previously unconverted forest land, and in tropical climates. These correlations are discussed topically in the sections that follow.

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[6] Both tobit and probit estimation produced virtually the same correlations among dependent variables and covariates with only minor changes in effect size and significance levels. Virtually all significant covariates maintain significance at the 95% confidence level or better, and all retain their sign.

I explore the correlations demonstrated in the full models by estimating sets of nested models specific the hypotheses advanced in the preceding chapter. Those nested models are presented topically in subsequent section of this chapter. Because the covariates are so uniquely associated with distinct types of conflict, I estimate all models for each specification of the dependent variable and report the results for each specification in individual tables.

Table 4.2 Full Models

Logistic Regression Model #	1	2	3
	All Armed Conflict	*Territory*	*Governance*
Conflict t-1	*8.750****	*5.193****	*5.509****
	[42.04]	*[26.66]*	*[36.63]*
Spatial lag	*22.42****	*6.308****	*7.901****
	[30.17]	*[38.17]*	*[57.46]*
Spatial lag t-1	*-10.18****	*-5.739****	*-5.819****
	[-25.24]	*[-26.04]*	*[-28.49]*
Polity IV	*0.0487****	*-0.0272***	*0.0190**
	[3.86]	*[-3.04]*	*[2.20]*
Polity IV abs val	*-0.027*	*0.298****	*-0.297****
	[-1.26]	*[14.86]*	*[-16.88]*
Low income country[A]	*1.244****	*-0.502**	*2.687****
	[5.12]	*[-2.18]*	*[9.06]*
High income country[A]	*0.259*	*-0.519**	*-1.687*
	[0.39]	*[-2.12]*	*[-1.67]*
Mean annual night lights	*0.0454***	*-0.00478*	*0.0954****
	[2.93]	*[-0.14]*	*[5.48]*
Pop density (natural log)	*0.182****	*0.0343*	*0.0745**
	[3.64]	*[0.90]*	*[2.12]*
NPP change (unadj.)	*0.00149*	*-0.00481*	*-0.000547*
	[0.60]	*[-1.03]*	*[-0.38]*
Rain-use efficiency adj. NPP	*-0.463*	*-1.277****	*1.038****
	[-1.36]	*[-5.43]*	*[7.81]*
Net rain-use efficiency adj. NPP	*0.0751*	*-31.90****	*0.373*
	[0.01]	*[-3.34]*	*[0.05]*
Positive climate adj. NPP	*15.27*	*25.29**	*-2.413*
	[1.46]	*[2.36]*	*[-0.27]*

continued on next page

Table 4.2 Full Models (continued)			
Logistic Regression Model #	1	2	3
	All Armed Conflict	*Territory*	*Governance*
Cropland density	*0.00454*	*0.00979***	*-0.000489*
	[0.86]	*[2.61]*	*[-0.16]*
Pasture density	*0.000318*	*0.0173****	*-0.00223****
	[0.50]	*[5.38]*	*[-10.65]*
Irrigated farming[B]	*-0.493*	*0.948*	*-0.607*
	[-0.49]	*[1.86]*	*[-1.32]*
Wetland/rice farming[B]	*-1.057*	*1.990****	*-1.552****
	[-1.03]	*[4.53]*	*[-4.88]*
Rainfed farming (humid)[B]	*0.888*	*1.401****	*-0.550**
	[1.26]	*[4.30]*	*[-2.44]*
Rainfed farming (highland)[B]	*1.014*	*2.407****	*-1.461****
	[1.48]	*[6.67]*	*[-6.04]*
Raindfed farming (dry)[B]	*0.581*	*0.731**	*0.0418*
	[0.82]	*[2.07]*	*[0.17]*
Dualistic farming[B]	*0.658*	*0.296*	*0.461**
	[0.97]	*[0.86]*	*[1.99]*
Closed forest[C]	*0.188*	*0.845****	*-0.122*
	[0.55]	*[3.82]*	*[-0.64]*
Fragmented forest[C]	*-0.379*	*0.980****	*-0.659****
	[-1.11]	*[4.67]*	*[-3.38]*
Woodlands[C]	*-0.182*	*1.048****	*-1.238****
	[-0.70]	*[6.17]*	*[-6.64]*
Aridity	*0.0891*	*-0.490***	*0.774****
	[0.51]	*[-3.18]*	*[6.41]*
Soil drainage	*-0.00129*	*0.0146****	*-0.0140****
	[-0.26]	*[4.15]*	*[-4.32]*
Climate zone	*0.691***	*0.688****	*-1.133****
	[3.00]	*[3.88]*	*[-3.62]*
Climate constraint: wetness[D]	*0.047*	*-0.519**	*0.439**
	[0.19]	*[-2.07]*	*[2.32]*
Climate constraint: moisture[D]	*-0.253*	*0.422*	*0.106*
	[-0.86]	*[1.66]*	*[0.37]*
Climate constraint: severe moisture[D]	*0.481*	*0.934****	*-0.21*
	[1.63]	*[4.06]*	*[-0.92]*
Climate constraint: temperature[D]	*-0.557*	*-1.212**	*0.551*
	[-1.14]	*[-2.25]*	*[1.38]*
Climate constraint: severe temperature[D]	*-0.776*	*-0.198*	*0.265*
	[-1.58]	*[-0.52]*	*[0.75]*
Constant	*-11.50****	*-11.03****	*-5.460****
	[-11.85]	*[-17.93]*	*[-9.20]*
N	*218935*	*218935*	*218935*
pseudo r^2	*0.973*	*0.582*	*0.783*
chi^2	*3526.9*	*6415*	*6430.4*

Robust z-scores clustered on cell id number in brackets

* *$p<0.05$, ** $p<0.01$, *** $p<0.003$*
[A] *Reference category is Middle income country*
[B] *Reference category is Other land*
[C] *Reference category is Not applicable/no farming*
[D] *Reference category is No climate constraints on agriculture*

Human encroachment and ecological productivity

Tables 4.3 (all armed conflict) *4.4* (territory conflicts) *& 4.5* (governance conflict) report the results of the models that estimate the relationship between human population growth, infrastructure expansion, ecological productivity, and each dependent variable. All models are estimated with population and light measures included.

Both increasing light and increasing population are significantly correlated with conflict, though the nature of the correlation depends on the type of conflict being modeled. Territorial conflicts are positively associated with increasing population density, whereas governance conflicts are positively correlated with increasing light expansion. The models estimated for the territorial and the governance conflicts demonstrate a unique relationship between these two variables. When population is significant, light is not, and vice versa. Likewise, for the two variations of conflict, when population is positively correlated, light is negatively correlated, and vice versa. However, in the full models population ceases to be significantly correlated with territorial conflict, and gains significance in governance conflicts. Likewise, the correlations for governance conflicts are both positive. This suggests that infrastructure and population contribute to the two types of conflict in unique ways. In territorial conflicts, population growth and constant or decreasing light are correlated with conflict, perhaps suggesting that increasing population is generating increasing consumption pressure which is not being met, leading marginalized groups to seek independence or sovereignty. This is supported by the ecological productivity covariates wherein positive changes in biomass productivity are negatively correlated with territorial conflict.

Table 4.3 Encroachment & Ecological Productivity- All Armed Conflict

Logistic Regression Model #	4	5	6	7
	Gross NPP	Rain Use Efficiency Adjusted NPP	Gross NPP & Climate Adj. NPP	Climate Adj. NPP
Conflict t-1	8.754***	8.740***	8.748***	8.746***
	[43.51]	[43.89]	[43.46]	[43.55]
Spatial lag	21.77***	21.84***	21.86***	21.86***
	[28.20]	[27.15]	[27.34]	[27.29]
Spatial lag t-1	-10.23***	-10.23***	-10.20***	-10.20***
	[-24.05]	[-24.61]	[-24.13]	[-24.22]
Polity IV	0.0461**	0.0405**	0.0416**	0.0418**
	[3.20]	[2.99]	[2.95]	[2.98]
Polity IV abs val	-0.0436	-0.0402	-0.0406	-0.0405
	[-1.85]	[-1.70]	[-1.72]	[-1.72]
Low income country[A]	0.823***	0.822***	0.842***	0.842***
	[3.76]	[3.71]	[3.80]	[3.79]
High income country[A]	-0.163	-0.121	-0.0655	-0.0669
	[-0.49]	[-0.36]	[-0.20]	[-0.20]
Mean annual night lights	0.0375**	0.0434***	0.0401**	0.0405**
	[2.89]	[3.35]	[3.07]	[3.10]
Pop density (natural log)	0.152**	0.136**	0.140**	0.139**
	[3.27]	[2.97]	[3.01]	[2.99]
NPP change (unadj.)	0.00268***		0.00146	
	[3.61]		[0.72]	
Rain-use efficiency adj. NPP		-0.327		
		[-1.07]		
Net rain-use efficiency adj. NPP		12.73**		
		[2.80]		
Positive climate adj. NPP			16.38***	17.09***
			[3.30]	[3.65]
Constant	-9.021***	-9.265***	-9.281***	-9.283***
	[-19.39]	[-17.80]	[-18.22]	[-18.24]
N	218935	218935	218935	218935
pseudo r^2	0.972	0.972	0.972	0.972
chi^2	3225.2	3169.1	3283.5	3186.7

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.000

[A] Reference category is *Middle income country*

Table 4.4 Encroachment & Ecological Productivity- Territory Conflicts

Logistic Regression Model #	8	9	10	11
	Gross NPP	Rain Use Efficiency Adjusted NPP	Gross NPP & Climate Adj. NPP	Climate Adj. NPP
Conflict t-1	5.006***	5.023***	5.005***	5.005***
	[26.44]	[26.65]	[26.51]	[26.52]
Spatial lag	5.767***	5.762***	5.770***	5.771***
	[39.97]	[39.98]	[40.01]	[40.00]
Spatial lag t-1	-5.381***	-5.361***	-5.374***	-5.370***
	[-25.49]	[-25.63]	[-25.57]	[-25.56]
Polity IV	-0.0591***	-0.0545***	-0.0586***	-0.0585***
	[-7.37]	[-6.63]	[-7.24]	[-7.23]
Polity IV abs val	0.224***	0.225***	0.226***	0.226***
	[11.75]	[11.52]	[11.64]	[11.65]
Low income country[A]	-0.333	-0.329	-0.338	-0.339
	[-1.46]	[-1.46]	[-1.49]	[-1.49]
High income country[A]	-0.600*	-0.632*	-0.624*	-0.626*
	[-2.45]	[-2.55]	[-2.53]	[-2.54]
Mean annual night lights	-0.0508	-0.0479	-0.0512	-0.0511
	[-1.18]	[-1.14]	[-1.20]	[-1.20]
Pop density (natural log)	0.0883**	0.0928**	0.0897**	0.0888**
	[3.05]	[3.29]	[3.12]	[3.09]
NPP change (unadj.)	0.000614		0.000969	
	[0.46]		[0.69]	
Rain-use efficiency adj. NPP		-1.105***		
		[-5.12]		
Net rain-use efficiency adj. NPP		-5.62		
		[-1.80]		
Positive climate adj. NPP			-3.198	-2.674
			[-0.87]	[-0.74]
Constant	-7.292***	-7.209***	-7.260***	-7.262***
	[-37.44]	[-36.63]	[-37.25]	[-37.28]
N	218935	218935	218935	218935
pseudo r^2	0.529	0.531	0.529	0.529
chi^2	7143	7000.4	7119.4	7102.1

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.000

[A] Reference category is *Middle income country*

Table 4.5 Encroachment & Ecological Productivity- Governance Conflicts

Logistic Regression Model #	12	13	14	15
	Gross NPP	Rain Use Efficiency Adjusted NPP	Gross NPP & Climate Adj. NPP	Climate Adj. NPP
Conflict t-1	4.924***	4.940***	4.921***	4.922***
	[34.60]	[34.60]	[34.62]	[34.62]
Spatial lag	7.249***	7.287***	7.248***	7.246***
	[58.97]	[59.09]	[58.93]	[59.00]
Spatial lag t-1	-5.249***	-5.283***	-5.243***	-5.248***
	[-26.33]	[-26.47]	[-26.33]	[-26.34]
Polity IV	0.0572***	0.0550***	0.0575***	0.0573***
	[6.44]	[6.07]	[6.40]	[6.38]
Polity IV abs val	-0.245***	-0.245***	-0.245***	-0.245***
	[-14.68]	[-14.57]	[-14.65]	[-14.66]
Low income country[A]	2.470***	2.515***	2.472***	2.473***
	[11.11]	[11.06]	[11.09]	[11.09]
High income country[A]	-1.727	-1.58	-1.733	-1.728
	[-1.94]	[-1.82]	[-1.94]	[-1.94]
Mean annual night lights	0.103***	0.0994***	0.103***	0.103***
	[6.68]	[6.69]	[6.64]	[6.62]
Pop density (natural log)	-0.00795	-0.00716	-0.00682	-0.00523
	[-0.31]	[-0.28]	[-0.27]	[-0.20]
NPP change (unadj.)	-0.00167		-0.0015	
	[-1.39]		[-1.35]	
Rain-use efficiency adj. NPP		0.826***		
		[6.72]		
Net rain-use efficiency adj. NPP		0.462		
		[0.15]		
Positive climate adj. NPP			-1.586	-2.434
			[-0.42]	[-0.66]
Constant	-6.765***	-6.851***	-6.749***	-6.746***
	[-29.77]	[-29.19]	[-29.42]	[-29.41]
N	218935	218935	218935	218935
pseudo r^2	0.76	0.76	0.76	0.759
chi^2	6728	6621.8	6734.6	6731.6

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.000

[A] Reference category is *Middle income country*

The inverse relationship - that decreasing productivity is positively associated with conflict - suggests that increasing consumption pressure (increased population) combines with diminished productive capacity to generate conflict.

In governance conflicts, increasing light can be interpreted in two ways. Increasing light couples with constant or decreasing population to produce conflict. This perhaps signals increasing consumption pressure associated with increasing economic well-being, since increasing light is likely produced by increasing electrification of an area, which depends on economic development to fund power generation. This increased well-being could economically enable power-seeking groups to make attempt a power grab. However, it is also possible that increasing light disrupts the productive capacity of an area, particularly when coupled with increasing population.

The full and nested models demonstrate a positive correlation between governance conflicts and positive changes in RUE adjusted biomass productivity. Given the global scope of the study and the structure of the NDVI data it is not possible to differentiate agricultural biomass from naturally occurring or invasive vegetation. Thus it is not possible to fully uncover the mechanism through which positive NDVI/NPP correlates with conflict. However, it is clear that governance conflicts occur in areas with changing ecological productivity, and from this it is possible to assume that the rate, type, and quantity of ecosystem service delivery is changing in these areas. Thus productive capacity is shifting, and these shifts are correlated with conflict.

The ability to deduce the nature of the relationships between ecological productivity, population growth, and infrastructure expansion is limited by data constraints. It would be useful to include sub-national time series economic data as a covariate to determine whether social groups in cells experiencing conflict are increasingly economically empowered or marginalized, and what types of conflict are associated with what type of economic growth. Likewise, including covariates that account for increased non-endemic vegetation, increased homogenization of land cover, and time series NDVI data rather than composites showing net change over time could all help distil the exact processes underlying ecological change and the occurrence of conflict. At best, the approach employed by these models demonstrates potential relationships and highlights the need to more rigorously study these relationships.

Other nested models

Tables 4.6 (all armed conflict) *4.7* (territory conflicts) *& 4.8* (governance conflict) present the results of nested models that explore the relationships of land use/land cover dynamics, geophysical and climatic conditions, and political and social controls to each dependent variable. These tables include the full model for their particular dependent variable for reference. All nested models are run with the spatial and temporal lags as well as the social and political controls as covariates. These nested models are discussed topically below.

Land use/land cover

When evaluating all armed conflicts land use and land cover measures are not significantly correlated with the occurrence of conflict. However, when the dichotomy between territorial and governance conflicts is imposed on those measures it becomes apparent that each type of conflict is associated with distinct LUCC dynamics. The cropland and pasture variables measure the density of agriculture and grazing within a cell, which serves as a coarse proxy for the intensity of human modification of natural systems through land use activities. The farming system categorical binary variables then measure the effect of various agricultural techniques. Territorial conflicts are generally associated with pastoral and agricultural lands, and the effects of those covariates are strongest for agricultural systems that depend directly on rainfall for irrigation. The inverse relationship exists for governance conflicts. Farmed and grazed lands are negatively correlated with conflict.

Table 4.6 All Armed Conflicts Nested

Logistic Regression Model #	1 Full Model	16 Controls (nested)	17 Land use/cover (nested)	18 Geophysical (nested)
Conflict t-1	8.750***	8.946***	8.909***	8.865***
	[42.04]	[47.93]	[45.44]	[47.66]
Spatial lag	22.42***	21.94***	22.19***	22.14***
	[30.17]	[29.23]	[34.88]	[27.65]
Spatial lag t-1	-10.18***	-10.43***	-10.42***	-10.29***
	[-25.24]	[-25.98]	[-26.54]	[-25.85]
Polity IV	0.0487***	0.0526***	0.0533***	0.0446***
	[3.86]	[3.43]	[3.83]	[3.37]
Polity IV abs val	-0.027	-0.0291	-0.0306	-0.0234
	[-1.26]	[-1.19]	[-1.36]	[-0.94]
Low income country[A]	1.244***	0.857***	1.178***	1.162***
	[5.12]	[3.80]	[4.83]	[4.66]
High income country[A]	0.259	0.131	0.672	0.0576
	[0.39]	[0.43]	[0.96]	[0.19]
Mean annual night lights	0.0454**			
	[2.93]			
Pop density (natural log)	0.182***			
	[3.64]			
NPP change (unadj.)	0.00149			
	[0.60]			
Rain-use efficiency adj. NPP	-0.463			
	[-1.36]			
Net rain-use efficiency adj. NPP	0.0751			
	[0.01]			
Positive climate adj. NPP	15.27			
	[1.46]			

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Table 4.6 All Armed Conflicts Nested (continued)

Logistic Regression Model #	1	16	17	18
	Full Model	Controls	Land use/cover	Geophysical
		(nested)	(nested)	(nested)
Cropland density	0.00454		0.0119**	
	[0.86]		[3.02]	
Pasture density	0.000318		0.000374	
	[0.50]		[0.63]	
Irrigated farming[B]	-0.493		-0.347	
	[-0.49]		[-0.36]	
Wetland/rice farming[B]	-1.057		-1.055	
	[-1.03]		[-1.02]	
Rainfed farming (humid)[B]	0.888		0.44	
	[1.26]		[0.60]	
Rainfed farming (highland)[B]	1.014		0.803	
	[1.48]		[1.11]	
Raindfed farming (dry)[B]	0.581		0.153	
	[0.82]		[0.21]	
Dualistic farming[B]	0.658		0.597	
	[0.97]		[0.83]	
Closed forest[C]	0.188		0.206	
	[0.55]		[0.96]	
Fragmented forest[C]	-0.379		-0.361	
	[-1.11]		[-1.38]	
Woodlands[C]	-0.182		-0.163	
	[-0.70]		[-0.73]	
Aridity	0.0891			-0.00773
	[0.51]			[-0.05]
Soil drainage	-0.00129			-0.00365
	[-0.26]			[-0.76]
Climate zone	0.691**			0.887***
	[3.00]			[4.81]
Climate constraint: wetness[D]	0.047			-0.0728
	[0.19]			[-0.30]
Climate constraint: moisture[D]	-0.253			-0.257
	[-0.86]			[-0.90]
Climate constraint: severe moisture[D]	0.481			-0.371
	[1.63]			[-1.77]
Climate constraint: temperature[D]	-0.557			-1.169**
	[-1.14]			[-2.65]
Climate constraint: severe temperature[D]	-0.776			-1.728***
	[-1.58]			[-4.01]
Constant	-11.50***	-8.705***	-9.543***	-9.709***
	[-11.85]	[-22.79]	[-12.35]	[-15.55]
N	218935	218935	218935	218935
pseudo r^2	0.973	0.971	0.972	0.971
chi^2	3526.9	3332.6	3562.5	3403.7

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003

[A] Reference category is *Middle income country*

[B] Reference category is *Other land*

[C] Reference category is *Not applicable/no farming*

[D] Reference category is *No climate constraints on agriculture*

Table 4.7 Territory Conflicts Nested				
Logistic Regression Model #	2	19	20	21
	Full Model	Controls (nested)	Land use/cover (nested)	Geophysical (nested)
Conflict t-1	5.193***	5.037***	5.015***	5.016***
	[26.66]	[26.03]	[24.96]	[26.83]
Spatial lag	6.308***	5.739***	6.008***	5.713***
	[38.17]	[39.85]	[37.31]	[40.65]
Spatial lag t-1	-5.739***	-5.350***	-5.637***	-5.329***
	[-26.04]	[-25.03]	[-25.36]	[-25.47]
Polity IV	-0.0272**	-0.0575***	-0.0508***	-0.0455***
	[-3.04]	[-7.09]	[-6.08]	[-5.19]
Polity IV abs val	0.298***	0.229***	0.258***	0.238***
	[14.86]	[12.16]	[14.18]	[12.43]
Low income country[A]	-0.502*	-0.241	-0.835***	-0.064
	[-2.18]	[-1.04]	[-3.58]	[-0.31]
High income country[A]	-0.519*	-0.871**	-0.407	-0.837**
	[-2.12]	[-3.11]	[-1.72]	[-3.03]
Mean annual night lights	-0.00478			
	[-0.14]			
Pop density (natural log)	0.0343			
	[0.90]			
NPP change (unadj.)	-0.00481			
	[-1.03]			
Rain-use efficiency adj. NPP	-1.277***			
	[-5.43]			
Net rain-use efficiency adj. NPP	-31.90***			
	[-3.34]			
Positive climate adj. NPP	25.29*			
	[2.36]			

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Table 4.7 Territory Conflicts Nested (continued)

Logistic Regression Model #	2	19	20	21
	Full Model	Controls	Land use/cover	Geophysical
		(nested)	(nested)	(nested)
Cropland density	0.00979**		0.00456	
	[2.61]		[1.56]	
Pasture density	0.0173***		0.0126***	
	[5.38]		[5.19]	
Irrigated farming[B]	0.948		1.146**	
	[1.86]		[2.87]	
Wetland/rice farming[B]	1.990***		1.715***	
	[4.53]		[4.61]	
Rainfed farming (humid)[B]	1.401***		1.043***	
	[4.30]		[3.69]	
Rainfed farming (highland)[B]	2.407***		1.956***	
	[6.67]		[6.56]	
Raindfed farming (dry)[B]	0.731*		1.070***	
	[2.07]		[3.69]	
Dualistic farming[B]	0.296		0.0671	
	[0.86]		[0.21]	
Closed forest[C]	0.845***		-0.0304	
	[3.82]		[-0.18]	
Fragmented forest[C]	0.980***		0.412*	
	[4.67]		[2.26]	
Woodlands[C]	1.048***		0.836***	
	[6.17]		[5.19]	
Aridity	-0.490**			-0.354***
	[-3.18]			[-3.40]
Soil drainage	0.0146***			0.00881**
	[4.15]			[2.89]
Climate zone	0.688***			0.145
	[3.88]			[0.97]
Climate constraint: wetness[D]	-0.519*			-0.813***
	[-2.07]			[-3.72]
Climate constraint: moisture[D]	0.422			0.262
	[1.66]			[1.14]
Climate constraint: severe moisture[D]	0.934***			-0.377*
	[4.06]			[-2.54]
Climate constraint: temperature[D]	-1.212*			-1.042*
	[-2.25]			[-2.25]
Climate constraint: severe temperature[D]	-0.198			-0.0462
	[-0.52]			[-0.14]
Constant	-11.03***	-7.223***	-8.710***	-7.539***
	[-17.93]	[-36.52]	[-21.81]	[-27.61]
N	218935	218935	218935	218935
pseudo r^2	0.582	0.527	0.56	0.536
chi^2	6415	7266.9	6684.8	7418.5

