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Biocomplexity in the Big Thicket

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Introduction: Overview of the Big Thicket and Biocomplexity

The Big Thicket is an ill-defined region of southeast Texas on the coastal plain of the Gulf of Mexico between the Trinity and Sabine rivers, not far from Houston. Because the biological-diversity index of the area is one of the highest in North America, the Big Thicket National Preserve (BTNP)—an archipelago of isolated conservation 'units' administered by the US National Park Service—was established in 1974. The BTNP is located in a matrix of privately owned timberland, small farms, and a few small towns. The major human impacts on the region, beginning in the late 19th century and continuing into the 21st, have been logging and milling by large industrial timber operations and oil and gas extraction. Because of its proximity to the refineries of Port Arthur and the city of Beaumont and the steady increase in the availability of automobiles after World War II, residential development has also been a major impact in the region—and now represents the most potent driver of land-use/land-cover change.

Few ecosystems are now free of extensive human influence. However, the way human activity affects natural systems and the way those anthropogenic changes in natural systems reciprocally affect human behavior is poorly understood. Therefore, the aggregate impact of the several decisions of private persons, corporations, and governments to buy and sell land, to explore for minerals, to harvest timber, to build homes, strip malls, factories, and roads is only perceptible after the fact. Detailed prediction of anthropogenic land-use/land-cover change is impossible with current tools. However, computer models can simulate the complex interactions between human and natural systems reliably enough to enable stakeholders and policy

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makers to visualize, in advance, a suite of scenarios to which present decisions might lead—and thus have the opportunity to take other decisions to optimize outcomes. Our central goal is to model this particular form of biocomplexity—coupled natural and human systems—to better inform decision taking and policy making. We chose the Big Thicket as a study area because it is especially dynamic and because its extraordinary biological diversity is gravely threatened. In a free-market democracy, stakeholders and policy makers may choose to sacrifice biodiversity for the sake of other benefits, but we believe that good simulation helps make better choices and may even reveal paths to win–win integration of usually zero-sum benefits, such as development and biodiversity conservation.

The BTNP is the most threatened of the 'crown jewels' in the national parks system, and for that reason alone the Big Thicket is a choice-worthy area to study. Our methods, however, are designed to be applicable to other areas in which land-use and land-cover changes are driven by human actions. Thus the Big Thicket study may also be regarded as but one among several proving grounds for a more general approach to decision taking and policy making in regard to coupled natural and human systems. Accordingly, we selected three other sites for study as well—one more in North America and two in South America. They are the landscapes comprising the Trinity River Greenbelt corridor in north-central Texas, the Caparo Forest Reserve, and the Imataca Forest Reserve—the latter two in Venezuela.

At the heart of our study are two coupled computer models: (1) a spatially explicit landscape model that includes forest dynamics and land-use/land-cover changes linked to a hydrological model and habitat fragmentation metrics; and (2) a multi-agent model of human actions, simulating the behaviors of various kinds of stakeholders that affect land use and land cover in the study areas. The former model projects the way the vegetation on an area evolves over time, and the way vegetation cover affects the way water percolates into the soil and/or runs into streams and reservoirs. The latter projects the way human beings make land-use decisions, especially to hold on to land in an undeveloped condition or sell it for development, based on the values they regard as more or less important. When these two models are coupled, the simulated human land-use decisions affect the simulated vegetative cover, the simulated dynamics of water and water quality, and the simulated wildlife habitat. Then when the simulated human agents perceive the resulting simulated environmental changes, they respond with a second round of simulated values-driven land-use decisions which, in turn, affect simulated land cover, water dynamics and quality, and habitat. As the models run, the way the study area might look in five, 10, 20, 50 years can be visualized on a series of maps showing possible states of future land use and land cover.