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003

[A] Reference category is *Middle income country*

[B] Reference category is *Other land*

[C] Reference category is *Not applicable/no farming*

[D] Reference category is *No climate constraints on agriculture*

Table 4.8 Governance Conflicts Nested

Logistic Regression Model #	3	22	23	24
	Full Model	Controls (nested)	Land use/cover (nested)	Geophysical (nested)
Conflict t-1	5.509***	4.907***	5.346***	4.915***
	[36.63]	[34.36]	[37.37]	[33.59]
Spatial lag	7.901***	7.216***	7.666***	7.320***
	[57.46]	[59.04]	[59.03]	[58.02]
Spatial lag t-1	-5.819***	-5.239***	-5.521***	-5.246***
	[-28.49]	[-26.00]	[-27.27]	[-26.11]
Polity IV	0.0190*	0.0604***	0.0441***	0.0431***
	[2.20]	[6.66]	[5.00]	[4.59]
Polity IV abs val	-0.297***	-0.237***	-0.265***	-0.250***
	[-16.88]	[-14.31]	[-16.23]	[-14.68]
Low income country[A]	2.687***	2.366***	3.224***	2.063***
	[9.06]	[10.74]	[13.02]	[8.05]
High income country[A]	-1.687	0.147	0.0898	0.162
	[-1.67]	[0.32]	[0.18]	[0.34]
Mean annual night lights	0.0954***			
	[5.48]			
Pop density (natural log)	0.0745*			
	[2.12]			
NPP change (unadj.)	-0.000547			
	[-0.38]			
Rain-use efficiency adj. NPP	1.038***			
	[7.81]			
Net rain-use efficiency adj. NPP	0.373			
	[0.05]			
Positive climate adj. NPP	-2.413			
	[-0.27]			

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Table 4.8 Governance Conflicts Nested (continued)				
Logistic Regression Model #	3	22	23	24
	Full Model	Controls (nested)	Land use/cover (nested)	Geophysical (nested)
Cropland density	-0.000489		0.0044	
	[-0.16]		[1.72]	
Pasture density	-0.00223***		-0.00221***	
	[-10.65]		[-11.70]	
Irrigated farming[B]	-0.607		-1.136**	
	[-1.32]		[-2.58]	
Wetland/rice farming[B]	-1.552***		-1.388***	
	[-4.88]		[-5.04]	
Rainfed farming (humid)[B]	-0.550*		-1.021***	
	[-2.44]		[-5.76]	
Rainfed farming (highland)[B]	-1.461***		-1.504***	
	[-6.04]		[-7.34]	
Raindfed farming (dry)[B]	0.0418		-0.706***	
	[0.17]		[-3.99]	
Dualistic farming[B]	0.461*		0.178	
	[1.99]		[0.98]	
Closed forest[C]	-0.122		0.527***	
	[-0.64]		[3.47]	
Fragmented forest[C]	-0.659***		-0.211	
	[-3.38]		[-1.27]	
Woodlands[C]	-1.238***		-1.071***	
	[-6.64]		[-5.90]	
Aridity	0.774***			0.504***
	[6.41]			[5.92]
Soil drainage	-0.0140***			-0.0122***
	[-4.32]			[-3.84]
Climate zone	-1.133***			-0.39
	[-3.62]			[-1.68]
Climate constraint: wetness[D]	0.439*			0.770***
	[2.32]			[4.63]
Climate constraint: moisture[D]	0.106			0.464
	[0.37]			[1.79]
Climate constraint: severe moisture[D]	-0.21			0.442**
	[-0.92]			[2.98]
Climate constraint: temperature[D]	0.551			0.207
	[1.38]			[0.50]
Climate constraint: severe temperature[D]	0.265			-0.145
	[0.75]			[-0.39]
Constant	-5.460***	-6.638***	-6.782***	-5.971***
	[-9.20]	[-29.63]	[-22.11]	[-13.08]
N	218935	218935	218935	218935
pseudo r^2	0.783	0.757	0.771	0.763
chi^2	6430.4	6948.2	7672.9	6774.7

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003

[A] Reference category is *Middle income country*

[B] Reference category is *Other land*

[C] Reference category is *Not applicable/no farming*

[D] Reference category is *No climate constraints on agriculture*

The structure of the farming system data limits constrains the ability to generalize the type of lands that governance conflicts occur on, as the reference category is *not applicable/not farmed* and includes barren lands, urban lands, unclassified lands, and lands characterized by artisanal fishing as the predominant form of agriculture. Like territorial conflicts, irrigated lands have a weaker effect than other farming systems. In both cases this suggests that dependence on natural processes and conditions for agricultural productivity affects the likelihood of conflict. In territorial conflicts, climate-dependent agricultural systems are more prone to conflict, whereas climate-dependent agriculture appears to reduce the likelihood of governance conflicts. From these correlations it appears that the type and intensity of human modification of natural systems affects the likelihood of conflict.

Land cover regimes also appear to be correlated with each type of conflict. In the nested models, territorial conflicts are positively and significantly correlated with fragmented and mosaic land cover compared to the reference category (*Other lands*), and negatively but not significantly correlated with closed forest compared to the reference. In contrast, governance conflicts appear strongly and positively correlated with closed forest and negatively correlated with fragmented and mosaic land cover compared to the reference. These relationships change slightly in the full models with closed forest becoming positive and significant for territorial conflicts and negative and not significant for governance conflicts. The general trends, however, remain. Territorial conflicts are more likely to occur in areas that are fragmented and mosaic, and thus more prone to human modification, where governance conflicts are more likely in the reference category, *Other lands*.

Three limitations of the land cover data obscure the nature of the covariates to the types of conflict. The first limitation is the lack of time series data at annual observations. The land cover was generalized from remotely sensed imagery from multiple years to generate a composite estimate of land cover for the year 2000. In order to better discern how land cover affects conflict, annual observations could account for land cover change, and better distill the relationship between conflict and LUCC. The second limitation is owed to the structure of the data. The land cover data are assigned according to one of four categories. The reference category, *Other lands*, does not distinguish between ice, urban, or barren lands, and thus says little other than conflict does or does not occur in the other three land cover classifications. Finally, the measurement of the data as the mode of all raster pixels contained in each fishnet cell assumes that the dominant land cover classification accounts for conflict in the cell. Perhaps, however, it is the mixture of the four categories rather than the dominant class that actually drives conflict processes. While these issues remain, the strong and largely consistent estimates across models suggest that there is a correlation between land cover and conflict that warrants further examination.

Geophysical conditions

As in the other nested models each type of conflict appears to be highly correlated with specific physical and climatic characteristics. Together the covariates explore the effects of temperature and water availability. The *Aridity* covariate (measured dry to wet) is negatively correlated with territorial conflicts, such that cells with higher moisture are less conflict prone, and vice-versa. Governance conflicts, however, are positively correlated with arid climates such that high moisture corresponds with conflict. These relationships are maintained in both full and nested models. Surprisingly, soil drainage (measured excessively drained to highly saturated) shows the opposite effect for both types of conflict. Increased water retention capacity correlates positively with territorial conflict, and negatively with governance conflicts. Taken together, dryer areas with good water retention experience more territorial conflict, and wetter areas with poor water retention experience more governance conflicts.

Climatic zone (based on temperature) also appears to correspond to each type of conflict. Territorial conflicts are associated with cooler temperature zones, whereas governance conflicts are associated with high temperature zones. While the signs of the correlations are constant between the nested and full models, the correlations are only statistically significant in the full models I tested the affect of boreal and arctic zones by creating dummy categorical variables for climate zones, and found that boreal and arctic zones predict failure perfectly, meaning that armed conflicts do not occur in these climate zones. Thus the correlation between decreased temperature and increased territorial conflict actually signals the higher incidence of these conflicts in temperate rather than tropical zones.

Finally, I tested the effect on conflict occurrence of climatic constraints on agricultural productivity and found that the full models generally confirm the correlations between moisture and conflict. Areas where agricultural production is seasonally constrained by too much moisture (*wetness*) experience less territorial conflict, and more governance conflict. Likewise, severe water deficiency (severe moisture constraints) is positively and significantly correlated with territorial conflict and negatively, but not significantly, correlated with governance conflicts. The relationship between temperature and conflict appears to hold as well, with temperature constraints correlating negatively and significantly to territorial conflict in both the nested and full models, and positively but not significantly correlated to governance conflicts.

Based on these correlations it appears that moisture and temperature both affect the likelihood of civil conflict. However, the exact nature of the relationships is obscured by the resolution of the data. Each of the three datasets is a composite of temperature or moisture over time, and classifies areas according to general trends experienced at the local level. While this provides evidence of the general climate conditions where distinct types of conflict occur, it does not allow exploration of how changes in temperature or precipitation affect the onset or duration of conflict. Local-level time series data on mean monthly and mean annual temperature and precipitation could be included as covariates in future studies to explore local sensitivity to climatic conditions.

Controls and lags

The spatial and temporal lags are the strongest correlates of armed conflict across all model specifications. For each dependent variable the three lags maintain their sign, approximate coefficient size, statistical significance, and relative strength. Further, these lags account for most of the explained variance in the models, and explain the incredibly large pseudo r^2. While minor fluctuations exist across specifications, these three lags demonstrate extremely robust correlations with conflict. Both conflict in the previous year and current conflict in adjacent cells (*Conflict t-1* and *Spatial lag* respectively) are positively correlated with each type of conflict in a cell. This suggests both a contagion and a duration effect of conflict, and confirms the general relationship found in previous studies. Conflict is spatially contagious[7], and once the transition to conflict has been made, conflict tends to endure. In each model the positive correlation of these two lags is slightly tempered by conflict in the previous year in adjacent cells. This tempering effect is smaller than the other two lags, and likely indicates the effect of conflict termination on model estimation, since few conflicts span the entire 14-year observation period.

The political controls (*Polity IV* and *Polity IV abs. val.*) demonstrate significant and inverse effects across dependent variables. The polity score is negatively and significantly correlated with territorial conflicts, suggesting that less democratic cells (more authoritarian/less democratic as they approach *-10* on the polity scale) are prone to conflict. Absolute value of polity (deviation from 0) is positively and significantly correlated with territorial conflicts, confirming that more consistent regimes are prone to conflict. Taken together, these covariates suggest that territorial conflicts occur in consistently undemocratic cells. Recalling that the definition of territorial conflict is includes conflicts over secession or autonomy, these relationships suggest that secession and autonomy claims occur in strong authoritarian states, where geographically isolated groups are likely marginalized by the regime.

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7 As discussed in the previous chapter, I assume that conflict is contiguously contagious, and thus do not include lags to model conflict in any other portion of a state.

The inverse relationships exist between these covariates and governance conflicts, with absolute value of polity score negatively and significantly correlated with conflict and polity score positively correlated with conflict. This suggests that governance conflicts are more likely in cells with inconsistent regimes that are transitioning toward democracy. Under this relationship it is possible that marginalized groups, or potential contenders for power capitalize on the weakness of the regime and vie for control of the state or for a different type of system, rather than opting to secede.

The 3-category economic control variable is split into three binary variables, with the middle-income category excluded for reference. Both high and low-income classes are negatively correlated (and both significantly correlated in the full models with territorial conflicts compared to the reference category suggesting that territorial conflicts occur in middle-income countries. Like the political control, this potentially suggests that minorities or isolated groups may be trying to secede from a regime under which they are marginalized. Conversely, the low-income category is positively and significantly correlated with governance conflicts compared to the reference across model specifications, indicating that governance conflicts occur in low-income countries, where larger proportions of the population are likely to be discontent with the regime and institutions that are failing to provide or equitably distribute resources.

MAUP controls

In order to assess whether the relationships between covariates and dependent variables is a product of different sizes of disaggregated grid cells capturing different sets of ecological conditions consistent with the MAUP discussed in the previous chapter, I estimate three full models for each dependent variable - *Tables 4.9* (all armed conflict) *4.10* (territory conflicts) *& 411* (governance conflict) - with samples restricted to various cell sizes. The first sample includes all cells for which there are no missing data in the covariates. The second sample contains those cells with an area $>100\ km^2$. The final sample is restricted to cells with an area $>1{,}000\ km^2$. There are very slight fluctuations in coefficient size and effect size among the covariates across samples. Generally as samples are restricted to larger cells, the effect size diminishes slightly. However, the sign of the correlation remains constant for all significant correlations across samples. The consistency of relationships, coefficients, and the very small changes in effect sizes across samples suggests that the slight variation witnessed at different cell resolutions is due to changes in the sample size, rather than different relationships appearing at different resolutions.

This is not a perfect test of the MAUP. Accurately assessing the variation between homogenous and heterogeneous cell sizes would require that the covariates be measure in two different fishnet grids and the correlations examined across measurement schemes. However, as discussed in the previous chapter, political boundaries do not correspond to a uniform grid, and as such the political and social variables cannot be accurately assigned to cells contain multiple countries. Thus a homogenous/heterogeneous model comparison would necessarily omit the political and social control covariates. With those omitted, the correlations exposed would not be comparable to those reported here.

Table 4.9: All Armed Conflicts MAUP Test			
Logistic Regression Model #	1	25	26
	Full Model	Cells >100km^2	Cells >1000km^2
Conflict t-1	8.750***	8.746***	8.752***
	[42.04]	[42.01]	[35.90]
Spatial lag	22.42***	22.40***	23.42***
	[30.17]	[30.13]	[22.78]
Spatial lag t-1	-10.18***	-10.18***	-10.10***
	[-25.24]	[-25.22]	[-20.23]
Polity IV	0.0487***	0.0489***	0.0489***
	[3.86]	[3.88]	[3.34]
Polity IV abs val	-0.027	-0.0272	-0.0272
	[-1.26]	[-1.27]	[-1.15]
Low income country[A]	1.244***	1.243***	1.255***
	[5.12]	[5.12]	[5.03]
High income country[A]	0.259	0.249	-0.0405
	[0.39]	[0.37]	[-0.04]
Mean annual night lights	0.0454**	0.0454**	0.0555***
	[2.93]	[2.94]	[3.42]
Pop density (natural log)	0.182***	0.183***	0.213***
	[3.64]	[3.66]	[3.54]
NPP change (unadj.)	0.00149	0.00156	0.00229
	[0.60]	[0.66]	[0.40]
Rain-use efficiency adj. NPP	-0.463	-0.467	-0.268
	[-1.36]	[-1.37]	[-0.75]
Net rain-use efficiency adj. NPP	0.0751	-0.207	-5.404
	[0.01]	[-0.02]	[-0.41]
Positive climate adj. NPP	15.27	15.5	15.31
	[1.46]	[1.46]	[1.29]

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Table 4.9: All Armed Conflicts MAUP Test (continued)

Logistic Regression Model #	1	25	26
	Full Model	Cells >100km^2	Cells >1000km^2
Cropland density	0.00454	0.00452	0.00373
	[0.86]	[0.86]	[0.58]
Pasture density	0.000318	0.000316	0.000193
	[0.50]	[0.49]	[0.31]
Irrigated farming[B]	-0.493	-0.507	-0.971
	[-0.49]	[-0.50]	[-0.67]
Wetland/rice farming[B]	-1.057	-1.071	-1.033
	[-1.03]	[-1.03]	[-0.64]
Rainfed farming (humid)[B]	0.888	0.876	0.674
	[1.26]	[1.23]	[0.57]
Rainfed farming (highland)[B]	1.014	0.999	0.698
	[1.48]	[1.44]	[0.60]
Raindfed farming (dry)[B]	0.581	0.564	0.294
	[0.82]	[0.79]	[0.25]
Dualistic farming[B]	0.658	0.645	0.446
	[0.97]	[0.94]	[0.39]
Closed forest[C]	0.188	0.184	0.186
	[0.55]	[0.54]	[0.47]
Fragmented forest[C]	-0.379	-0.375	-0.445
	[-1.11]	[-1.09]	[-1.11]
Woodlands[C]	-0.182	-0.183	-0.176
	[-0.70]	[-0.70]	[-0.55]
Aridity	0.0891	0.0903	0.0503
	[0.51]	[0.51]	[0.27]
Soil drainage	-0.00129	-0.00126	0.000228
	[-0.26]	[-0.26]	[0.05]
Climate zone	0.691**	0.689**	0.769**
	[3.00]	[2.99]	[2.73]
Climate constraint: wetness[D]	0.047	0.0499	0.224
	[0.19]	[0.20]	[0.87]
Climate constraint: moisture[D]	-0.253	-0.25	-0.24
	[-0.86]	[-0.85]	[-0.73]
Climate constraint: severe moisture[D]	0.481	0.486	0.365
	[1.63]	[1.65]	[1.06]
Climate constraint: temperature[D]	-0.557	-0.555	-0.461
	[-1.14]	[-1.14]	[-0.94]
Climate constraint: severe temperature[D]	-0.776	-0.77	-0.527
	[-1.58]	[-1.57]	[-0.91]
Constant	-11.50***	-11.48***	-11.51***
	[-11.85]	[-11.75]	[-8.17]
N	218935	218529	204492
pseudo r^2	0.973	0.972	0.976
chi^2	3526.9	3527.2	3288.7

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003
[A] Reference category is *Middle income country*
[B] Reference category is *Other land*
[C] Reference category is *Not applicable/no farming*
[D] Reference category is *No climate constraints on agriculture*

Table 4.10: Territory MAUP Test			
Logistic Regression Model #	2	27	28
	Full Model	Cells >100km^2	Cells >1000km^2
Conflict t-1	5.193***	5.177***	5.127***
	[26.66]	[26.52]	[24.97]
Spatial lag	6.308***	6.312***	6.231***
	[38.17]	[38.05]	[36.35]
Spatial lag t-1	-5.739***	-5.725***	-5.679***
	[-26.04]	[-25.97]	[-24.50]
Polity IV	-0.0272**	-0.0259**	-0.0302**
	[-3.04]	[-2.88]	[-3.19]
Polity IV abs val	0.298***	0.295***	0.298***
	[14.86]	[14.81]	[14.25]
Low income country[A]	-0.502*	-0.506*	-0.355
	[-2.18]	[-2.19]	[-1.45]
High income country[A]	-0.519*	-0.515*	-0.575*
	[-2.12]	[-2.09]	[-2.22]
Mean annual night lights	-0.00478	-0.00534	0.00289
	[-0.14]	[-0.16]	[0.06]
Pop density (natural log)	0.0343	0.0382	0.0183
	[0.90]	[1.00]	[0.45]
NPP change (unadj.)	-0.00481	-0.00305	-0.00486
	[-1.03]	[-0.66]	[-0.95]
Rain-use efficiency adj. NPP	-1.277***	-1.280***	-1.272***
	[-5.43]	[-5.43]	[-5.35]
Net rain-use efficiency adj. NPP	-31.90***	-34.30***	-33.35**
	[-3.34]	[-3.56]	[-3.21]
Positive climate adj. NPP	25.29*	27.33*	29.34*
	[2.36]	[2.55]	[2.54]

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Table 4.10: Territory MAUP Test (continued)

Logistic Regression Model #	2	27	28
	Full Model	Cells >100km^2	Cells >1000km^2
Cropland density	0.00979**	0.00934*	0.00982*
	[2.61]	[2.48]	[2.52]
Pasture density	0.0173***	0.0170***	0.0180***
	[5.38]	[5.30]	[5.30]
Irrigated farming[B]	0.948	0.937	1.103*
	[1.86]	[1.85]	[2.05]
Wetland/rice farming[B]	1.990***	1.992***	2.199***
	[4.53]	[4.54]	[4.65]
Rainfed farming (humid)[B]	1.401***	1.403***	1.520***
	[4.30]	[4.31]	[4.35]
Rainfed farming (highland)[B]	2.407***	2.392***	2.562***
	[6.67]	[6.64]	[6.60]
Raindfed farming (dry)[B]	0.731*	0.708*	0.850*
	[2.07]	[2.01]	[2.23]
Dualistic farming[B]	0.296	0.282	0.468
	[0.86]	[0.82]	[1.27]
Closed forest[C]	0.845***	0.812***	0.828***
	[3.82]	[3.65]	[3.47]
Fragmented forest[C]	0.980***	0.987***	0.979***
	[4.67]	[4.69]	[4.48]
Woodlands[C]	1.048***	1.044***	1.018***
	[6.17]	[6.15]	[5.83]
Aridity	-0.490**	-0.484**	-0.459**
	[-3.18]	[-3.14]	[-2.76]
Soil drainage	0.0146***	0.0146***	0.0145***
	[4.15]	[4.16]	[4.02]
Climate zone	0.688***	0.693***	0.747***
	[3.88]	[3.91]	[3.92]
Climate constraint: wetness[D]	-0.519*	-0.516*	-0.643*
	[-2.07]	[-2.05]	[-2.42]
Climate constraint: moisture[D]	0.422	0.426	0.453
	[1.66]	[1.67]	[1.69]
Climate constraint: severe moisture[D]	0.934***	0.935***	0.996***
	[4.06]	[4.07]	[4.14]
Climate constraint: temperature[D]	-1.212*	-1.213*	-1.630*
	[-2.25]	[-2.26]	[-2.25]
Climate constraint: severe temperature[D]	-0.198	-0.194	-0.105
	[-0.52]	[-0.50]	[-0.26]
Constant	-11.03***	-11.00***	-11.36***
	[-17.93]	[-17.93]	[-17.11]
N	218935	218529	204492
pseudo r^2	0.582	0.582	0.582
chi^2	6415	6410.9	5999.3

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003
[A] Reference category is *Middle income country*
[B] Reference category is *Other land*
[C] Reference category is *Not applicable/no farming*
[D] Reference category is *No climate constraints on agriculture*

Table 4.11: Governance MAUP Test			
Logistic Regression Model #	3	29	30
	Full Model	Cells >100km^2	Cells >1000km^2
Conflict t-1	5.509***	5.523***	5.445***
	[36.63]	[36.62]	[33.63]
Spatial lag	7.901***	7.902***	7.902***
	[57.46]	[57.33]	[55.16]
Spatial lag t-1	-5.819***	-5.830***	-5.672***
	[-28.49]	[-28.49]	[-26.36]
Polity IV	0.0190*	0.0183*	0.0244**
	[2.20]	[2.12]	[2.65]
Polity IV abs val	-0.297***	-0.297***	-0.303***
	[-16.88]	[-16.87]	[-16.30]
Low income country[A]	2.687***	2.688***	2.746***
	[9.06]	[9.04]	[8.74]
High income country[A]	-1.687	-1.705	-2.085
	[-1.67]	[-1.69]	[-1.55]
Mean annual night lights	0.0954***	0.0956***	0.131***
	[5.48]	[5.48]	[7.07]
Pop density (natural log)	0.0745*	0.0738*	0.0785*
	[2.12]	[2.10]	[2.11]
NPP change (unadj.)	-0.000547	-0.000597	-0.000665
	[-0.38]	[-0.40]	[-0.15]
Rain-use efficiency adj. NPP	1.038***	1.041***	1.047***
	[7.81]	[7.83]	[7.67]
Net rain-use efficiency adj. NPP	0.373	0.346	-2.704
	[0.05]	[0.04]	[-0.28]
Positive climate adj. NPP	-2.413	-2.556	-1.232
	[-0.27]	[-0.27]	[-0.11]

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Table 4.11: Governance MAUP Test (continued)

Logistic Regression Model #	3	29	30
	Full Model	Cells >100km^2	Cells >1000km^2
Cropland density	-0.000489	-0.00039	-0.00239
	[-0.16]	[-0.12]	[-0.74]
Pasture density	-0.00223***	-0.00223***	-0.00232***
	[-10.65]	[-10.65]	[-9.84]
Irrigated farming[B]	-0.607	-0.618	-0.41
	[-1.32]	[-1.35]	[-0.87]
Wetland/rice farming[B]	-1.552***	-1.575***	-1.500***
	[-4.88]	[-4.94]	[-4.34]
Rainfed farming (humid)[B]	-0.550*	-0.573*	-0.444*
	[-2.44]	[-2.54]	[-1.97]
Rainfed farming (highland)[B]	-1.461***	-1.481***	-1.302***
	[-6.04]	[-6.11]	[-5.20]
Raindfed farming (dry)[B]	0.0418	0.0339	0.195
	[0.17]	[0.14]	[0.77]
Dualistic farming[B]	0.461*	0.443	0.577*
	[1.99]	[1.91]	[2.43]
Closed forest[C]	-0.122	-0.109	-0.0971
	[-0.64]	[-0.57]	[-0.47]
Fragmented forest[C]	-0.659***	-0.657***	-0.672**
	[-3.38]	[-3.35]	[-3.28]
Woodlands[C]	-1.238***	-1.236***	-1.292***
	[-6.64]	[-6.63]	[-6.80]
Aridity	0.774***	0.776***	0.819***
	[6.41]	[6.38]	[6.10]
Soil drainage	-0.0140***	-0.0140***	-0.0147***
	[-4.32]	[-4.31]	[-4.32]
Climate zone	-1.133***	-1.135***	-1.002**
	[-3.62]	[-3.62]	[-3.04]
Climate constraint: wetness[D]	0.439*	0.431*	0.466*
	[2.32]	[2.28]	[2.37]
Climate constraint: moisture[D]	0.106	0.0989	0.118
	[0.37]	[0.34]	[0.38]
Climate constraint: severe moisture[D]	-0.21	-0.222	-0.257
	[-0.92]	[-0.97]	[-1.07]
Climate constraint: temperature[D]	0.551	0.551	0.374
	[1.38]	[1.38]	[0.81]
Climate constraint: severe temperature[D]	0.265	0.261	0.124
	[0.75]	[0.74]	[0.34]
Constant	-5.460***	-5.444***	-5.733***
	[-9.20]	[-9.17]	[-9.07]
N	218935	218529	204492
pseudo r^2	0.783	0.783	0.788
chi^2	6430.4	6410.9	5826.5

Robust z-scores clustered on cell id number in brackets

* p<0.05, ** p<0.01, *** p<0.003
[A] Reference category is *Middle income country*
[B] Reference category is *Other land*
[C] Reference category is *Not applicable/no farming*
[D] Reference category is *No climate constraints on agriculture*

Summary

I return now to the hypotheses advanced in the previous chapter. Population density is positive and significant at the 0.05 level or better in the full models, and in all of the nested models. This suggests that H_1 holds across models. The proxy measure for human encroachment also maintains a positive and significant affect in the full models *1* and *3*, and in the nested models and. Like H_1, there is evidence to support H_2. From the dichotomized dependent variable, however, it appears that population density and infrastructure expansion are not mutually exclusive phenomena, but rather exert influence on each other's relationship to the dependent variables. Further, for a given type of conflict these variables have an inverse effect on the dependent variable.

> *H_1: Human population density is positively correlated with the occurrence of armed conflict; as population density increases consumption pressure on ecosystem services at the local scale.*
>
> *H_2: Human encroachment into natural areas is positively correlated with the occurrence of armed conflict as it simultaneously increases consumption pressure on ecosystem services and decreases productive capacity by altering relationships among the biotic and abiotic components of those areas; and*

Based on the effects of the light and population covariates on the dependent variables in the nested models, I thus contend that population density is positively correlated with territorial conflict, and that human encroachment into natural areas is positively correlated with governance conflict. Considering the full models, it is reasonable to argue that population density is also positively correlated with governance conflict, though admittedly the interplay between infrastructure and population density warrants further exploration.

Like H_1 and H_2 there is sufficient reason to accept the propositions advanced in H_3 and H_4, albeit conditionally.

> *H_3: Human modification of natural land cover and land use is positively correlated with the occurrence of armed conflict; as it disrupts productive capacity at the local scale; and*
>
> *H_4: Ceteris paribus, land cover regimes characterized by high biomass productivity (closed canopy forests, grasslands, and similarly biologically rich regions) are negatively correlated with the occurrence of armed conflict.*
>
> *H_5: Changes in biological productivity (either increases or decreases) are positively correlated with the occurrence of armed conflict, as these are likely to be the locations where social-social and social-ecological relationships are being renegotiated based on changing productive capacity.*

Land use systems and land cover regimes characterized by human modification of natural vegetative structures (i.e. farming and grazing) are positively associated with territorial conflicts, and negatively associated with governance wars. While these relationships appear to hold generally from the nested to the full models, the correlation between *closed forest* and the dependent variables switches signs when all covariates are included. To uncover the dynamics between land cover change and conflict, a more precise measurement scheme on annual intervals is required.

Biological productivity, as measured by change in NPP over time, likewise appears to correlate uniquely to the two types of conflict. Between the nested and the full models it appears that declining productivity is correlated with the occurrence of territorial conflicts, where increasing productivity is correlated with governance conflicts. H_5 thus appears to hold in both cases, as it posits that change, regardless of sign, in productivity affects the delivery of ecosystem services sufficient to disrupt social systems.

> *H_6: Physical conditions that promote biological productivity are negatively correlated with the occurrence of armed conflict; and*
>
> *H_7: Climatic conditions that promote biological productivity are negatively correlated with the occurrence of armed conflict.*

The two factors used to measure physical and climatic conditions aridity and temperature, demonstrate the same inverse effect as the other covariates. Again both propositions advanced by H_6 and H_7 can be accepted conditionally, relative to the correlations demonstrated in the nested models. Higher water availability appears to be positively correlated with governance conflict, whereas water stress appears correlated positively with territorial conflict. Temperature also exhibits a dichotomous relationship, with lower temperatures associated positively with territorial conflicts, and higher temperatures associated with governance conflicts.

The global scope of this study and the structure of the available global datasets limit the extent to which I am able to explore the relationships between covariates and the dependent variables using this methodology. The evidence demonstrated through multivariate analyses suggests that changes in physical and ecological conditions are correlated to armed conflict. However, with the exception of the population and light data, the data available at the global scale are composites of general trends over time. The statistical work reported above demonstrates connections between various types of conflict and these general ecological trends. However, without accurate time series data it is unclear exactly how shifts in these trends affect conflict likelihood for a given location.

The following chapter discusses in greater detail the implications of the relationships reported here. After that discussion, I suggest revisions to the methodological approach of this study, and highlight areas for further study.

Chapter 5. Resilience revisited

The statistical work in the previous chapter demonstrates several interesting connections between local ecological characteristics and the occurrence of violent armed conflict. From the multivariate approach applied, it is apparent that different types of conflict are associated with distinct ecological relationships, distinct demographic profiles, and distinct economic and political conditions. This chapter begins by exploring those associations through the resilience framework discussed in the opening chapters. This chapter then goes on to discuss the limitations of the methodological approach applied in this study, and suggests areas for methodological refinement and future research.

Resilience revisited

The opening chapters outlined a theory of social resilience. In that theory, humans and their biotic and abiotic counterpart coexist in nested systems. The character of those social-ecological systems (SES) is defined by the values and interaction of all constituent components, as well as by the influence of processes at higher and lower levels within the nested systems. A stable system state (marked by specific system functions and characteristics) is a set of values toward which system components gravitate, given the values of other components in the system. Because the value of one component is dependent on the values of other components and the relationships that those values produce, there are multiple stable states for any SES. That is to say that there are multiple possible values toward which components gravitate, and the particular attractor that the system gravitates toward at a given time depends on all the relationships and values of the system at that time. These attractors are referred to as basins of attraction. Because the system is constantly changing, the system orbits the attractor according to a trajectory, and that trajectory changes with fluctuations in the values of system components. Resilience is a concept that describes a system's ability to absorb change or stress while maintaining the essential function or character of the system in a given basin of attraction. Changes in component values introduce stress on the system, and sufficiently large or sustained stress can cause perturbation of the trajectory of the system orbit around a specific attractor. In systems with low resilience, or under conditions of low resilience, those perturbations can sufficiently alter the system trajectory away from one stable state, and toward a different attractor. When a system enters a different basin of attraction (i.e. when component values gravitate toward alternate values) it is considered a regime shift. Alternate values for system components produce markedly different relationships within the system, and thus produce system functions and characteristics.

The statistical work of the previous chapter disaggregated the world into a set of grid cells, each with unique social and ecological characteristics. While the imposition of grid cells was arbitrary (not based explicitly on any biophysical, ecological, or social factors), for the purposes of this research each grid cell can be considered a nested SES. The framework applied herein considers two possible stable states for each cell:

cooperation/no conflict and conflict. The conflict state is further dichotomized such that three potential states exist: cooperation/no conflict, territorial conflict, and governance conflict. The statistical models operate with the nested systems theory in mind. The function or character of the social component of the SES is defined as either experiencing one form of conflict, or not experiencing conflict in a given year. The value of the dependent variable is simultaneously a mathematic function of the values of all system components considered by the covariates, the value of the dependent variable over time, as well as the influence of adjacent SES in the larger system.

The results of the work reported here provide strong evidence for the existence of multiple stable states for these arbitrary SESs. Across the study area and across the study period cooperation/no conflict is the predominant state for most cells. As the descriptive statistics in *table 3.1* reported, for the entire period 1991-2004 over 93% of cells never experienced conflict. In the parlance of the resilience framework, those cells were sufficiently resilient to perturbation and change in their components and adjacent relationships to remain in a basin where the function of the social components of the system is characterized by cooperation rather than violent competition. Because of the prevalence of non-conflict systems, we can consider that basin of attraction to be extremely wide and deep. Most grid cells are able to absorb change-induced stress and retain a non-conflict character or function.

Some cells demonstrate lower resilience to change in their social and ecological components. Under certain ecological conditions a small number of cells experience a regime shift into one of two stable states, defined by violent competition among the social components over either territory or governance. The specific conflict basin that a system transitions into depends heavily on the political and economic characteristics of its social components. However, these factors alone do not account for the transition to specific types of conflict. Rather, political and social conditions act in concert with changing ecological characteristics, and changes in the nature of the interaction between social, biotic, and abiotic components and processes to produce conflict. Further, the effect size of many physical and ecological covariates is at least as large as the political and economic controls.

What is clear is that each type of conflict is correlated with a distinct set of relationships and values among the components of a SES. What is interesting from the statistical work is that the relationships between the covariates and one type of conflict generally have the inverse affect on the other type of conflict. That is to say that territorial and governance conflicts have distinct and unique ecological drivers.

The limited number of regime shifts witnessed over the study period suggests that the conflict basins are rather narrow, and that transitioning into either one is uncommon. However, the powerful and consistent effect of the temporal lag suggests that conflict states are very stable. Once a system has moved into a conflict basin it tends to remain there. Further, the powerful and consistent effect of the spatial lag suggests that a regime shift to conflict for a given cell exerts an attractive influence on adjacent cells, pulling them toward conflict basins as well. While extremely stable and spatially attractive, conflict basins are not inescapable. A cell that experienced conflict in previous years is likely to continue experiencing conflict. Likewise, a cell whose neighbors are in conflict is likely to experience conflict. However, when both conditions are met, conflict in neighbors and conflict in the past, a cell is slightly less likely to continue experiencing conflict.

Methodological limitations

As discussed in previous chapters, the methodological approach taken herein allows an exploration of potential relationships between the occurrence of conflict and certain ecological and biophysical characteristics at the local level. Indeed, the correlations demonstrated in the statistical models provide compelling evidence that the relationship of humans and their environment helps to determine where conflict will occur, and what sorts of ecological changes human communities are sensitive to. There are limitations to this approach however. Specifically, while the approach taken makes great strides in identifying *where* and *under what conditions* different types of conflicts occur, it cannot directly explore *why* those conflicts occur. The theoretical framework provided in earlier chapters points toward certain explanations, with ecological change forcing the renegotiation of social relationships, and creating opportunities for conflict to emerge. However, conflict is fundamentally a product of the interactions among people. The reasons that conflict emerges are direct products of individuals', groups', and institutions' motivations and interactions. Ecological and biophysical factors/changes themselves are not sufficient to incite conflict. The empirical work here explores the relationship of *humans* to their environment, but fundamentally omits the interaction of *people* that actual cause conflict. Thus this framework can explore where and when conflict might occur, but cannot explain the onset or the duration of conflict. Further, while the data suggest certain relationships and associations, the nature of these relationships and the mechanisms through which they drive conflict processes remains obscured, particularly since people are left out of the equation.

These limitations are byproducts of the scale of the research. By examining the occurrence of armed conflict at the global level the research design explores broad trends common to all conflicts (as defined here). This omits the individual nuance and complexity that gives rise to each incident of conflict. While governance conflicts appear to occur in specific areas under specific conditions, the actual mechanisms through which tension and stress lead to conflict may be uniquely intrinsic to each individual conflict. The methodological framework applied here lacks the ability to explore those mechanisms.

The global scale of the research limits the utility of this methodology in another important way. Global level data sets that are uniformly consistent throughout do not exist for many social, ecological, and physical variables. Where they do exist, they are generally coarse measurements of a certain condition of factor, and omit much of the nuance of the phenomenon at the micro or local scales. Further, the data that do exist are typically composites generated over time, but referencing only one static state of a variable across the globe. Time series data at annual (or better) observations are difficult and costly to collect, and thus most variables lack consistent data over time. Such variables however, are constantly changing, and it is these changes that are likely responsible for conflict. After all, the presence of certain conditions alone accounted for conflict we would witness permanent conflict in those areas. Since conflict cycles ebb and flow, we must thus measure change in variables over time to better understand the drivers of conflict.

Because of the coarseness of data employed in this study, the methodological approach taken here cannot explore causation of conflict. Rather, the framework at its best can only highlight geographic locations where social and ecological conditions combine to produce conflict. Having identified those areas, a logical next step is to narrow future studies to a finer resolution, and examine the local conditions that drive conflict. Higher resolution data are typically more readily available and less costly to produce than global data. Future studies could select several conflict prone areas and employ better measures of ecosystem service dependence, biological productivity change over time, fractal growth patterns in conflict location and geographic scope, and better measures of human economic, political, and somatic well-being. Tracking these variables over time at the very local scale could provide a great deal of insight into why and when changes in SES lead to conflict. Further, operating at a higher resolution would allow the flow of natural goods and services to be accounted for throughout a system. The methodology employed here is not able to measure flows of variables across cells. However, the contagion effect of conflict witnessed in the strength and consistency of the spatial lags suggests that there is something about geographic contiguity that affects conflict likelihood. We can speculate that contiguity lowers transaction costs for conflict spread, however, such speculation is weightless in the absence of data. From the statistical models presented earlier there is compelling evidence that suggests contiguity matters. The theory presented here considers that contiguity might matter because of the flow of variables and changes in variables across space. Refining the focus of study to smaller areas will allow measurement of finer and higher resolution data. Such data could provide insight into why exactly contiguity matters for conflict.

A further limitation of the approach taken here is its inability to explain conflict cessation. Said differently, the methodological approach taken here examines what factors are associated with the shift from cooperation/coexistence to conflict, but fails to examine the inverse - shifts from conflict to cooperation. The slight negative correlation between the spatial-temporal lag (conflict in neighbors in the previous year) and conflict occurrence suggests that something about neighboring cells having been in conflict in previous year slightly lowers conflict propensity for a given cell. There are, however, no dependent variables or covariates included in the models to explore that relationship.

A final limitation is the terrestrial focus of the research. All covariates deal explicitly with terrestrial ecosystems and ecosystem services. Many human communities around the world, and many local, national, and interstate economies, depend directly on the goods and services provided by freshwater and marine ecosystems. Those systems were omitted from this study due to a paucity of reliable and consistent data at the global scale. Future research into local level conflict should incorporate these systems. Trends in these systems could be modeled using a variety of indicators, from pollutant levels to turbidity to catch per unit effort (CPUE) time series data. Including variables to model local dynamics in marine and freshwater ecosystems over time could provide a more comprehensive understanding of how changes in ecosystem service delivery affects conflict occurrence at the local level.

Conclusion

The limitations of the methodological framework applied in this research highlight much of what we do not know about conflict processes, particularly as related to the ecological correlates of violence. Despite these multiple unknowns, there are several important things that we do know. Civil, extra-state, and sub-state wars are the most prevalent expressions of armed conflict witnessed in the world today. These wars are fought predominantly in economically underdeveloped countries with transitioning, non-democratic, or ill-functioning democratic political regimes. In these states, conflict is simultaneously a product of distribution of wealth, health and human development, ethnic, linguistic, and religious divisions, political opportunism, and many other social characteristics. None of these factors operative individually. Rather, they all simultaneously affect each other, and combine to produce virulent results in some places. But why are these virulent results expressed in these countries and not others, and why in certain places and not others?

One answer may be that local ecological conditions and processes affect whether or not conflict will occur in a given area. A common characteristic of underdeveloped countries that experience civil war is the direct dependence of large sectors of their populations on natural goods and services for subsistence and for livelihood opportunities. Further, large sectors of these economies depend directly on natural goods and natural capital as primary input. Finally, many groups in these areas have a direct cultural, historic, and spiritual connection to their environment in salient but intangible ways. Changes in the rate, quantity, and quality of natural goods and ecosystem services stress those sectors and those populations, forcing them to constantly adapt to new conditions. Change creates space for the renegotiation of relationships, but change alone cannot explain the occurrence of conflict. Rather, it is the course that adaptation to change takes, and the character of relationships that are renegotiated due to change that ultimately drives, prevents, or mitigates conflict.

From the work presented here it is apparent that local ecological conditions do in fact affect conflict processes and dynamics. Because of that influence, those interested in preventing, resolving, or otherwise affecting conflict must be cognizant of local relationships between social groups and the natural world. We must consider how changes in the natural world will affect the groups who depend on the goods and services that ecological factors provide, and likewise how those groups will have to adjust to a changing environment. Humans are inescapably tied to the natural world. Our continued survival as a species is directly and inexorably dependent on the continued flow of natural goods and services from their origin to consumption. There is a real cost associated with the disruption of that flow. When peoples needs cease to be met, when meeting them becomes increasingly costly, or when alternative satisfiers cannot be substituted, we are likely to witness regime shifts. In many instances, those regime shifts will be away from cooperation and toward conflict. The real danger lies in the fact that the shift into conflict is likely to be stable and sustained. As shown through this research, the basin of conflict is sheer and deep. Once in, it is difficult for a system to escape.

The research presented here is not definitive, but is rather a starting point. The traditional social-scientific and biological/ecological treatment of the social and natural worlds as coincidental at best, and mutually exclusive at worst, is quickly giving way to deeper and more comprehensive intellectual frameworks that embrace and explore the complexity of the world. The study presented here demonstrates the potential utility in considering a range of non-traditional relationships in social-scientific research by synthesizing geospatial and traditional statistical methodologies. This is not the first attempt to do so. It is, however, one of the first attempts to consider ecological variables at absolute locations as they correlate to the occurrence of armed conflict. While this approach raises perhaps more questions than it answers, it also demonstrates a way forward in social-ecological research.

Chapter 6. Geographic trends in conflict propensity

The preceding chapters explored the connections between humans and their environment, particularly the relationships between ecological processes and conditions and human conflict. This research suggests that while conflict has place-specific drivers - drivers that stem from the socio-cultural context of a place and a group - there are certain spatial relationships that also affect conflict processes and dynamics. As noted earlier, local geographic and biophysical factors are not necessarily *drivers* of conflict, but certainly do affect the likelihood of it. Conflict occurs in specific locations, with specific ecological dynamics. The conflicts that are witnessed today are not equally distributed across entire countries. Rather, conflicts in the contemporary era occur in islands of violence. While conflict is ultimately a social process, it has been argued here that the locations where conflict emerges are partially explained by the ecological relationships that exist at those locations.

In order to explore the locational aspects of conflict, I estimate in-sample predicted probabilities of each type of conflict using logistic regression. *Figures 6.1-6.3* report the results of those models. Further, I calculate mean predicted probabilities for each grid cell based on the annual predicted probability estimated in the above models to identify those physical locations with the greatest conflict propensity across the 14-year sample period. While it would be very useful forecast out-of-sample conflict probabilities for each grid cell, the data constraints involved in operating at fine resolution on the global scale preclude such forecasting. Specifically, without time series data for each covariate on annual observations, it is not possible to forecast which locations will likely experience violent conflict in years outside the sample period. However, by generating mean in-sample conflict propensity, I am able to demonstrate those locations most prone to conflict based on their ecological profiles. The formula for generating that mean propensity is:

$$\text{Pr(conflct)}_i = \frac{\Sigma_{i1\text{-}i14}}{14}$$

where:

I1-i14 = annual predicted probability of conflcit in cell *i*

The following tables report the results of the predictive models:

Table 6.1 Logistic predictive model for All Armed Conflcits

Classified	TRUE D	TRUE ~D	Total
+	16394	190	16584
-	317	202034	218935
Total	16711	20224	218935

Classified + if predicted Pr(D) >= .5
True D defined as all_conflict !=0

Sensitivity	Pr(+ | D)	98.10%
Specificity	Pr(- | ~D)	99.91%
Positive predictive value	Pr(D | +)	98.85%
Negative predictive value	Pr(~D | -)	99.84%
False + rate for true ~D	Pr(+ | D)	0.09%
False - rate for true D	Pr(- | ~D)	1.90%
False + rate for classified +	Pr(D | +)	1.15%
False -rate for classified -	Pr(~D | -)	0.16%
Correctly classified		**99.77%**

Table 6.2 Logistic predictive model for Territory Conflcits

Classified	TRUE D	TRUE ~D	Total
+	2510	1342	3852
-	3010	212073	215083
Total	5520	213415	218935

Classified + if predicted Pr(D) >= .5
True D defined as all_conflict !=0

Sensitivity	Pr(+ | D)	45.47%
Specificity	Pr(- | ~D)	99.37%
Positive predictive value	Pr(D | +)	65.16%
Negative predictive value	Pr(~D | -)	98.60%
False + rate for true ~D	Pr(+ | D)	0.63%
False - rate for true D	Pr(- | ~D)	54.53%
False + rate for classified +	Pr(D | +)	34.84%
False -rate for classified -	Pr(~D | -)	1.40%
Correctly classified		**98.01%**

Table 6.3 Logistic predictive model for Governance Conflicts

Classified	TRUE D	TRUE ~D	Total
+	10015	2493	12508
-	1809	204618	206427
Total	11824	207111	218935

Classified + if predicted Pr(D) >= .5
True D defined as all_conflict !=0

Sensitivity	Pr(+ | D)	84.70%
Specificity	Pr(- | ~D)	98.80%
Positive predictive value	Pr(D | +)	80.07%
Negative predictive value	Pr(~D | -)	99.12%
False + rate for true ~D	Pr(+ | D)	1.20%
False - rate for true D	Pr(- | ~D)	15.30%
False + rate for classified +	Pr(D | +)	19.93%
False -rate for classified -	Pr(~D | -)	0.88%
Correctly classified		**98.04%**

Logistic regression estimates the probability of a positive versus a negative outcome on the dependant variable given a set of values of covariates. The odds ratio that it produces is then log transformed, and the result is a score ranging between *0* and *1*. Any predicted value $< .50$ is assigned a value of zero, and $> .50$ is assigned a value of *1*. Applied to the models of conflict, predicted probabilities $< .50$ are predicted as not being in conflict, and $> .50$ are predicted to be in conflict in a given year of observation.

The following series of maps display the mean risk of conflict for each grid cell in the sample for each type of conflict. While it is not possible to predict the onset of conflict using the methodology applied in earlier chapters, it is possible to identify those cells whose particular ecological profiles make them most prone to conflict. As noted earlier, the onset of conflict is dependent on the ways in which social actors and groups renegotiate their relationships as they adapt to changes in the natural and social-ecological world. That said, the areas highlighted as high-risk in the following maps demonstrate a high propensity to experience conflict based on their unique ecological profiles. It is in these areas that we must be most cognizant of the specific ways that human communities interface with their natural environments, and the ways that changes in those relationships will affect the human populations.

The geospatial and spatial-statistical approach implemented in this research presents a way forward in conflict research. It is my hope that by first identifying the ecological correlates of conflict, and then identifying those areas with the greatest vulnerability to conflict, those who work to prevent conflict across the world will be better equipped to identify and mitigate the challenges that marginalized and underdeveloped communities face before those challenges give rise to collective violence.

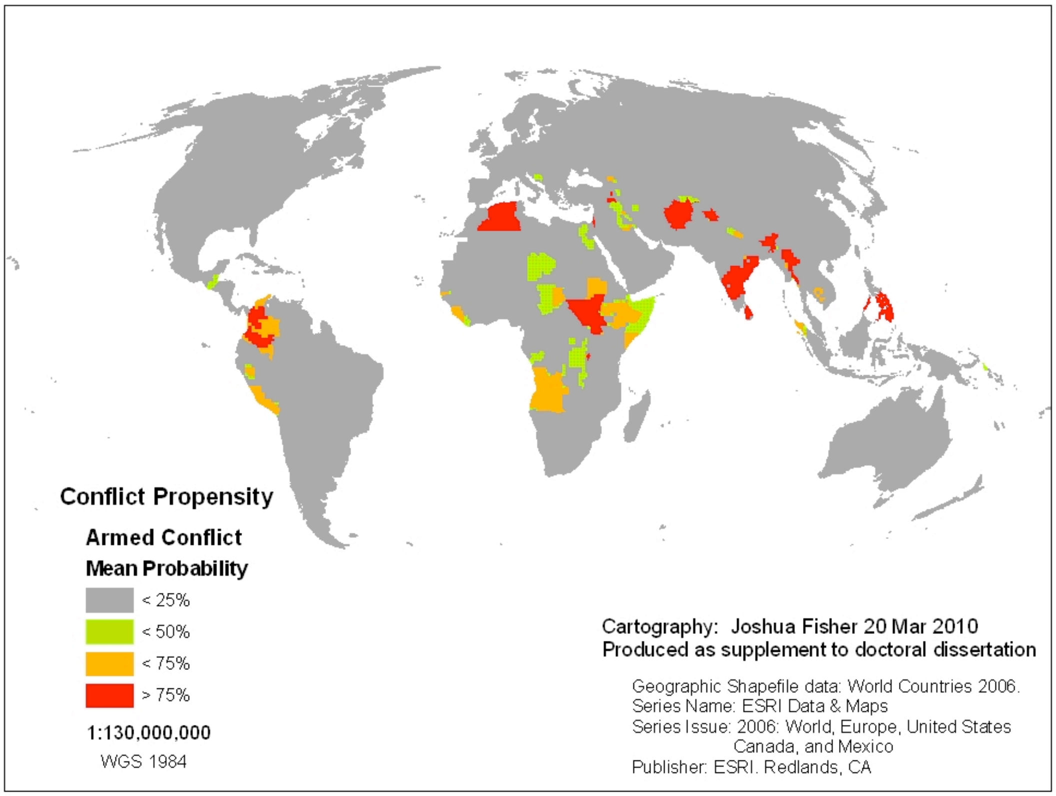

Figure 6.1 Map of mean predicted armed conflict probability

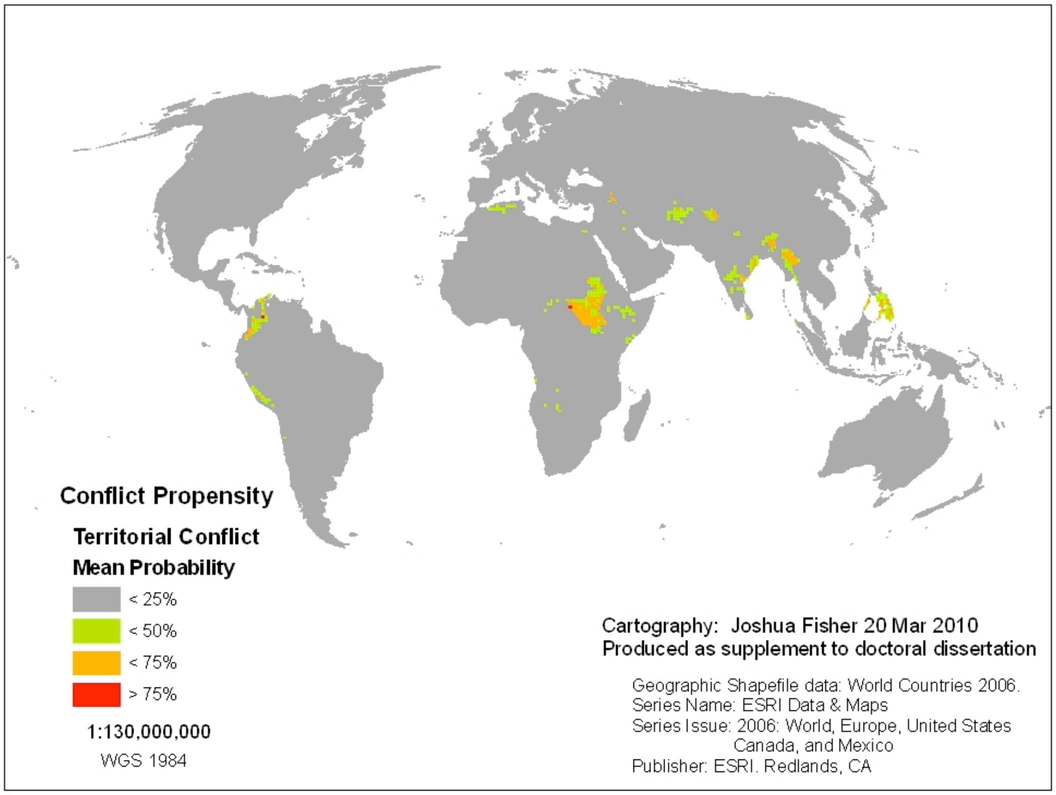

Figure 6.2 Map of mean predicted territorial conflict probability

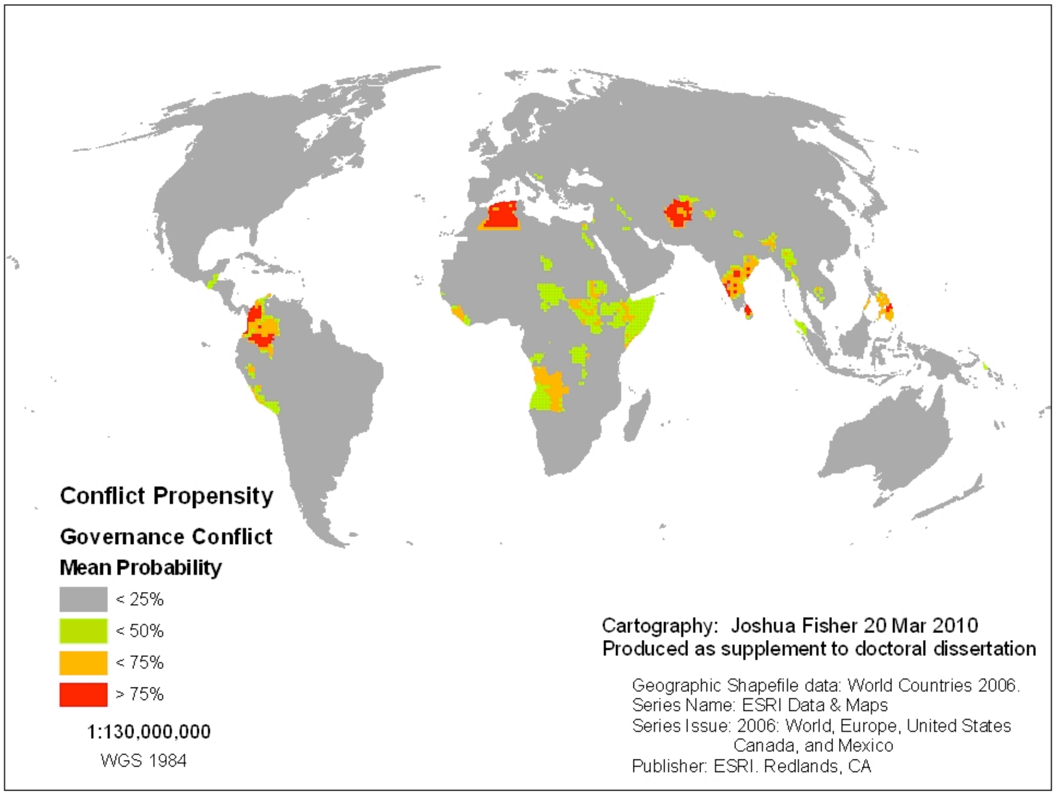

Figure 6.3 Map of mean predicted governance conflict probability

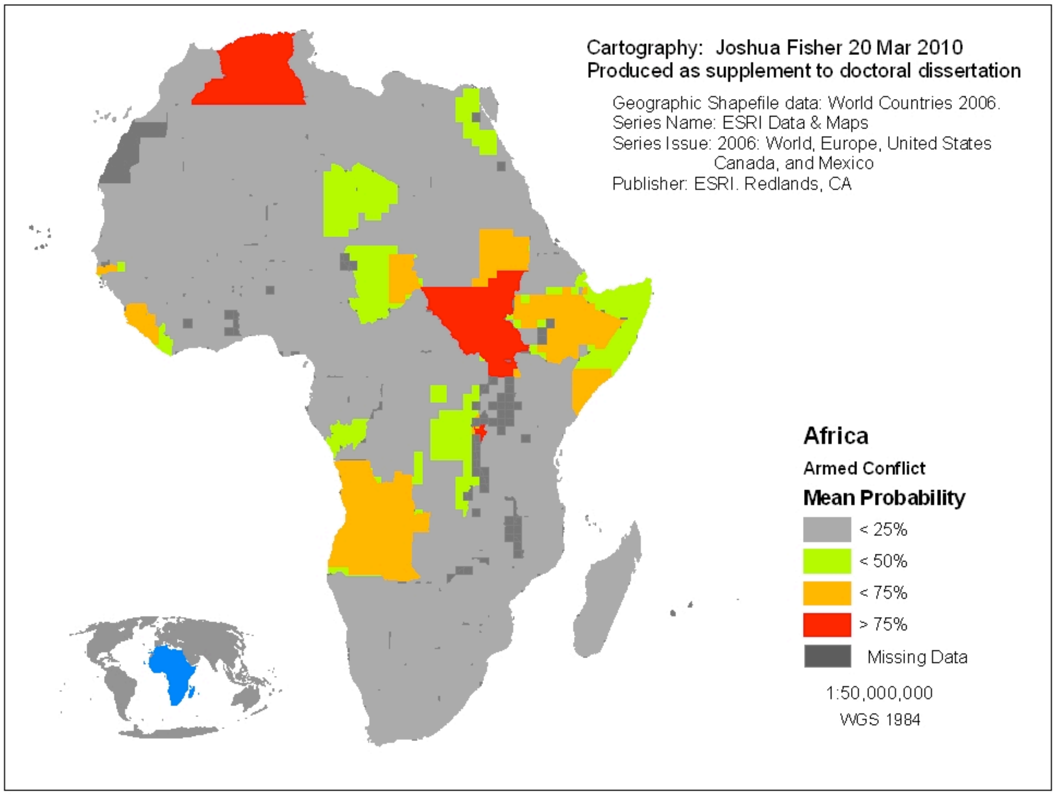

Figure 6.4 Map of mean predicted armed conflict probability in Africa

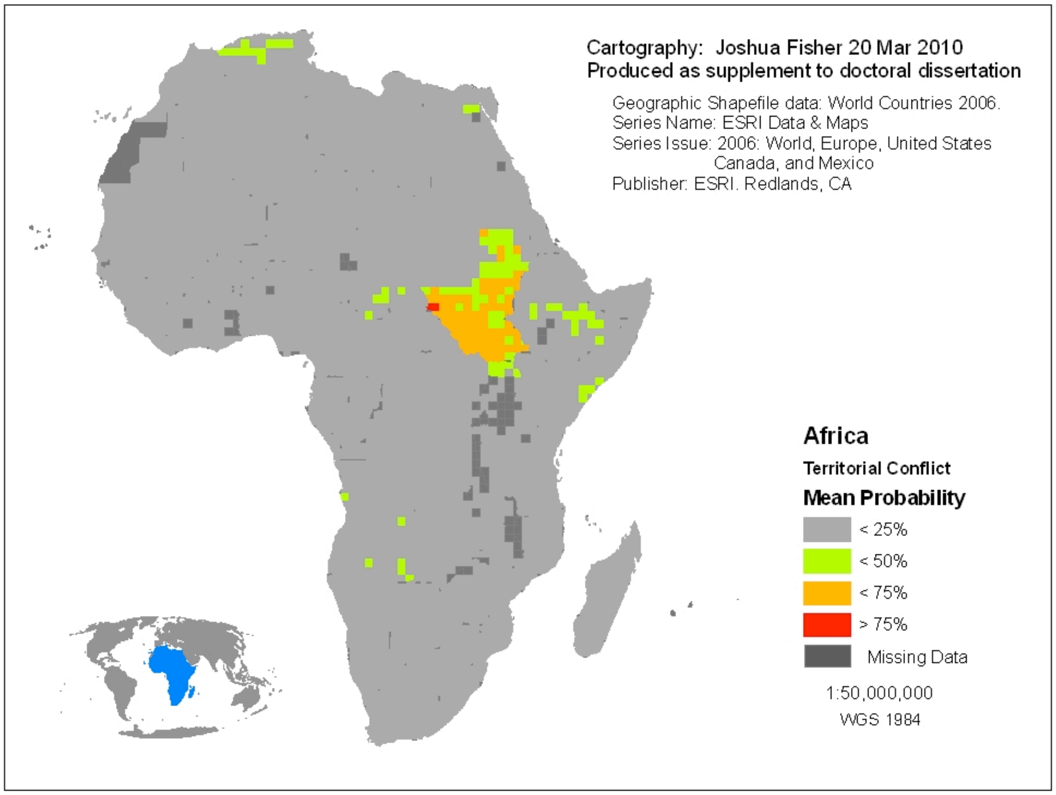

Figure 6.5 Map of mean predicted territorial conflict probability in Africa

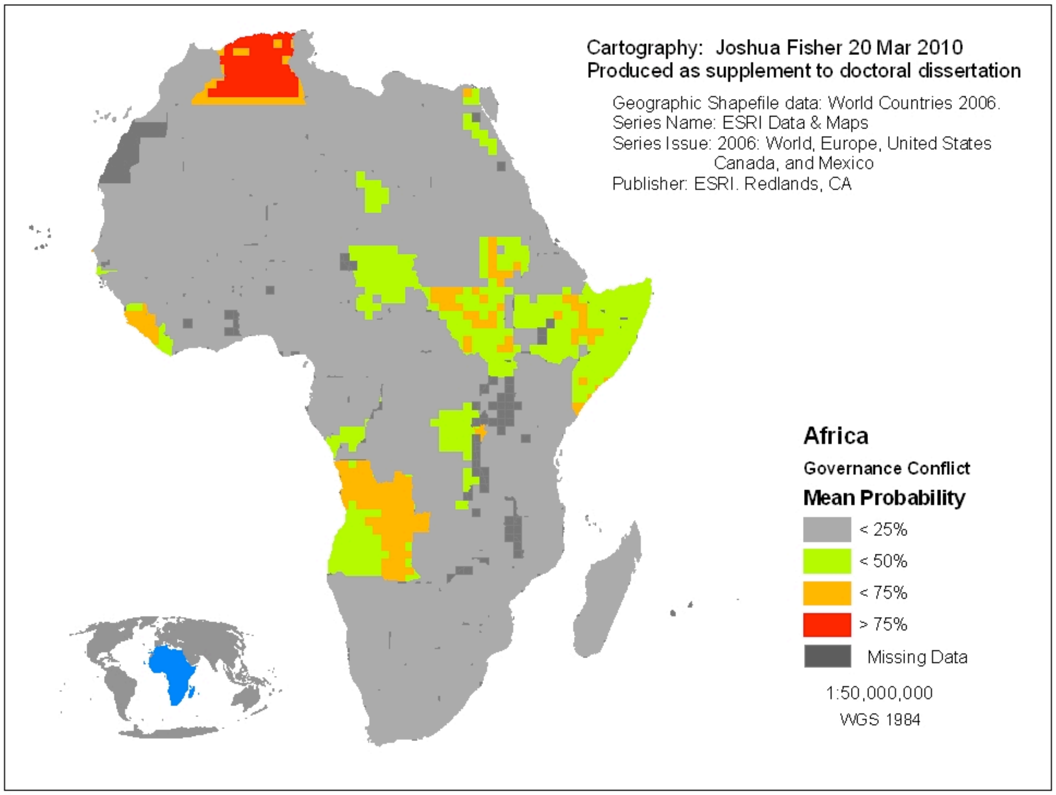

Figure 6.6 Map of mean predicted governance conflict probability in Africa

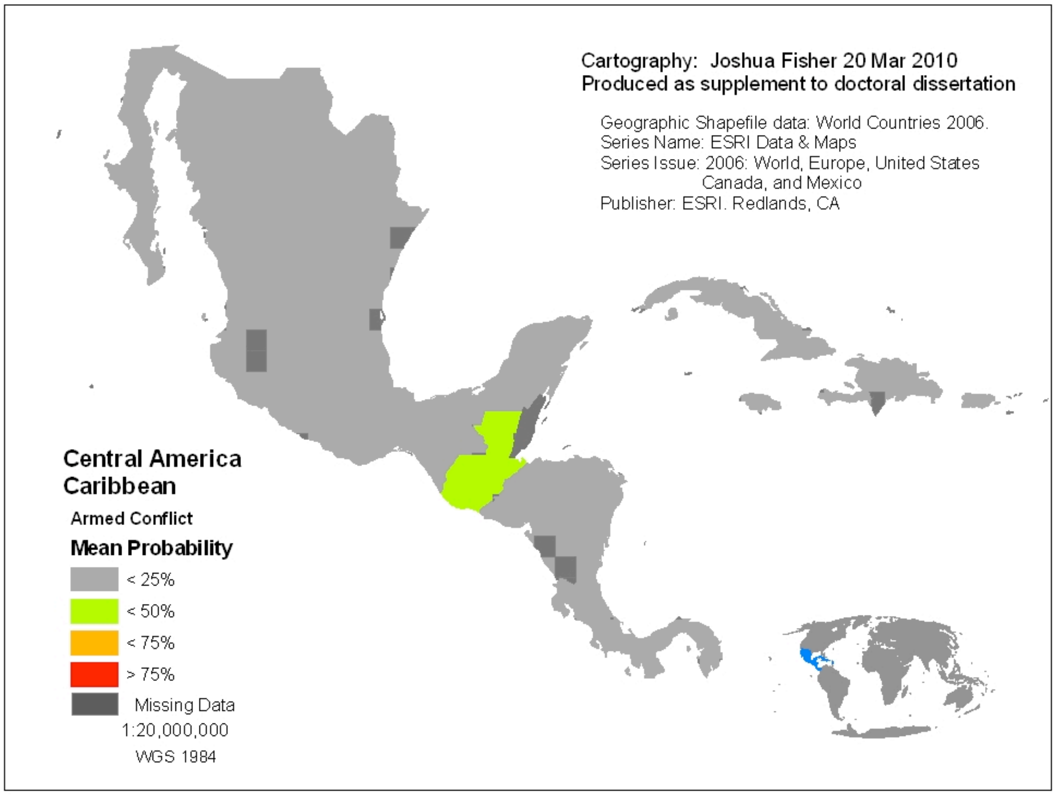

Figure 6.7 Map of mean predicted armed conflict probability in Central America

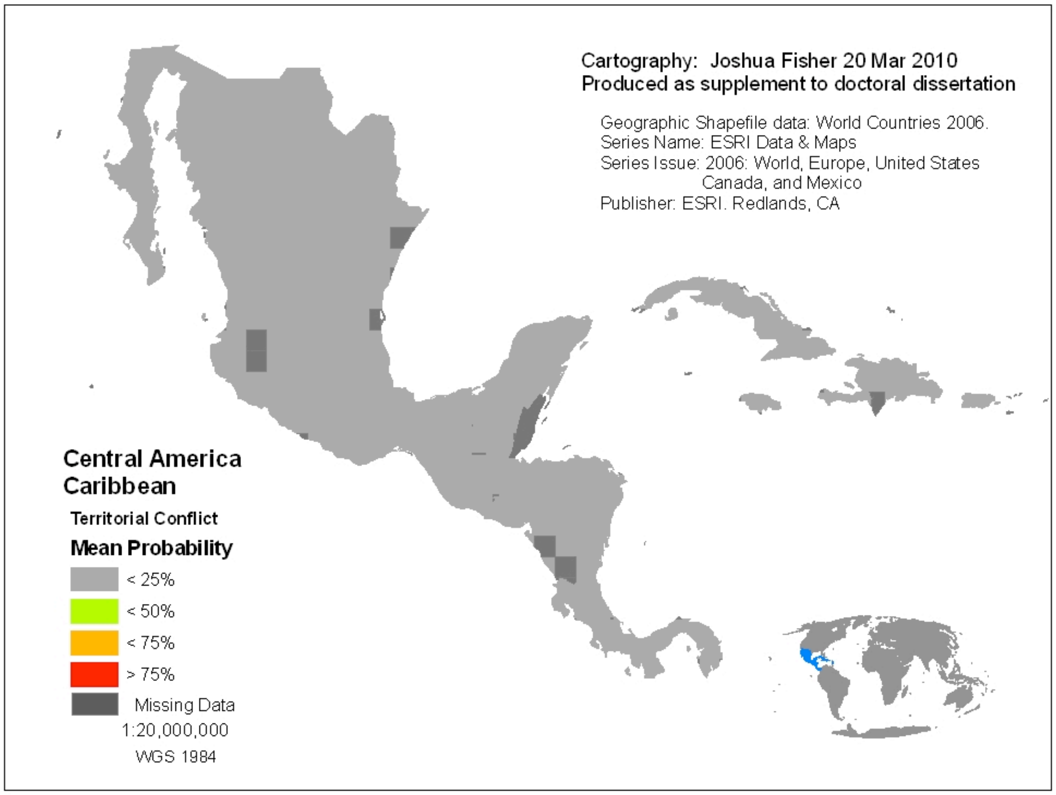

Figure 6.8 Map of mean predicted territorial conflict probability in Central America

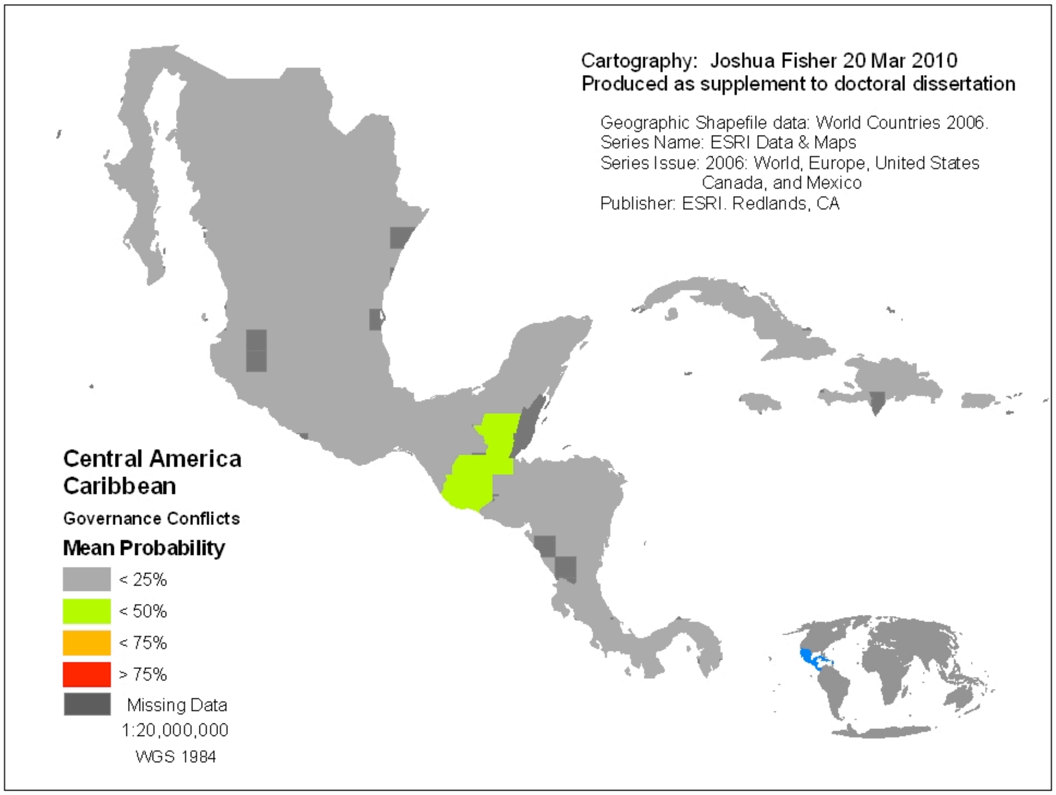

Figure 6.9 Map of mean predicted governance conflict probability in Central America

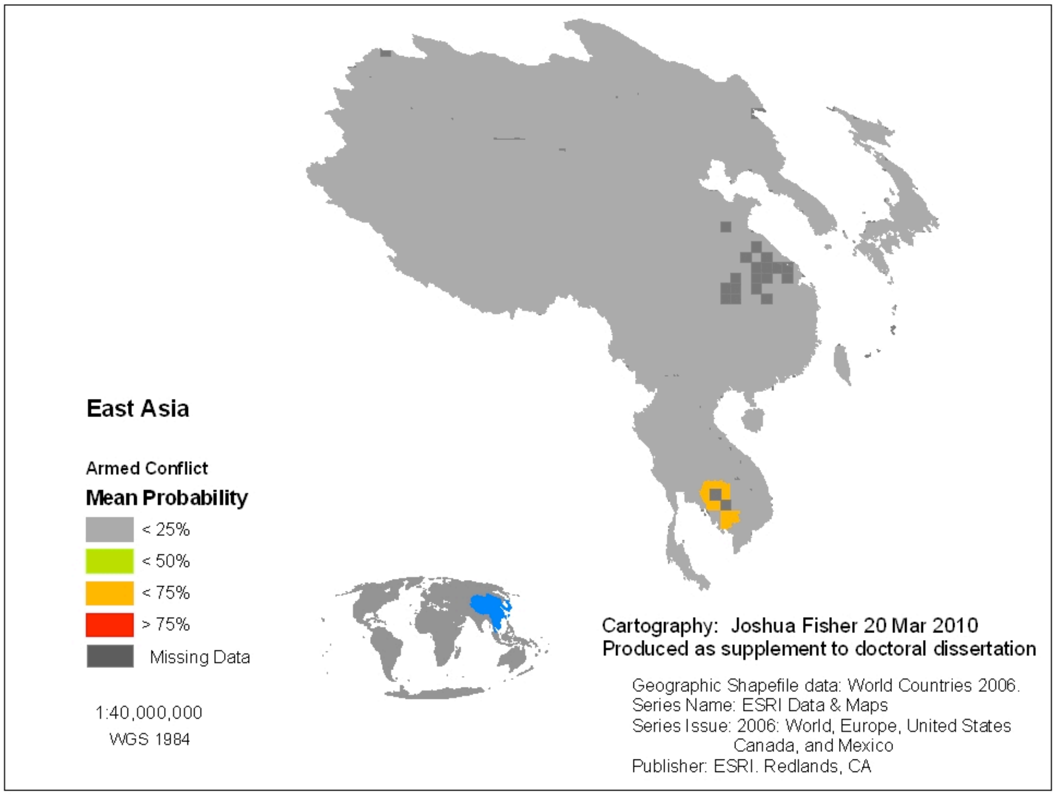

Figure 6.10 Map of mean predicted armed conflict probability in East Asia

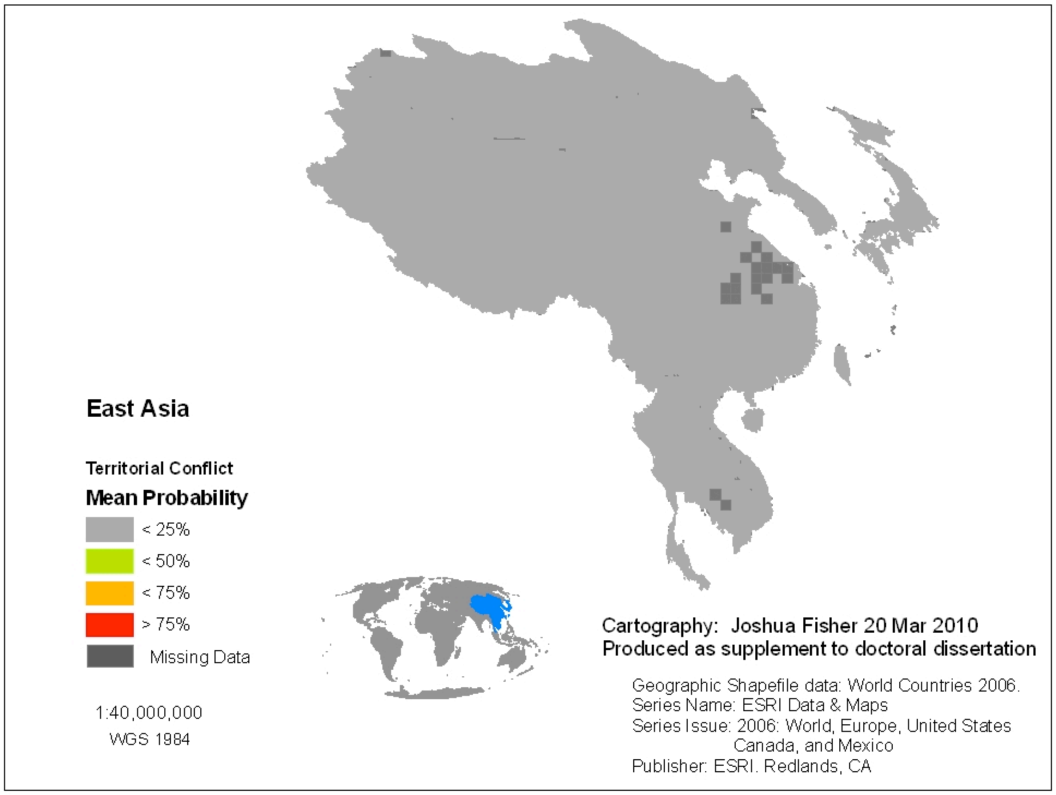

Figure 6.11 Map of mean predicted territorial conflict probability in East Asia

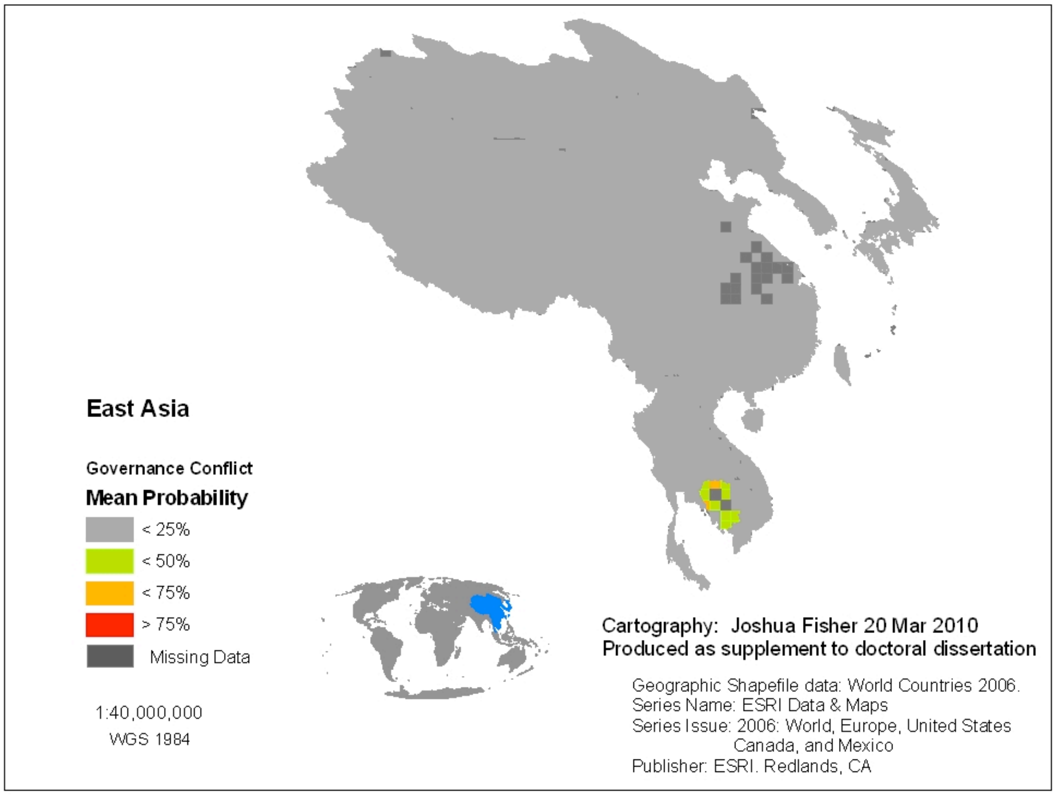

Figure 6.12 Map of mean predicted governance conflict probability in East Asia

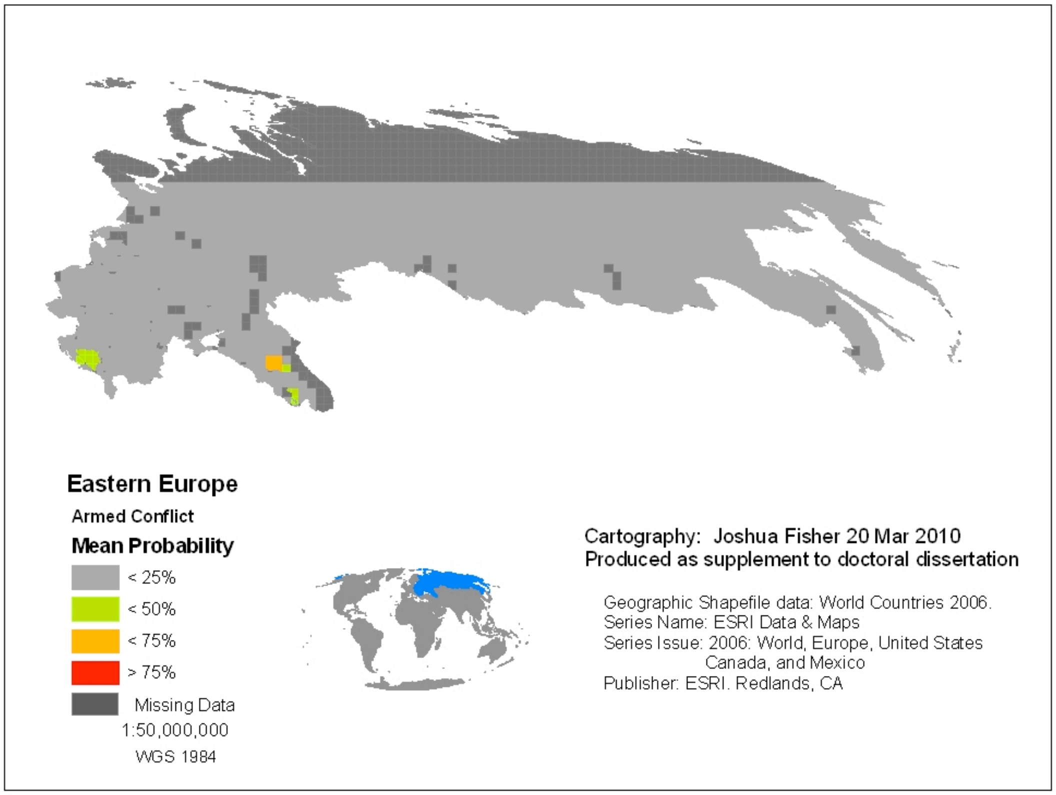

Figure 6.13 Map of mean predicted armed conflict probability in Eastern Europe

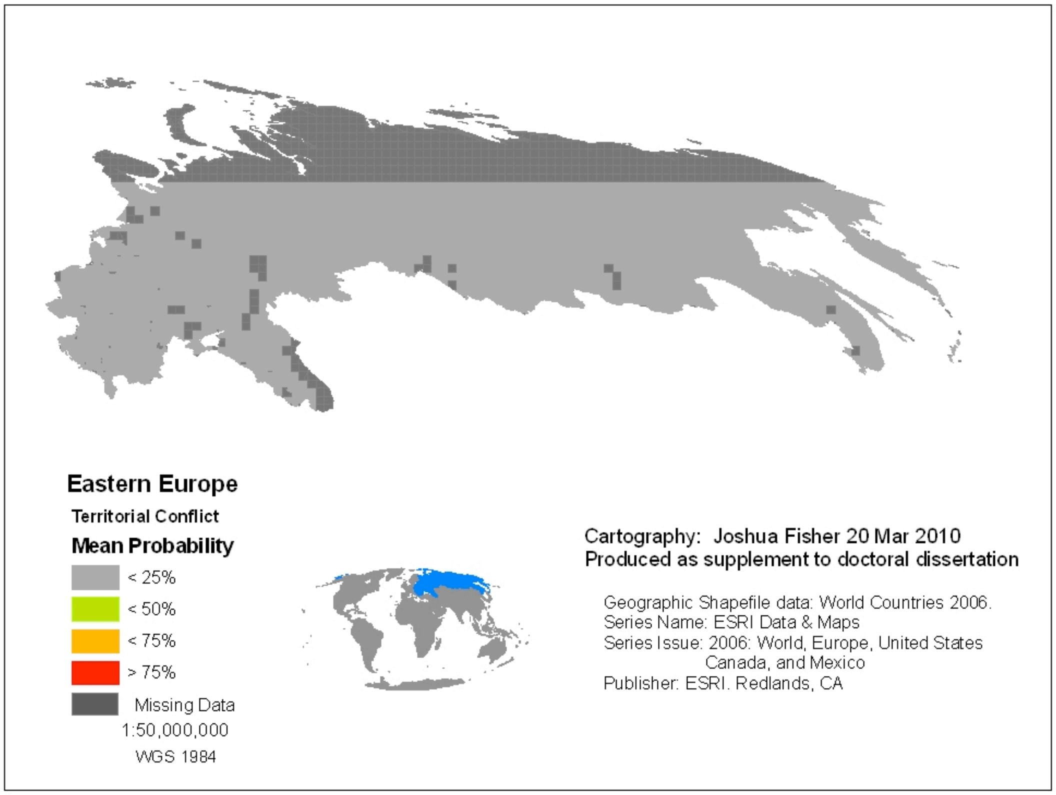

Figure 6.14 Map of mean predicted territorial conflict probability in Eastern Europe

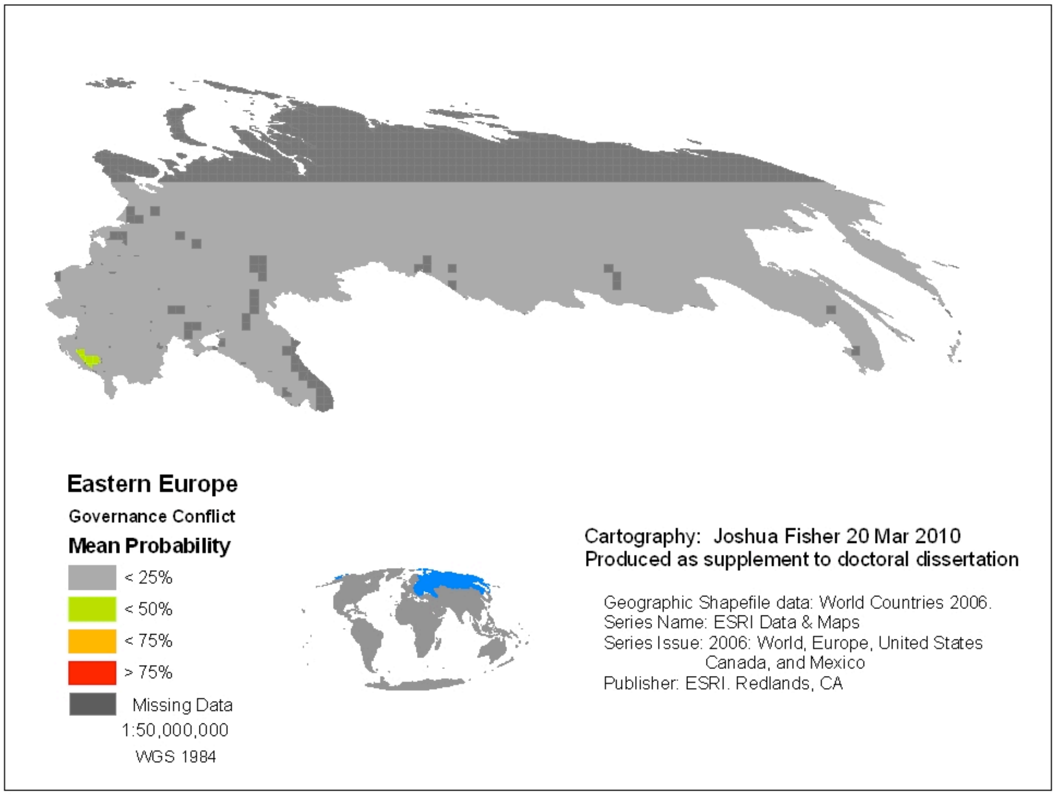

Figure 6.15 Map of mean predicted governance conflict probability in Eastern Europe

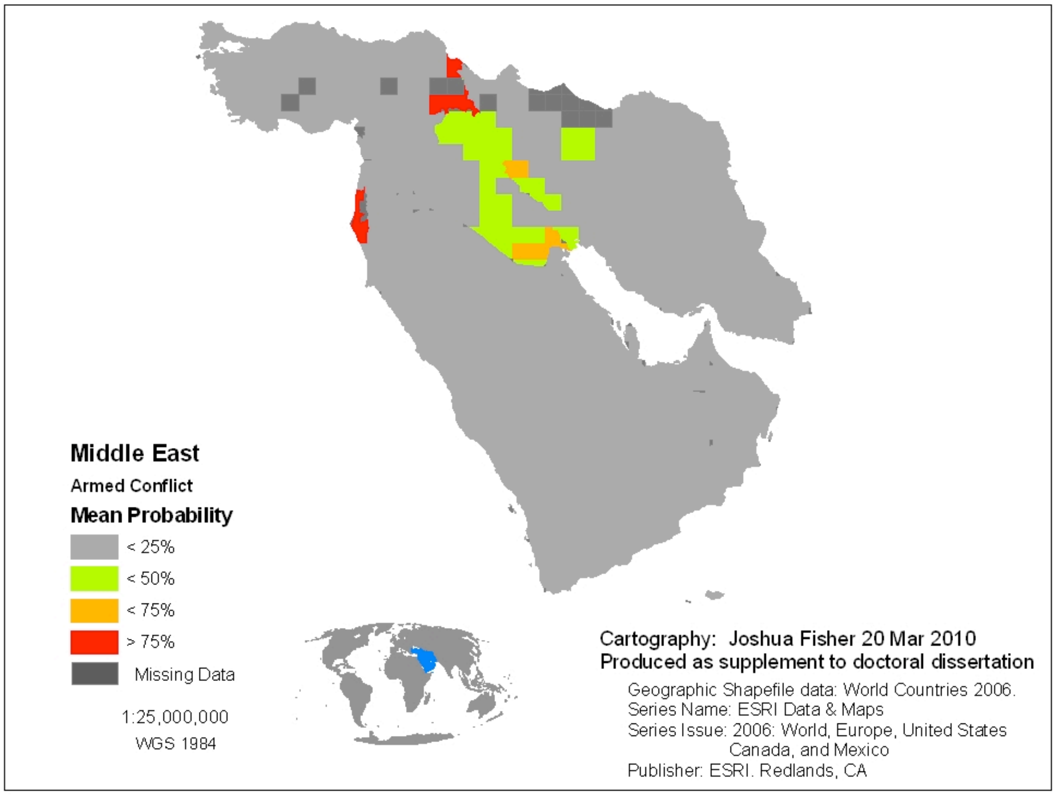

Figure 6.16 Map of mean predicted armed conflict probability in the Middle East

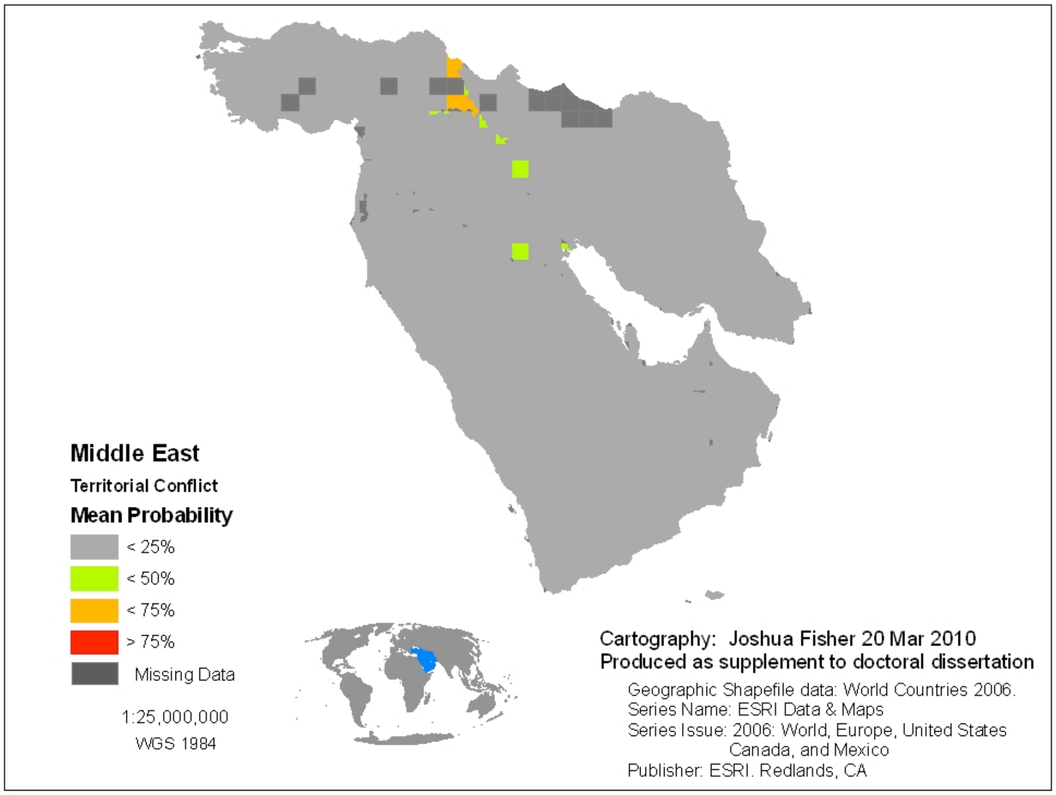

Figure 6.17 Map of mean predicted territorial conflict probability in the Middle East

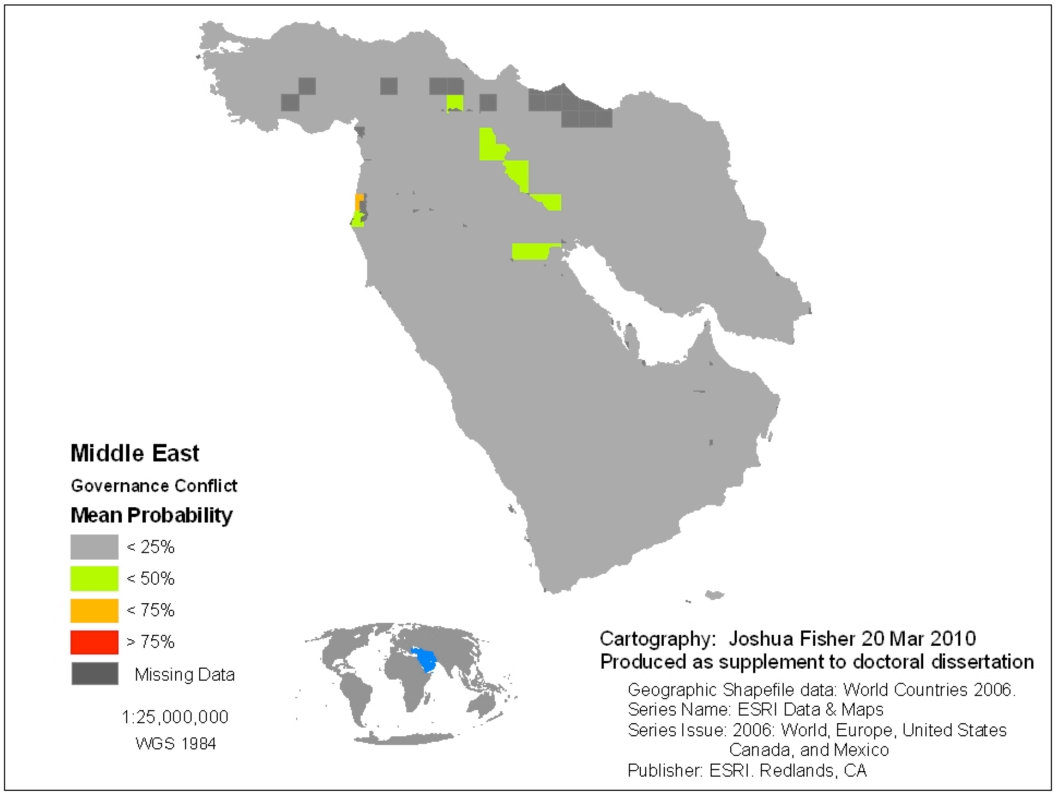

Figure 6.18 Map of mean predicted governance conflict probability in the Middle East

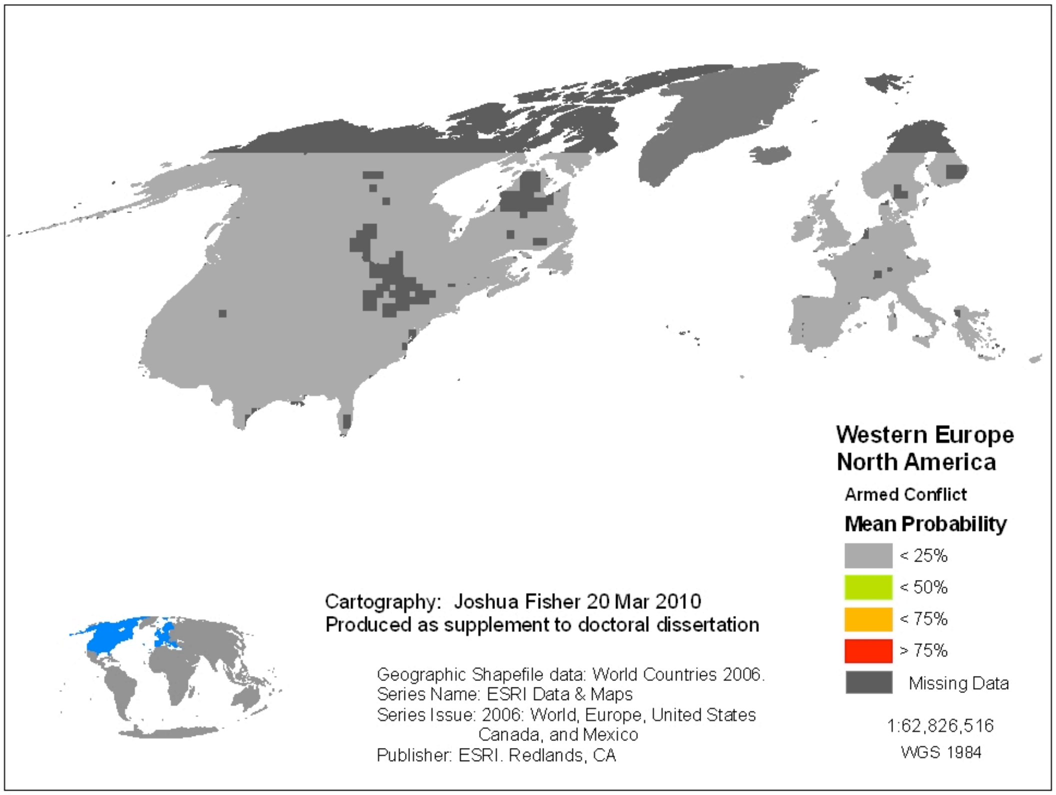

Figure 6.19 Map of mean predicted armed conflict probability in North America and Western Europe

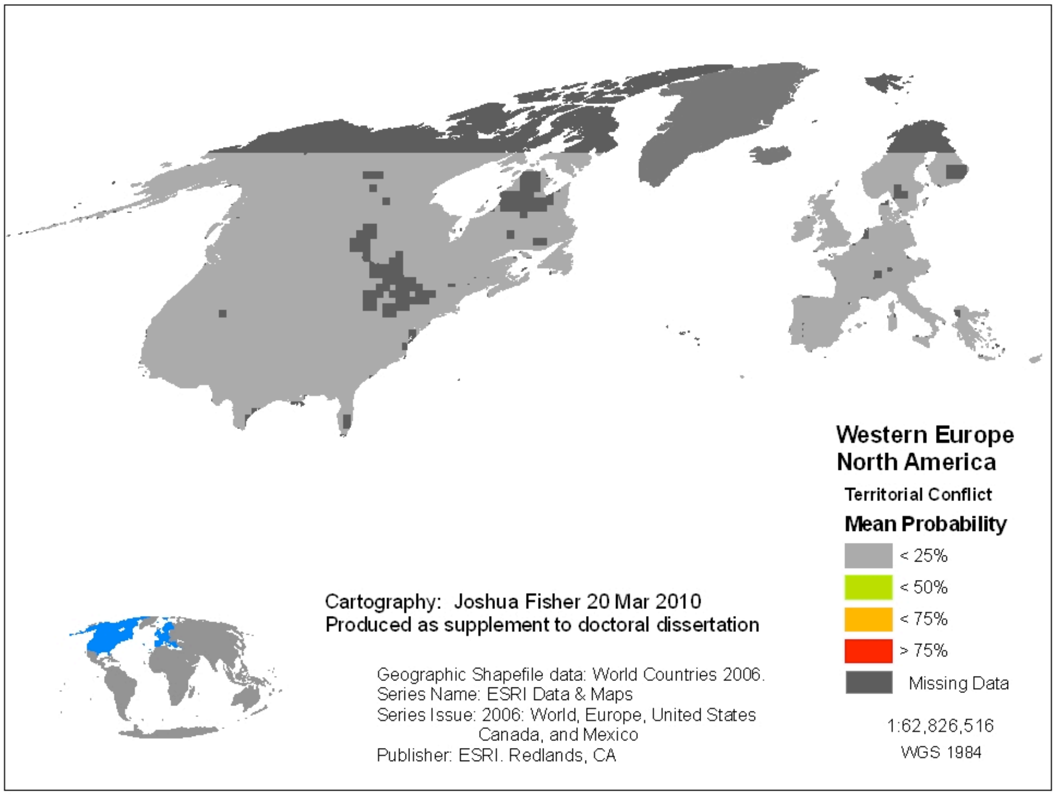

Figure 6.20 Map of mean predicted territorial conflict probability in North America and Western Europe

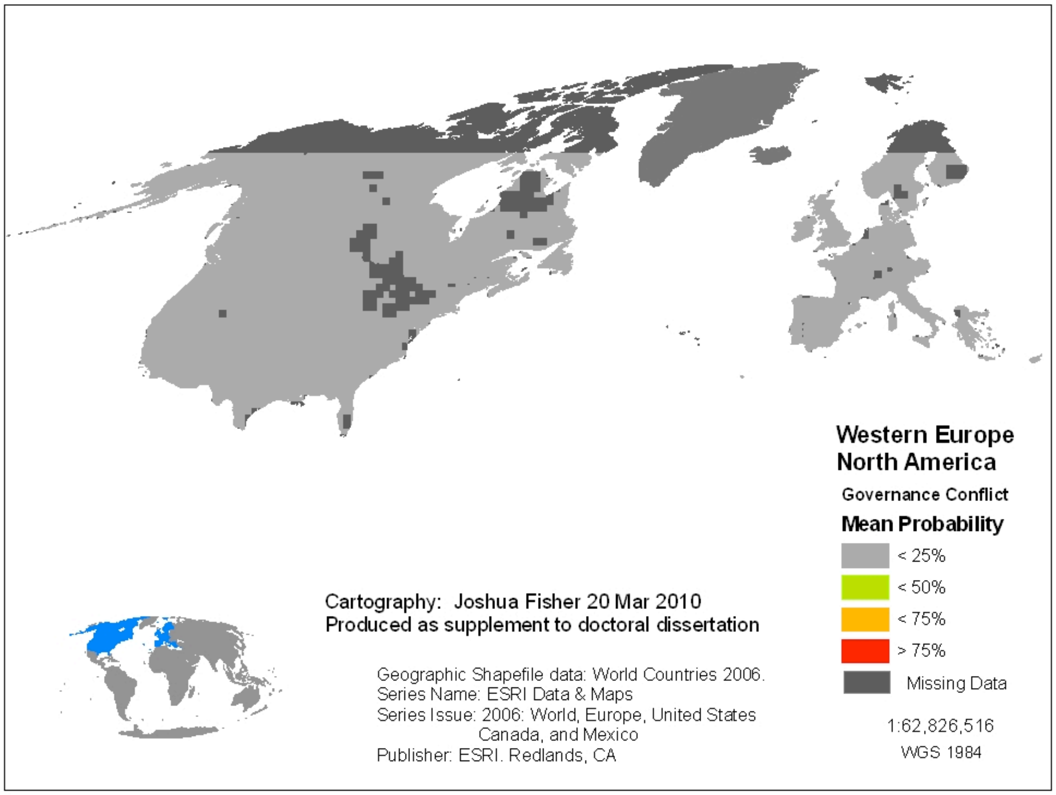

Figure 6.21 Map of mean predicted governance conflict probability in North America and Western Europe

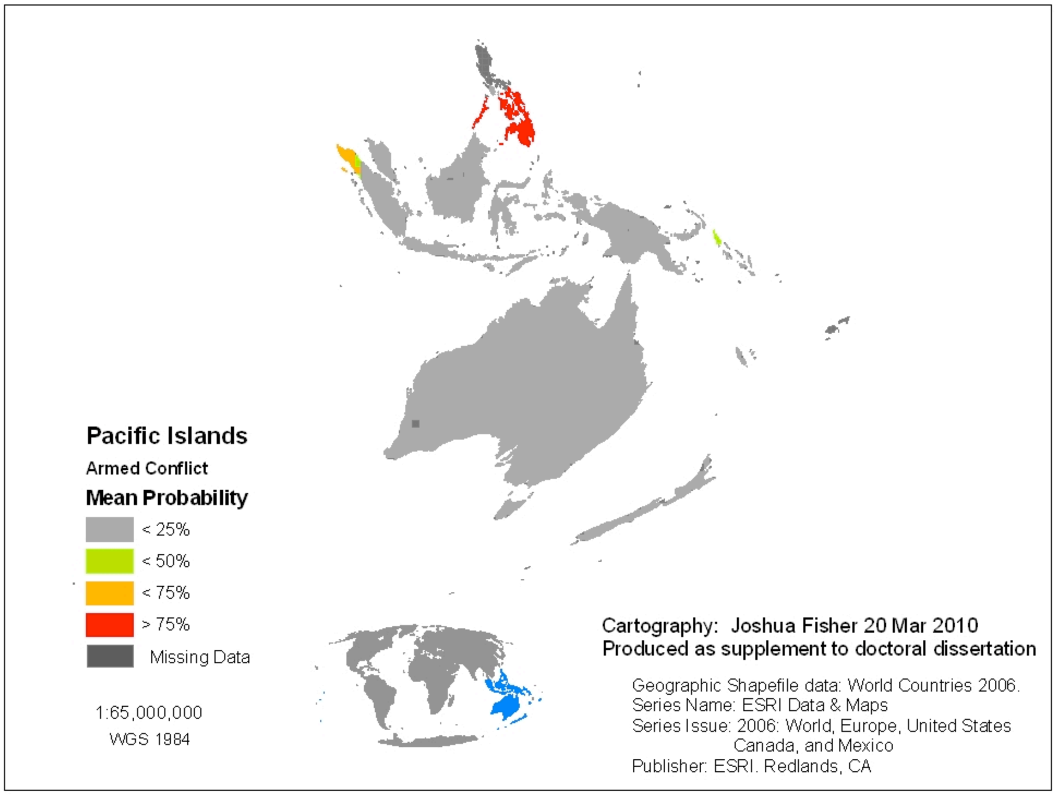

Figure 6.22 Map of mean predicted armed conflict probability in the Pacific

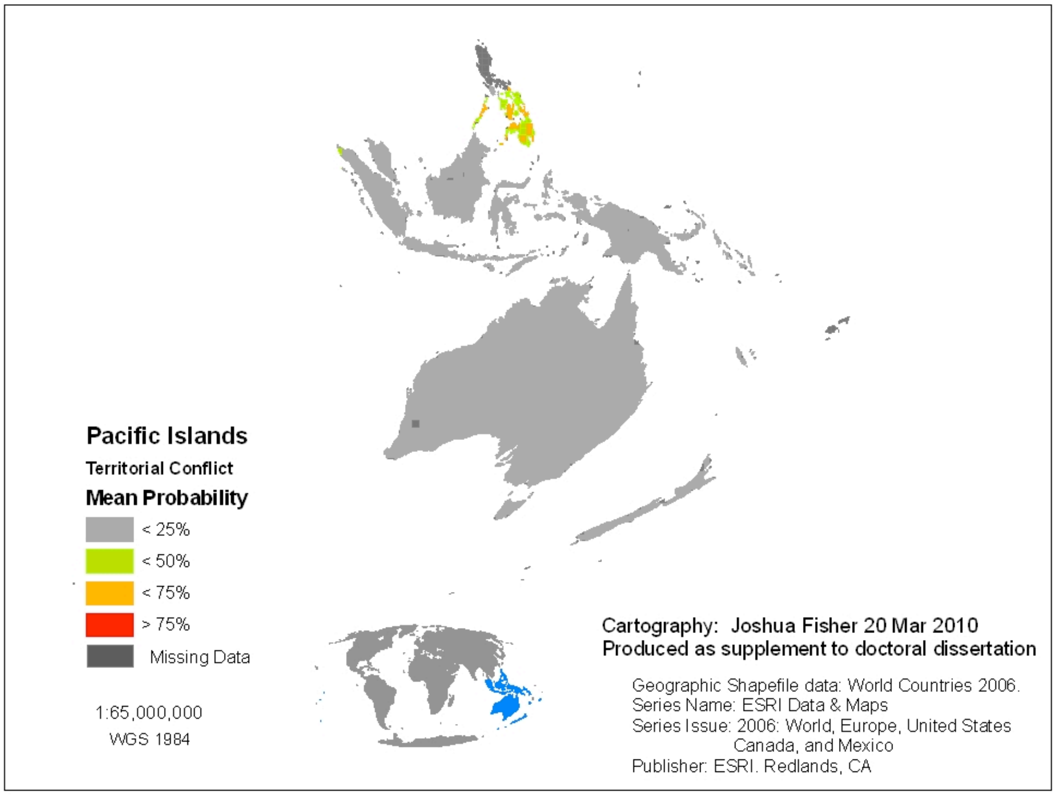

Figure 6.23 Map of mean predicted territorial conflict probability in the Pacific

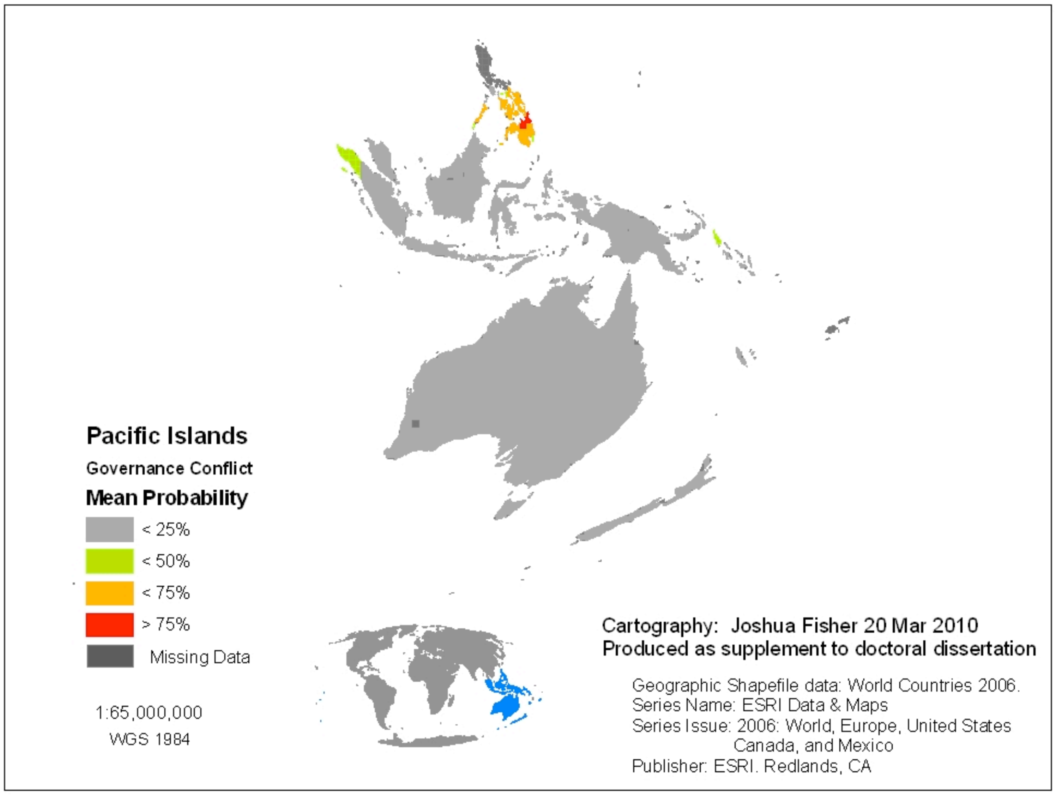

Figure 6.24 Map of mean predicted governance conflict probability in the Pacific

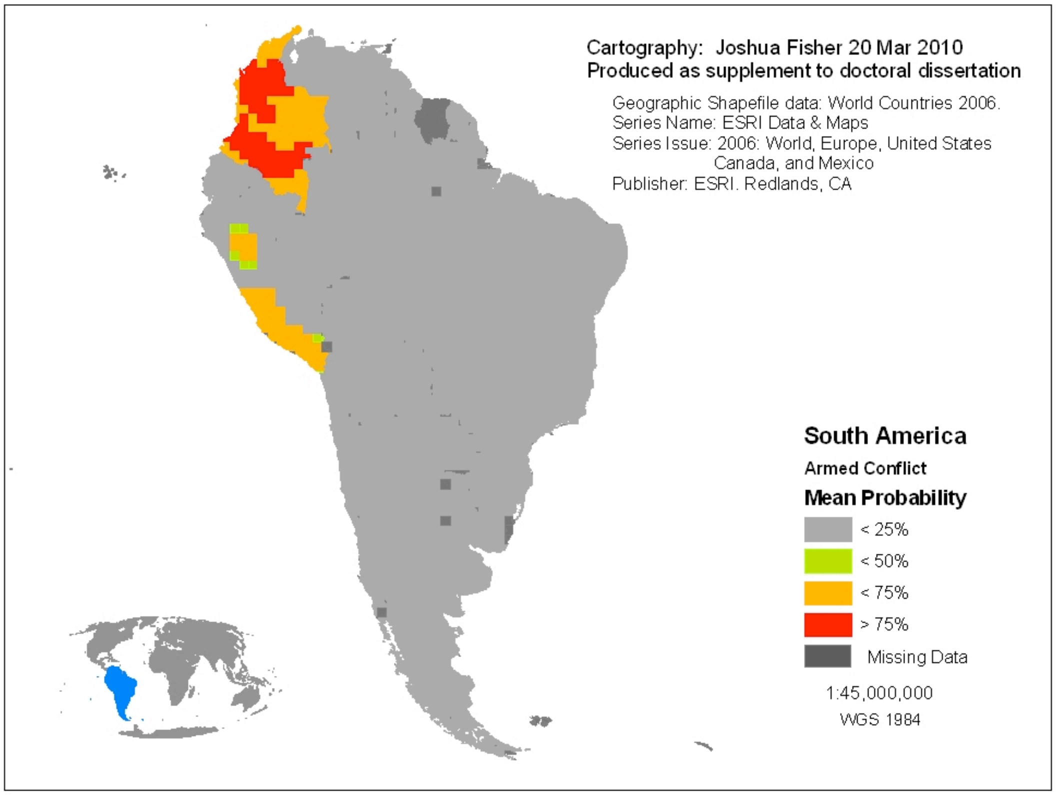

Figure 6.25 Map of mean predicted armed conflict probability in South America

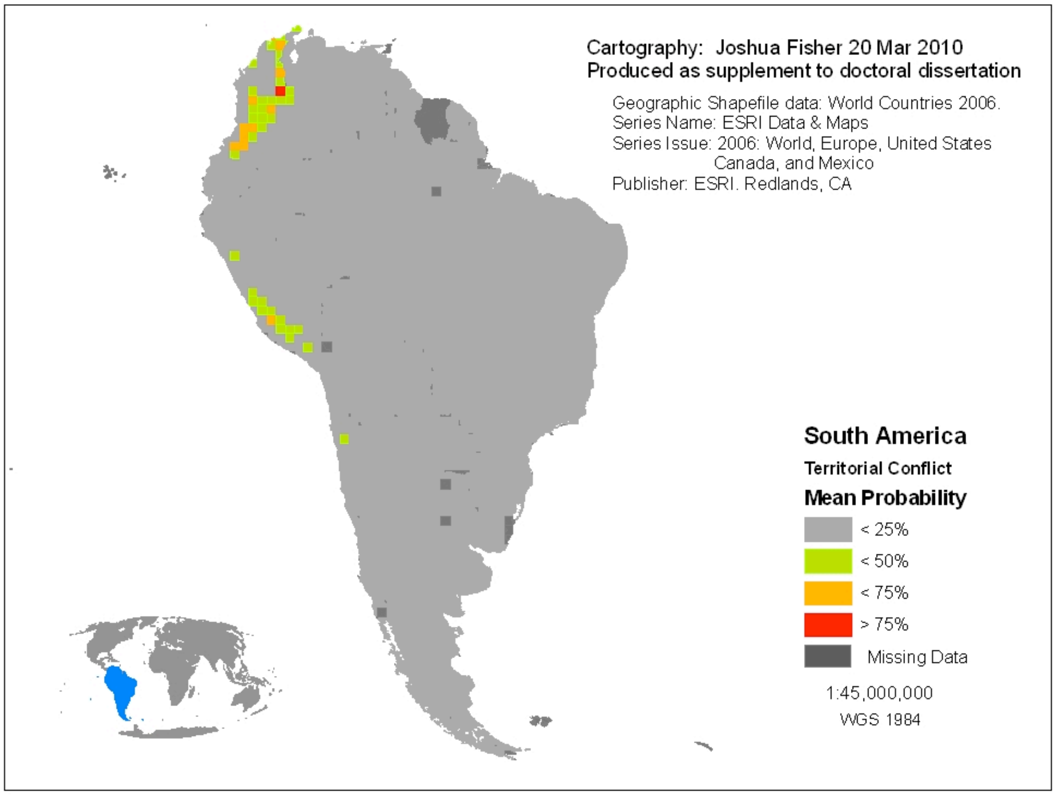

Figure 6.26 Map of mean predicted territorial conflict probability in South America

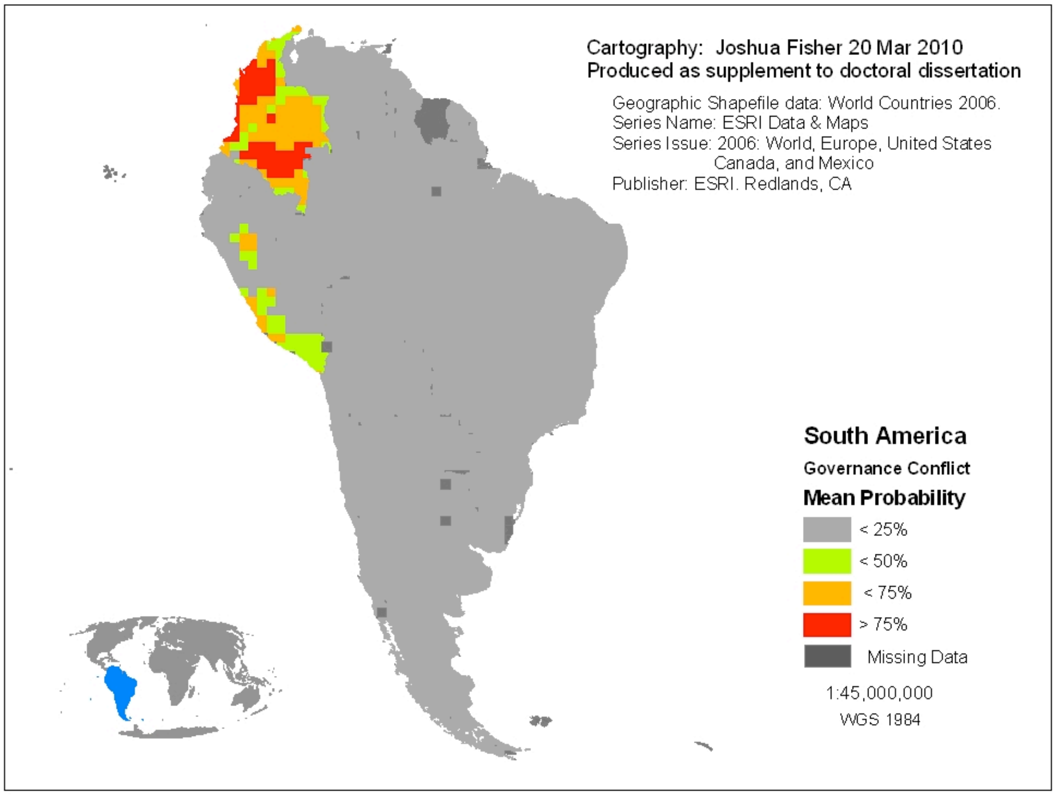

Figure 6.37 Map of mean predicted governance conflict probability in South America

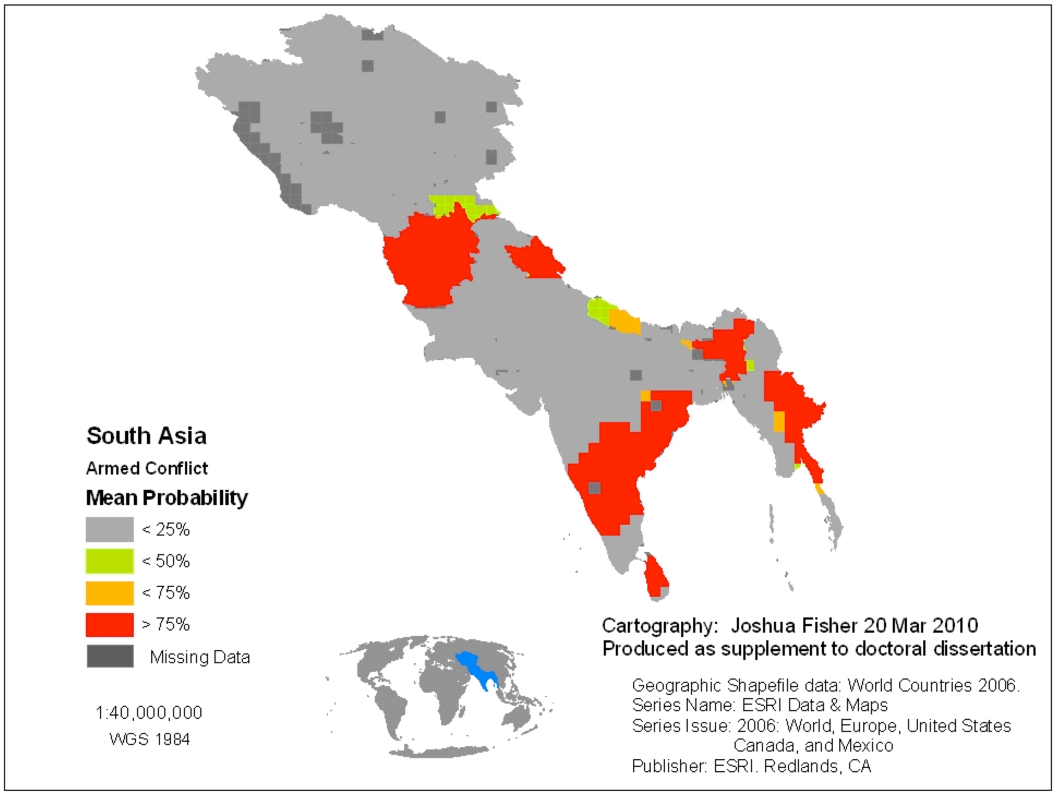

Figure 6.28 Map of mean predicted armed conflict probability in South Asia

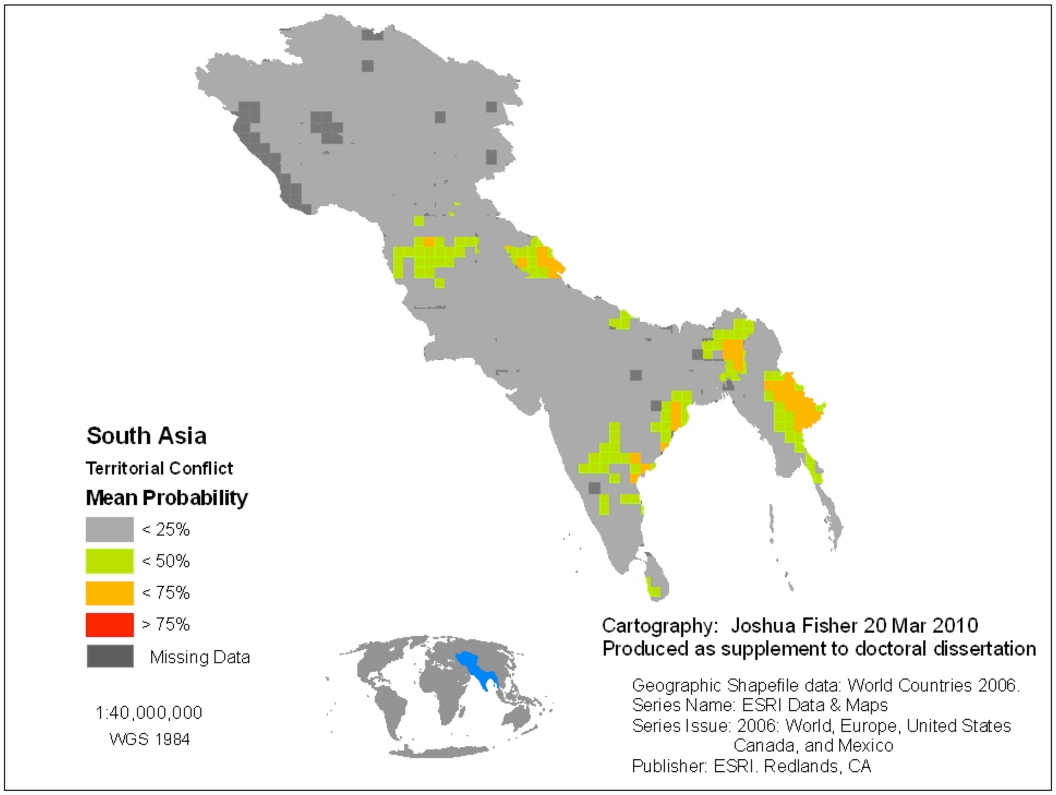

Figure 6.29 Map of mean predicted territorial conflict probability in South Asia

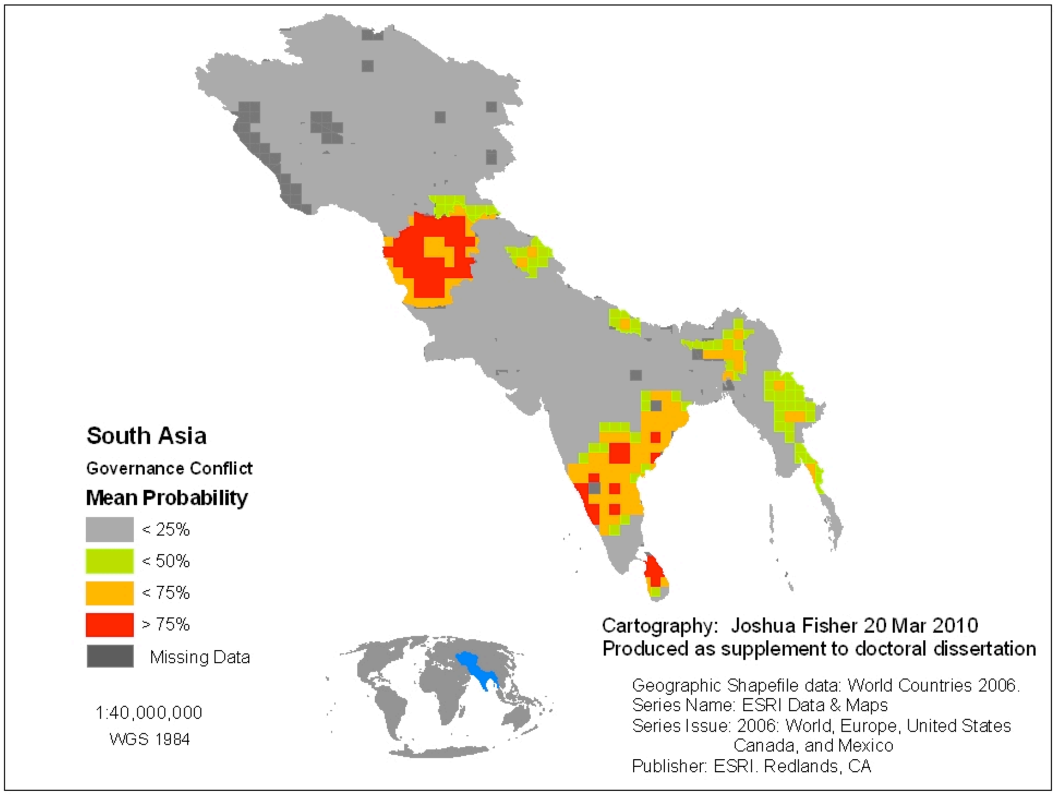

Figure 6.30 Map of mean predicted governance conflict probability in South Asia

Appendix

The following pages contain the metadata files that accompany each spatial dataset for the covariates. The authors and sources of the metadata for each dataset are included in the metadata for each file. Each metadata description listed below can be found verbatim in the metadata files that accompany each dataset download. The only exception is for the Gridded Population of the World GPWv.3 file. For this file I condensed the metadata for four downloads into one file.

The metadata for each dataset are presented in this appendix in the following order:

Version 2 DMSP-OLS Nighttime Lights Time Series

The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 65 degrees latitude. A number of constraints are used to select the highest quality data for entry into the composites:

* Data are from the center half of the 3000 km wide OLS swaths. Lights in the center half have better geolocation, are smaller, and have more consistent radiometry.

* Sunlit data are excluded based on the solar elevation angle.

* Glare is excluded based on solar elevation angle.

* Moonlit data are excluded based on a calculation of lunar illuminance.

* Observations with clouds are excluded based on clouds identified with the OLS thermal band data and NCEP surface temperature grids.

* Lighting features from the aurora have been excluded in the northern hemisphere on an orbit-by-orbit manner using visual inspection.

Each composite set is named with the satellite and the year (F121995 is from DMSP satellite number F12 for the year 1995). Three image types are available as geotiffs for download from the version 2 composites:

F1?YYYY_v2_cf_cvg.tif: Cloud-free coverages tally the total number of observations that went into each 30 arc second grid cell. This image can be used to identify areas with low numbers of observations where the quality is reduced. In some years there are areas with zero cloud- free observations in certain locations.

F1?YYYY_v2_avg_vis.tif: Raw avg_vis contains the average of the visible band digital number values with no further filtering. Data values range from 0-63. Areas with zero cloud-free observations are represented by the value 255.

F1?YYYY_v2_stable_lights_avg_vis.tif: The cleaned up avg_vis contains the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires have been discarded. Then the background noise was identified and replaced with values of zero. Data values range from 1-63. Areas with zero cloud-free observations are represented by the value 255.

Global composities are available for the satellite years below:

F101992
F101993
F101994
F121994
F121995
F121996
F121997
F121998
F121999
F141997
F141998
F141999
F142000
F142001
F142002
F152001
F152002
F152003

Each tar ball contains the raw average visible band, cleaned up average visible band, cloud free coverage data, and a readme file. The data files have been compressed with gzip.

For information on tar and gzip see our link located at: http://www.ngdc.noaa.gov/dmsp/tar_zip.html

----

Whenever using or distributing DMSP data or derived images, use the following credit:

Image and data processing by NOAA's National Geophysical Data Center.
DMSP data collected by US Air Force Weather Agency.

National Geophysical Data Center
E/GC 325 Broadway
Boulder, Colorado USA 80305-3328

Fax: 303-497-651

Gridded Population of the World Version 3 (GPWv3): Population Grids.

SUGGESTED CITATION
Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World Version 3 (GPWv3): Population Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw. (date of download).

ARCHIVE CONTENTS
The data contained in this archive are the final version of GPWv3, and should be used instead of the previous (alpha, beta) versions.

This archive contains population counts, both UN-adjusted and unadjusted, in ArcInfo GRID format. The raster data are at 2.5 arc-minutes resolution and contain the following data:

p90ag	population counts in 1990, adjusted to match UN totals
p05ag	population counts in 2005, adjusted to match UN totals
p00ag	population counts in 2000, adjusted to match UN totals
p95ag	population counts in 1995, adjusted to match UN totals

The ArcInfo GRID format is intended for use with software that can read this ESRI format, such as ArcView or ArcMap with the Spatial Analyst extension, or other non-ESRI software that supports read (e.g., access through GDAL libraries). For other software packages ASCII and BIL formats are available via http://sedac.ciesin.columbia.edu/gpw.

The data are stored in geographic coordinates of decimal degrees based on the World Geodetic System spheroid of 1984 (WGS84).

USE CONSTRAINTS:
 Users should acknowledge CIESIN and CIAT as the source used in the creation of any reports, publications, new data sets, derived products, or services resulting from the use of this data set. CIESIN and CIAT also request reprints of any publications and notification of any redistributing efforts.

DISTRIBUTION LIABILITY
CIESIN follows procedures designed to ensure that data disseminated by CIESIN are of reasonable quality. If, despite these procedures, users encounter apparent errors or misstatements in the data, they should contact SEDAC User Services at +1 845-365-8920 or via email at ciesin.info@ciesin.columbia.edu. Neither CIESIN nor NASA verifies or guarantees the accuracy, reliability, or completeness of any data provided. CIESIN provides this data without warranty of any kind whatsoever, either express or implied. CIESIN shall not be liable for incidental, consequential, or special damages arising out of the use of any data provided by CIESIN.

ACKNOWLEDGEMENTS
This work, including access to the data and technical assistance, is provided by CIESIN, with funding from the National Aeronautics and Space Administration under Contract NAS5-03117 for the Continued Operation of the Socioeconomic Data and Applications Center (SEDAC).

Title: Global map of aridity - 10 arc minutes
Date: 2009-01-30T11:27:00
Date type: creation
Edition first:
Presentation form: mapDigital

Abstract: Grid of estimated aridity with a spatial resolution of 10 arc minutes. This dataset represents average yearly precipitation divided by average yearly potential evapotranspiration, an aridity index defined by the United Nations Environmental Programme (UNEP).

The classification of the aridity index is:

Classification Aridity Index Global land area
Hyperarid AI < 0.05 7.5%
Arid 0.05 < AI < 0.20 12.1%
Semi-arid 0.20 < AI < 0.50 17.7%
Dry subhumid 0.50 < AI < 0.65 9.9%

Purpose: The aridity index dataset is useful to locate areas that suffer from a lack of available water. Lower values on the aridity index may adversely affect agricultural production and livestock health due to the dryness of the climate.

Status: completed
Descriptive keywords: precipitation , rainfall , aridity , climate , meteorology , available water (theme).
Descriptive keywords: World (place).
Spatial representation type: grid
Distance: [uom]
Distance: 10 arc minutes
Language: English
Character set: utf8
Topic category code: climatologyMeteorologyAtmosphere

Extent

Temporal Extent
Begin date 1961
End date 1990

Extent

Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information: The input data used to calculate this dataset are part of the "CRU CL 2.0 Global Climate Dataset" prepared by the Climate Research Unit of the University of East Anglia, UK, and distributed through the website: http://www.cru.uea.ac.uk/~timm/grid/CRU_CL_2_0.html).

Distribution info

OnLine resource Online link to the 'The CRU CL 2.0'- website
Data for download Global map of aridity - 10 arc minutes

Spatial representation info

Number of dimensions 4
Dimension name row

Dimension size 1080
Resolution
[uom] arc minutes,
Resolution 10
Dimension name column
Dimension size 2160
Resolution
[uom] arc minutes,
Resolution 10
Dimension name time
Dimension size 12
Resolution
[uom] month,
Resolution 1
Dimension name vertical
Dimension size
Resolution
[uom] mm/day,
Resolution 10
Cell geometry area
Transformation parameter availability yes
Reference system info

Metadata

File identifier 221072ae-2090-48a1-be6f-5a88f061431a
Language English
Character set utf8
Date stamp 2009-02-04T21:35:50
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Jippe Hoogeveen
Organisation name FAO-UN
Position name Water Resources Officer
Delivery point Viale delle Terme di Caracalla
City Rome
Administrative area
Postal code 00100
Country Italy
Electronic mail address jippe.hoogeveen@fao.org
Role Point of Contact

Title **Soil Drainage Class**
Date 2007-02-13
Date type Publication
Edition 3.6
Presentation form mapDigital

Abstract: The raster dataset of soil drainage has a spatial resolution of 5 * 5 arc minutes and is in geographic projection. Information with regard to soil drainage was obtained from the "Derived Soil Properties" of the FAO-UNESCO Soil Map of the World which contains raster information on soil properties.

Purpose This database will be used mainly for poverty and food insecurity mapping, particularly for analysing where the people live at global scales in relation to:

- Agroecological zones
- Marginal or productive lands
- Major foodcrop production systems, in particular those important to food security for the rural poor.

Status completed
Point of contact
Individual name Freddy Nachtergaele
Organisation name FAO - UN
Position name Senior Officer
Delivery point Viale delle Terme di Caracalla
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Country Italy
Electronic mail address freddy.nachtergaele@fao.org
Role pointOfContact
Maintenance and update frequency asNeeded

Descriptive keywords Soil Drainage Class , Drained , Moisture , Drainage , Terrastat , DSMW , Digital Soil Map of the World (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code Geoscientific Information
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information: The soil drainage class indicates the possibility to evacuate excess moisture form a soil based on the soil unit's classification name, the soil phase(s) indicated for the dominant unit and the slope class. It takes into account the full composition of each mapping unit as given in the mapping unit composition. Soil drainage is indicated by 7 classes from very excessive to very poorly drained.

The dataset is available for download (below) in both ASCII and ESRI GRID formats. A layer (.lyr) and legend (.avl) file and informative document are provided in the downloads.

Structure of the attributes

The first digit indicates the dominant class.
The second digit indicates the associated class.
The same classes are used in the first and second digit, except that a zero as second digit indicates that the class pointed by the first digit occurs in >80% of the pixel.

Soil Drainage Class

The classes are:
1: Not applicable
2: Excessively drained
3: Soils extremely drained
4: Well drained
5: Moderately well drained
6: Imperfectly drained
7: Poorly drained
8: Very poorly drained
97: Water bodies

Distribution info

OnLine resource Land and Water Digital Media Series (20)
Data for download Soil Drainage Class - ESRI GRID dataset
Data for download Soil Drainage Class - ASCII GRID dataset
Spatial representation info
Number of dimensions 3
Dimension name row
Dimension size 2160
Resolution
[uom] ,
Resolution
Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution
Dimension name vertical
Dimension size
Resolution
[uom] ,
Resolution
Cell geometry area
Transformation parameter availability yes
Reference system info
Code WGS 1984 - Geographic
Data quality info
Hierarchy level dataset

Metadata

File identifier 52d9b6b0-bb4c-11db-ac8b-000d939bc5d8
Language English
Character set utf8
Date stamp 2007-02-13T11:24:01

Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
Individual name Emelie Healy
Organisation name FAO - UN
Role author

Title **Thermal Climates**
Date 2007-02-16
Date type Publication
Edition 3.6
Presentation form mapDigital

Abstract: The raster dataset of thermal climates has a spatial resolution of 5 * 5 arc minutes and is in geographic projection. Information with regard to thermal climates was obtained from the "Derived Soil Properties" of the FAO-UNESCO Soil Map of the World which contains raster information on soil properties.

Purpose: This database will be used mainly for poverty and food insecurity mapping, particularly for analysing where the people live at global scales in relation to:

- Agroecological zones
- Marginal or productive lands
- Major foodcrop production systems, in particular those important to food security for the rural poor.

Status completed
Point of contact
Individual name Freddy Nachtergaele
Organisation name FAO - UN
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Delivery point Viale delle Terme di Caracalla
City Rome
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Country Italy
Electronic mail address freddy.nachtergaele@fao.org
Role pointOfContact
Maintenance and update frequency asNeeded
Descriptive keywords: Thermal Climates , Temperature , Agro Ecological Zones , Tropics, Subtropics, Temperate, Boreal, Polar and Arctic , Digital Soil Map of the World (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code Geoscientific Information
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information: The thermal climates were obtained through classifying monthly temperatures corrected to sea level. The thermal climates distinguished in global AEZ are the following: tropics, subtropics (2 subtypes), temperate (3subtypes), boreal (3 subtypes) and polar/arctic.

A layer (.lyr) and legend (.avl) file are provided in the data download.

Distribution info
OnLine resource Land and Water Digital Media Series (20)

Data for download Thermal Climates - ESRI GRID dataset
Spatial representation info
Number of dimensions 3
Dimension name row
Dimension size 2160
Resolution
[uom] ,
Resolution
Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution
Dimension name vertical
Dimension size
Resolution
[uom] ,
Resolution
Cell geometry area
Transformation parameter availability yes
Reference system info
Code WGS 1984 - Geographic
Data quality info
Hierarchy level dataset

Metadata

File identifier 0ba2a840-bdd3-11db-a0f6-000d939bc5d8
Language English
Character set utf8
Date stamp 2007-02-16T16:33:26
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
Individual name Emelie Healy
Organisation name FAO - UN
Role author

Title **Global land area with climate constraints (FGGD)**
Date 2007-08-23
Date type Publication
Edition 1.0
Presentation form mapDigital

Abstract The FGGD climate constraints map is a global raster datalayer with a resolution of 5 arc-minutes. Each pixel contains a class value for the degree to which climate constrains agricultural production potential in the pixel area. The data are from FAO and IIASA, 2000, Global agro-ecological zones, as reported in FAO and IIASA, 2007, Mapping biophysical factors that influence agricultural production and rural vulnerability, by H. von Velthuizen et al.

Purpose The FGGD Digital Atlas consists of more than 100 global database that allows to analyse food insecurity and poverty in relation to the environment.
Status completed

Point of contact
Organisation name FAO - GIS UNIT
Position name GIS Manager
Delivery point Viale delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address gis-manager@fao.org
Role pointOfContact
Maintenance and update frequency asNeeded
Descriptive keywords climate , climate constraints (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints copyright
Other constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code climatologyMeteorologyAtmosphere
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information This dataset is contained in Module 4 "Environmental conditions" of Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007).

Distribution info
Data for download Global land area with climate constraints - Grid format (572 MB)
Interactive Map Global land area with climate constraints
(OGC-WMS Server: http://geonetwork3.fao.org/ows/14132)
View in Google Earth Global land area with climate constraints View in Google Earth
OnLine resource Mapping biophysical factors that influence agricultural production and rural vulnerability
Spatial representation info

Number of dimensions 2
Dimension name row
Dimension size 2160
Resolution
[uom] ,
Resolution 0.08333333
Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution 0.08333333
Cell geometry area
Transformation parameter availability
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset

Metadata
File identifier a5c063f0-853d-11db-b9b2-000d939bc5d8
Language English
Character set utf8
Date stamp 2006-12-06T16:22:55
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
Individual name Mirella Salvatore
Organisation name FAO - GIS UNIT
Position name Consultant
Delivery point Via delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address mirella.salvatore@fao.org
Role Point of Contact

Title Occurrence of cropland (FGGD)
Date 2007-05-29
Date type Publication
Edition 1.0
Presentation form mapDigital

Abstract The FGGD land cover occurrence maps are global raster datalayers with a resolution of 5 arc-minutes. Each pixel in each map contains a value representing the percentage of the area belonging to the land cover type concerned. The method is described in FAO and IIASA, 2007, Mapping biophysical factors that influence agricultural production and rural vulnerability, by H. von Velthuizen et al.

Purpose The FGGD Digital Atlas consists of more than 100 global database that allows to analyse food insecurity and poverty in relation to the environment.
Status completed

Point of contact
Individual name
Organisation name FAO - GIS UNIT
Position name GIS Manager
Delivery point Viale delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address gis-manager@fao.org
Role pointOfContact
Maintenance and update frequency asNeeded
Descriptive keywords cropland , land use , food security , (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints copyright
Other constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code imageryBaseMapsEarthCover
Topic category code farming
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information This dataset is contained in Module 5 "Land use patterns and land cover" of Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007).

Distribution info
Data for download Occurrence of cropland - Grid format (2.24 MB)
Interactive Map Occurrence of cropland
(OGC-WMS Server: http://geonetwork3.fao.org/ows/14067)
View in Google Earth Occurrence of cropland View in Google Earth
Spatial representation info
Number of dimensions 2

Dimension name row
Dimension size 2160
Resolution
[uom] ,
Resolution 0.08333333
Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution 0.08333333
Dimension name vertical
Dimension size
Resolution
[uom] ,
Resolution
Cell geometry area
Transformation parameter availability
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset

Metadata

File identifier 6ce5f550-758d-11db-b9b2-000d939bc5d8
Language English
Character set utf8
Date stamp 2009-04-21T16:50:07
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
Individual name Mirella Salvatore
Organisation name FAO - GIS UNIT
Position name Consultant
Delivery point Via delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address mirella.salvatore@fao.org
Role Point of Contact

Title **Occurrence of pasture and browse (FGGD)**
Date 2007-05-29
Date type Publication
Edition 1.0
Presentation form mapDigital

Abstract The FGGD land cover occurrence maps are global raster datalayers with a resolution of 5 arc-minutes. Each pixel in each map contains a value representing the percentage of the area belonging to the land cover type concerned. The method is described in FAO and IIASA, 2007, Mapping biophysical factors that influence agricultural production and rural vulnerability, by H. von Velthuizen et al.

Purpose The FGGD Digital Atlas consists of more than 100 global database that allows to analyse food insecurity and poverty in relation to the environment.
Status completed

Point of contact
Individual name
Organisation name FAO - GIS UNIT
Position name GIS Manager
Delivery point Viale delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address gis-manager@fao.org
Role pointOfContact
Maintenance and update frequency asNeeded
Descriptive keywords pasture , grazing land , livestock (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints copyright
Other constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code imageryBaseMapsEarthCover
Topic category code farming

Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information This dataset is contained in Module 5 "Land use patterns and land cover" of Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007).

Distribution info
Data for download Occurrence of pasture and browse - Grid format (3.19 MB)
Interactive Map Occurrence of pasture and browse
(OGC-WMS Server: http://geonetwork3.fao.org/ows/14068)
View in Google Earth Occurrence of pasture and browse View in Google Earth
Spatial representation info

Number of dimensions 2
Dimension name row
Dimension size 2160
Resolution
[uom] ,
Resolution 0.08333333
Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution 0.08333333
Dimension name vertical
Dimension size
Resolution
[uom] ,
Resolution
Cell geometry area
Transformation parameter availability
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset

Metadata

File identifier 913e79a0-7591-11db-b9b2-000d939bc5d8
Language English
Character set utf8
Date stamp 2009-02-26T16:55:10
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
Individual name Mirella Salvatore
Organisation name FAO - GIS UNIT
Position name Consultant
Delivery point Via delle Terme di Caracalla, 1
City Rome
Postal code 00153
Country Italy
Electronic mail address mirella.salvatore@fao.org
Role Point of Contact

Title **Global Positive Trend of RUE-Adjusted NDVI (1981-2003)**
Date 2008-10-22T07:00:00
Date type Publication
Edition First edition
Presentation form mapDigital

Abstract Land improvement, or bright spots, is preliminarily identified by 1) a positive trend in sum NDVI for those areas where NDVI does not depend on rainfall and 2) for areas where NDVI is correlated with rainfall, a positive trend in rain-use efficiency. This is so-called positive RUE-adjusted NDVI. The positive RUE-adjusted NDVI is further adjusted by a positive trend in energy-use efficiency, that is so-called climate-adjusted NDVI.

Rain-use efficiency(RUE) is represented by the ratio of annual sum NDVI to annual precipitation, calculated from the VASClimO 1.1 data. The VASClimO 1.1 comprises the most complete monthly precipitation data for 1951-2000, compiled from long, quality-controlled station records, gridded at resolution of 0.5°, from 9 343 stations (Beck and others 2005). For 2001-2003, these were supplemented by the GPCC full data re-analysis product (Schneider and others 2008) to produce monthly rainfall values matching the GIMMS NDVI data.

Purpose Land improvement is as same important as degradation for a reference of sustainably land management. Bright spots are also identified in the study case where land is being used sustainably or is showing improved quality and productivity.
Status completed

Point of contact
Organisation name Food and Agriculture Organization of United Nations - HQs
Delivery point Viale delle Terme di Caracalla
City Rome
Postal code 00153
Country Italy
Role owner
Point of contact
Organisation name ISRIC - World Soil Information
Facsimile +31-(0)317-471700
Delivery point Duivendaal 9
City Wageningen
Administrative area Wageningen
Postal code 6701 AR
Country The Netherlands
Electronic mail address soil.isric@wur.nl
Role owner
Point of contact
Individual name
Organisation name UN FAO - HQs
Position name Director of Land and Water Division
Delivery point Viale delle Terme di Caracalla
City Rome
Administrative area
Postal code 00153
Country Italy
Electronic mail address NRL-Director@fao.org
Role pointOfContact
Descriptive keywords NDVI .

Descriptive keywords Land degradation .
Descriptive keywords Land improvement , Remote sensing , Rain-use efficiency , GLADA .
Descriptive keywords World (place).
Spatial representation type grid
Language English
Character set utf8
Topic category code environment

Extent
Temporal Extent
Begin date 1981-07-01T07:00:00
End date 2003-12-01T13:56:00
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information: Within the FAO program Land Degradation Assessment in Drylands (LADA), the present "Global Assessment of Land Degradation and Improvement" uses remote sensing to identify areas where significant biological change is happening, both hot spots of land degradation and bright spots of land improvement. In the next phase of the program, hot spots and bright spots will be further characterised in the field by national teams.

Distribution info
OnLine resource ISRIC - World Soil Information website
OnLine resource LADA - Land Degradation Assessment in Drylands - FAO 2008 Web site
Data for download Global positive trend of RUE-adjusted NDVI 1981-2003
Data for download GLADA Report 5 - Global Assessment of Land Degradation and Improvement- PDF format
Interactive Map Global Positive Trend of RUE-Adjusted NDVI (1981-2003) (OGC-WMS Server: http://geonetwork3.fao.org/ows/37061)
View in Google Earth Global Positive Trend of RUE-Adjusted NDVI (1981-2003) View in Google Earth
Spatial representation info
Number of dimensions 2
Dimension name row
Dimension size 1780
Resolution
[uom] Decimal degrees
Resolution 0.072727
Dimension name column
Dimension size 4943
Resolution
[uom] Decimal degrees
Resolution 0.072727
Cell geometry area
Transformation parameter availability yes
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset

Statement
Description Last Updated
DateTime 2008-10-30T15:34:00

Metadata

File identifier 0b06eb36-5a9a-4754-9e6c-7729f5d83afa
Language English
Character set utf8
Date stamp 2010-02-12T17:24:42
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Zhanguo Bai
Role author

Title Global Negative Trend in RUE-adjusted NDVI (1981-2003)
Date 2008-10-22T07:00:00
Date type Publication
Edition First edition
Presentation form mapDigital

Abstract: Land degradation means a loss of net primary productivity but a decrease in productivity is not necessarily land degradation. To distinguish between declining productivity caused by land degradation and decline due to other factors, it is necessary to eliminate false alarms arising from climatic variability and changes in land use and management. Rainfall variability has been taken into account by using both rain-use efficiency(RUE) and RESTREND. RUE is considered by, first, identifying pixels where there is a positive relationship between productivity and rainfall. For those areas where productivity depends on rainfall and where productivity declined but RUE increased, we attribute the decline of productivity to drought. Those areas are masked (urban areas are also masked). NDVI trends are presented for the remaining parts of the country as RUE-adjusted NDVI, or a proxy of land degradation.

Areas of land degradation are identified by a sequence of analyses of remotely sensed data:
1. Simple NDVI indicators: NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation and coefficient of variation. Their trends are analysed over the 23-year period of the GIMMS data.
2. The annual sum NDVI, representing the aggregate of greenness over the year, period is chosen as the standard proxy for annual biomass productivity. NDVI is translated to net primary productivity (NPP) by correlation with MODIS data.
3. To distinguish between declining productivity caused by land degradation and decline owing to rainfall variability, the following procedure was adopted:
a. Identify the areas where there is a positive relationship between productivity and rainfall, i.e. where rainfall determines NPP;
b. For those areas where rainfall determines productivity, RUE is considered: where productivity declined but RUE increased, declining productivity is attributed to declining rainfall and these areas are masked;
c. For the remaining areas with a positive relationship between productivity and rainfall but declining RUE, and also for areas where there is a negative relationship between NDVI and rainfall, i.e. humid and irrigated areas where rainfall does not determine NPP, NDVI trend was calculated as RUE-adjusted NDVI;
d. Land degradation is indicated by a negative trend in RUE-adjusted NDVI and may be quantified as RUE-adjusted NPP.
4. Residual trends of NDVI (RESTREND).
5. Energy-use efficiency - ratio of annual sum NDVI to accumulated temperature, combined with RUE-adjusted NPP to arrive at climate-adjusted NPP.
6. Calculation of loss of NPP in degrading areas.
7. Comparison of climate-adjusted NPP with land cover and land use, aridity, soil and terrain, rural population density and indices of poverty.

Purpose: We have defined land degradation as a long-term loss of ecosystem function and we use net primary productivity (NPP) as an indicator. Land degradation here is an interpretation of GIMMS time series NDVI data, i.e. a measure of greenness, which is taken as a proxy for NPP. The proxy is several steps removed from recognisable symptoms of land degradation as it is commonly understood - such as soil erosion, salinity or nutrient depletion. Greenness is determined by several factors and, to interpret it in terms of land degradation and improvement, these other factors must be accounted for â?? in particular variability of rainfall and temperature and changes in land use and management, rain-use efficiency (RUE, NPP per unit of rainfall) accounts for rainfall variability and, to some extent, local soil and land characteristics. We assume that, where NPP is limited by rainfall, a declining trend in RUE indicates land degradation. Where rainfall is not limiting, NPP is the best indicator available. Taken together, the two indicators may provide a more robust assessment than either used alone.
Status completed

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Role pointOfContact
Descriptive keywords NDVI .
Descriptive keywords Land degradation .
Descriptive keywords Land improvement , Remote sensing , Rain-use efficiency , GLADA .
Descriptive keywords World (place).
Spatial representation type grid
Language English
Character set utf8
Topic category code environment

Extent
Temporal Extent
Begin date 1981-07-01T07:00:00
End date 2003-12-01T13:56:00
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information: Within the FAO program Land Degradation Assessment in Drylands (LADA), the present "Global Assessment of Land Degradation and Improvement" uses remote sensing to identify areas where significant biological change is happening, both hot spots of land degradation and bright spots of land improvement. In the next phase of the program, hot spots and bright spots will be further characterised in the field by national teams.

Distribution info

OnLine resource ISRIC - World Soil Information website
OnLine resource LADA - Land Degradation Assessment in Drylands - FAO 2008 Web site
Data for download Global negative trend in RUE-adjusted NDVI 1981-2003
Data for download GLADA Report 5 - Global Assessment of Land Degradation and Improvement- PDF format
Spatial representation info
Number of dimensions 2
Dimension name row
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Resolution
[uom] Decimal degrees
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Cell geometry area
Transformation parameter availability yes
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset
Statement
Description Last Updated
DateTime 2008-10-22T10:00:00

Metadata

File identifier 0fe8ff82-b09f-41d8-9fbe-2d54e4ccec73
Language English
Character set utf8
Date stamp 2010-02-10T13:00:44
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Zhanguo Bai
Role author

Title **Global Positive Trend of Climate-Adjusted NDVI (1981-2003)**
Date 2008-10-22T07:00:00
Date type Publication
Edition First edition
Presentation form mapDigital

Abstract Land improvement, or bright spots, is identified by combination of: 1) a positive trend in sum NDVI for those areas where NDVI does not depend on rainfall; 2) for areas where NDVI is correlated with rainfall, a positive trend in rain-use efficiency; and 3) a positive trend in energy-use efficiency, i.e., climate-adjusted NDVI.

Energy-use efficiency(EUE) is represented by the ratio of annual sum NDVI to annual accumulated temperature (day degrees above 0oC), calculated from CRU 2.1 monthly data. CRU TS 2.1 comprises monthly values of station-observed meteorological data from the beginning of the 20th century, gridded at 0.5 degree resolution (Mitchell and Jones 2005). Monthly temperature values since January 1981 are used to calculate energy-use efficiency.

Purpose: Land improvement, or a successful story of land management, is as same important as degradation for a reference of sustainably land management. Bright spots are also identified in the study case where land is being used sustainably or is showing improved quality and productivity.
Status completed

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Role pointOfContact
Descriptive keywords NDVI .
Descriptive keywords Land degradation .
Descriptive keywords Land improvement , Remote sensing , Rain-use efficiency , GLADA .
Descriptive keywords World (place).

Spatial representation type grid
Language English
Character set utf8
Topic category code environment

Extent
Temporal Extent
Begin date 1981-07-01T07:00:00
End date 2003-12-01T13:56:00
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information: Within the FAO program Land Degradation Assessment in Drylands (LADA), the present "Global Assessment of Land Degradation and Improvement" uses remote sensing to identify areas where significant biological change is happening, both hot spots of land degradation and bright spots of land improvement. In the next phase of the program, hot spots and bright spots will be further characterised in the field by national teams.

Distribution info
OnLine resource ISRIC - World Soil Information website
OnLine resource LADA - Land Degradation Assessment in Drylands - FAO 2008 Web site
Data for download Global trend of positive climate-adjusted NDVI 1981-2003 - IMG format
Data for download GLADA Report 5 - Global Assessment of Land Degradation and Improvement - PDF format
Interactive Map Global Positive Trend of Climate-Adjusted NDVI (1981-2003)
(OGC-WMS Server: http://geonetwork3.fao.org/ows/37057)
View in Google Earth Global Positive Trend of Climate-Adjusted NDVI (1981-2003) View in Google Earth
Spatial representation info
Number of dimensions 2
Dimension name row
Dimension size 1870
Resolution
[uom] Decimal degrees
Resolution 0.072727
Dimension name column
Dimension size 4943
Resolution
[uom] Decimal degrees
Resolution 0.072727
Cell geometry area
Transformation parameter availability yes
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset
Statement
Description Last Updated
DateTime 2008-10-30T15:34:00

Metadata

File identifier 36b1197c-4e8b-428d-a4ac-015753bfd1ed
Language English
Character set utf8
Date stamp 2010-02-10T16:07:35
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Zhanguo Bai
Role author

Title **Global Change In Net Primary Productivity (1981-2003)**
Date 2008-10-22T07:00:00
Date type Publication
Edition First edition
Presentation form mapDigital

Abstract Land degradation is defined as a long-term decline in ecosystem function and measured in terms of net primary productivity(NPP). Long-term NPP measurement is not available; the remotely-sensed normalized difference vegetation index (NDVI) is used as a proxy; its deviation from the norm may serve as an indicator of land degradation and improvement if other factors that may be responsible (climate, soil, terrain and land use) are accounted for. NDVI is a ratio measuring of photosynthetically active green biomass. The higher the NDVI, the more living green biomass can be found. There is a high correlation between NDVI and NPP; the GIMMS NDVI time series has been translated to NPP using MODIS NPP data (Justice and others 2002, Running and others 2004) for the overlapping period 2000-2003, i.e., NPP was estimated by correlation with MODIS 8-day NPP values for the overlapping years of the GIMMS and MODIS datasets (2000-2003), re-sampling the annual mean MODIS NPP at 1km resolution to 8km resolution using nearest-neighbour assignment.

NDVI from July 1981 to December 2003 are produced by the Global Inventory Modelling and Mapping Studies (GIMMS) group from measurements made by the AVHRR radiometer on board US National Oceanic and Atmospheric Administration satellites. The fortnightly images at 8km-spatial resolution are corrected for calibration, view geometry, volcanic aerosols, and other effects not related to vegetation cover (Tucker and others 2004). These data are compatible with those from other sensors such as MODIS, SPOT Vegetation, and Landsat ETM+ (Tucker and others 2005, Brown and others 2006).

Purpose: The translation of NDVI into NPP can provide a measure of land degradation and improvement open to economic analysis.
Status completed

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Descriptive keywords NDVI .
Descriptive keywords Land degradation .
Descriptive keywords Land improvement , Remote sensing , Rain-use efficiency , GLADA .
Descriptive keywords World (place).
Spatial representation type grid
Language English
Character set utf8
Topic category code environment

Extent
Temporal Extent
Begin date 1981-07-01T07:00:00
End date 2003-12-01T13:56:00
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information: Within the FAO program Land Degradation Assessment in Drylands (LADA), the present "Global Assessment of Land Degradation and Improvement" uses remote sensing to identify areas where significant biological change is happening, both hot spots of land degradation and bright spots of land improvement. In the next phase of the program, hot spots and bright spots will be further characterised in the field by national teams.

Distribution info
OnLine resource ISRIC - World Soil Information website
OnLine resource LADA - Land Degradation Assessment in Drylands - FAO 2008 Web site
Data for download Global change in net primary productivity 1981-2003 - IMG format
Data for download GLADA Report 5 - Global Assessment of Land Degradation and Improvement â?? PDF format
Interactive Map Global Change In Net Primary Productivity (1981-2003)
(OGC-WMS Server: http://geonetwork3.fao.org/ows/37049)
View in Google Earth Global Change In Net Primary Productivity (1981-2003) View in Google Earth
Spatial representation info
Number of dimensions 2
Dimension name row
Dimension size 1840
Resolution
[uom] Decimal degrees
Resolution 0.072727
Dimension name column
Dimension size 4424
Resolution
[uom] Decimal degrees
Resolution 0.072727
Cell geometry area
Transformation parameter availability yes

Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset
Statement
Description Last Updated
DateTime 2008-10-30T15:34:00

Metadata

File identifier f362b407-7f38-43d3-b69f-8a0ed92fe7fe
Language English
Character set utf8
Date stamp 2010-02-08T16:27:12
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Zhanguo Bai
Role author

Title **Global Change in Rain-Use Efficiency 1981-2003**
Date 2008-10-22T07:00:00
Date type Publication
Edition First edition
Presentation form mapDigital
Abstract Rain-use efficiency (RUE) is considered to make allowance for the effect of fluctuations in rainfall on biomass productivity. RUE may fluctuate dramatically in the short term - often, there is a sharp decline in RUE in a wet year and we assume that the vegetation, whether cultivated or semi-natural, cannot make immediate use of the additional rain. However, where rainfall is the main limiting factor on biomass productivity, we judge that the long-term trend of RUE is a good indicator of land degradation or improvement (Houerou 1984, 1988, 1989; Snyman 1998; Illius and O'Connor 1999; O'Connor and others 2001). RUE also accommodates the effects of local variations in slope, soil and vegetation (Justice and others 1991).

Rain-use efficiency was calculated as the ratio of annual sum NDVI and station-observed annual rainfall.

Purpose: The rain-use efficiency, i.e. production per unit of rainfall, is analysed to present the spatial pattern, temporal trends and confidence over the period; it is also used to adjust the NDVI trend.
Status completed

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Descriptive keywords NDVI .
Descriptive keywords Land degradation .
Descriptive keywords Land improvement , Remote sensing , Rain-use efficiency , GLADA .
Descriptive keywords World (place).
Spatial representation type grid

Language English
Character set utf8
Topic category code environment
Extent
Temporal Extent
Begin date 1951-01-01T16:35:00
End date 2003-12-31T08:00:00
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information : Within the FAO program Land Degradation Assessment in Drylands (LADA), the present "Global Assessment of Land Degradation and Improvement" uses remote sensing to identify areas where significant biological change is happening, both hot spots of land degradation and bright spots of land improvement. In the next phase of the program, hot spots and bright spots will be further characterised in the field by national teams.

Distribution info
OnLine resource ISRIC - World Soil Information website
OnLine resource LADA - Land Degradation Assessment in Drylands - FAO 2008 Web site
Data for download Global change in rain-use efficiency 1981-2003 - IMG format
Data for download GLADA Report 5 - Global Assessment of Land Degradation and Improvement
Interactive Map Global change in rain-use efficiency 1981-2003
(OGC-WMS Server: http://geonetwork3.fao.org/ows/37051)
View in Google Earth Global change in rain-use efficiency 1981-2003 View in Google Earth
Spatial representation info
Number of dimensions 2
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Dimension size 1870
Resolution
[uom] Decimal degrees
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Dimension name column
Dimension size 4943
Resolution
[uom] Decimal degrees
Resolution 0.072727
Cell geometry area
Transformation parameter availability yes
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset
Statement
Description Last Updated
DateTime 2008-10-30T15:34:00
Metadata
File identifier c7a67bd5-49da-44e7-be0e-6b0b9fd38d6a
Language English
Character set utf8

Date stamp 2010-02-09T17:29:03
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author Zhanguo Bai
Role author

Title **Farming system classes in developing and transition countries, 2000 (FGGD)**
Date 2007-06-21
Date type Publication
Edition 1.0
Presentation form mapDigital

Abstract The FGGD farming system classes map is a global raster datalayer with a resolution of 5 arc-minutes. Each pixel is classified as belonging to one of seven farming system classes, aggregated from the original 45 farming systems contained in the farming systems map. The data are taken from regional maps generated for inclusion in FAO and World Bank, 2001, Farming systems and poverty, by J. Dixon et al.

Purpose: The FGGD Digital Atlas consists of more than 100 global database that allows to analyse food insecurity and poverty in relation to the environment.
Status completed

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Role pointOfContact
Maintenance and update frequency asNeeded
Descriptive keywords farming systems , cropland , developing country , transition country (theme).
Descriptive keywords World (place).
Access constraints copyright
Use constraints copyright
Other constraints
Spatial representation type grid
Language English
Character set utf8
Topic category code farming

Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90
Supplemental Information: This dataset is contained in Module 5 "Land use patterns and land cover" of Food Insecurity, Poverty and Environment Global GIS Database (FGGD) (FAO, 2007).

Distribution info
Data for download Farming system classes in developing and transition countries, 2000 - Grid format (481 KB)
Interactive Map Farming system classes in developing and transition countries, 2000 (OGC-WMS Server: http://geonetwork3.fao.org/ows/14074)
View in Google Earth Farming system classes in developing and transition countries, 2000 View in Google Earth

OnLine resource Farming Systems and Poverty
Spatial representation info
Number of dimensions 2
Dimension name row
Dimension size 2160
Resolution
[uom] ,
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Dimension name column
Dimension size 4320
Resolution
[uom] ,
Resolution 0.08333333
Dimension name vertical
Dimension size
Resolution
[uom] ,
Resolution
Cell geometry area
Transformation parameter availability
Reference system info
Code GCS_WGS_1984
Data quality info
Hierarchy level dataset

Metadata

File identifier 4e463d70-7593-11db-b9b2-000d939bc5d8
Language English
Character set utf8
Date stamp 2009-04-21T17:13:54
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Metadata author
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Electronic mail address mirella.salvatore@fao.org
Role Point of Contact

Title The World's Forests 2000.
Date 2001-07-01
Date type creation
Edition First edition.
Presentation form mapDigital

Abstract The forest cover map is the first comprehensive worldwide view of forests, using a consistent methodology and standard data. The map has a resolution of 1 km and is based on 1992-93 and 1995-96 AVHRR data. Four broad land cover categories are presented following FAO standard classification: closed forest, open/fragmented forest, other wooded land and other land. Due to the coarse source data, the map cannot be used to obtain reliable country forest cover statistics. The final map has been drafted through validation with information/maps based on higher resolution data, e.g. Landsat TM or SPOT images. An accuracy assessment will be carried out in year 2000 to determine the classification accuracy.

Purpose : The primary use of the map is to show the current extent of forests at a global and regional level. Other potential uses include sampling for forest change assessments and modelling, and to supplement regions lacking recent, reliable forest inventory data.

Status onGoing
Descriptive keywords FORESTS .
Descriptive keywords Forest cover , FRA 2000 .
Descriptive keywords World (place).
Spatial representation type grid
Language English
Character set utf8
Topic category code imageryBaseMapsEarthCover
Topic category code environment

Extent
Temporal Extent
Begin date 1992-07-01
End date 1996-07-01
Extent
Geographic bounding box
North bound latitude 90
West bound longitude -180
East bound longitude 180
South bound latitude -90

Supplemental Information: The map has been developed at the EROS Data Center (EDC) of the United States of America. The UNEP World Conservation Monitoring Center (UNEP-WCMC) in the United Kingdom has collaborated in the map validation.

Distribution info
OnLine resource Link to FAO Forestry website
Interactive Map The World's Forests 2000
(OGC-WMS Server: http://geonetwork3.fao.org/ows/1253)
View in Google Earth The World's Forests 2000 View in Google Earth
Data for download The World's Forests 2000 - grid file
OnLine resource for_00.axl
Spatial representation info
Number of dimensions 2

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Dimension size 2000
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Resolution 0.009
Cell geometry
Transformation parameter availability
Data quality info
Hierarchy level dataset
Statement
Description Last Updated
DateTime 2002-05-31 19:58:00

Metadata

File identifier b9f2ee20-88fd-11da-a88f-000d939bc5d8
Language Tatar
Character set utf8
Date stamp 2009-04-09T12:07:39
Metadata standard name ISO 19115:2003/19139
Metadata standard version 1.0
Maintenance and update frequency asNeeded
Metadata author
Individual name Dan Altrell
Role Point of Contact

References

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Curriculum Vitae

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