We begin by contextualizing our study of biocomplexity in the Big Thicket in relation to contemporary environmental philosophy, more particularly: environmental pragmatism; the philosophy of place and space; debate about the wilderness idea; the philosophy of conservation; and postmodern ontology. We then provide a more detailed biogeographical account of the Big Thicket; its history of settlement, preservation, and development; and its current opportunities and threats. We go on to describe our general approach to modeling, briefly comparing our study of biocomplexity in the Big Thicket with parallel research in our other study sites, and noting the generalization that parallel studies in disparate landscapes and cultures

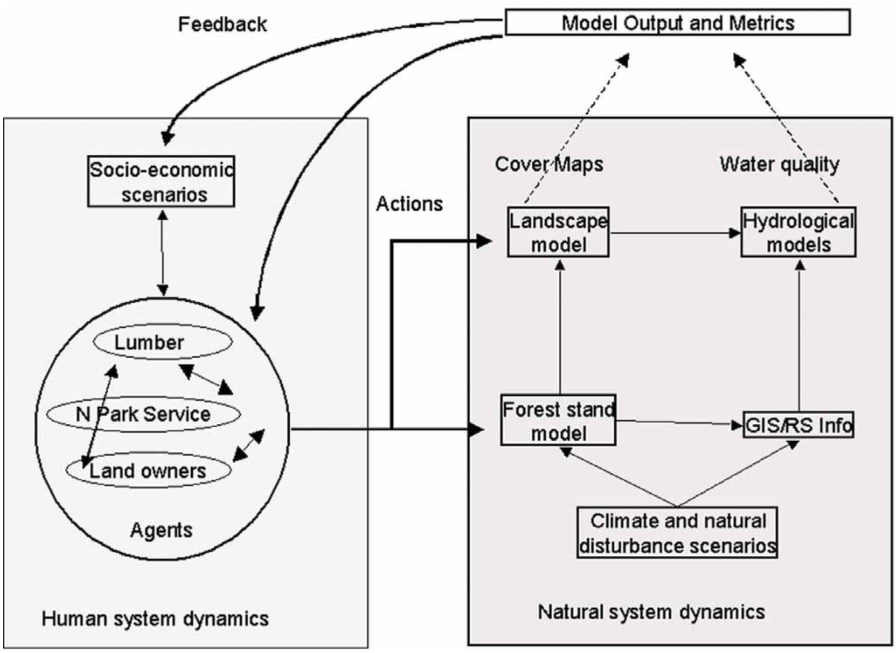

Figure 1. Human–natural systems coupled models.

make possible. We conclude with a discussion of the critique of economic valuation in contemporary environmental philosophy and an alternative method for quantifying and comparing values and rationally choosing among them. Our goal is to provide a better quantitative understanding of the interplay between human actions and landscape dynamics. This will give landowners, other stakeholders, and policy makers reliable information about the probable impact of their decisions on the future composition and structure of local biotic communities, and the functionality and serviceability of associated ecosystems. It will thus facilitate a more informed analysis of the long-term consequences of private choices and public policies on the natural systems in which human systems are embedded and with which they interact.

The Pragmatic Turn in Environmental Philosophy

From its inception in the early 1970s and for most of the subsequent quarter-century, environmental philosophy was dominated by theoretical metaethics and even metaphysics, with a decided non-anthropocentric, even anti-anthropocentric bias. An enormously influential and seminal paper by historian Lynn White seems to have set environmental philosophy off on this course.[2] White suggested that the alleged anthropocentrism of Christianity and its Judaic foundations were at the root of our contemporary environmental crisis. He further argued that because our environmental problems are ultimately philosophical—that is, traceable to an inherited worldview, the Judeo-Christian tradition, which, in his account, inspired both

Western science and technology—their solution is also philosophical, dependent on critiquing and eventually transforming that worldview. Accordingly, the first academic environmental-philosophy papers took the central problematic to be constructing a non-anthropocentric environmental ethic.[3] Environmental philosophers subsequently appeared to settle on the provision of intrinsic value (or inherent worth) for some set of non-human natural entities and/or nature as a whole to be the conceptual linchpin of non-anthropocentric environmental ethics.[4]

Bryan G. Norton was among the first environmental philosophers to contest the non-anthropocentric approach to environmental ethics from a pragmatist point of view.[5] He was joined by a number of other environmental pragmatists, notably Anthony Weston, Andrew Light, and Ben Minteer.[6] Pragmatists argue that preoccupation with theorizing the intrinsic value of nature and constructing non-anthropocentric environmental ethics has rendered environmental philosophy largely irrelevant to environmental policy formation. While non-anthropocentric environmental ethics and its core concept of the intrinsic value of nature may be indirectly influencing public policy, as some apologists have argued, a recent empirical study confirms the allegation that it has had little immediate and direct influence.[7] As a remedy, some environmental pragmatists have suggested deploying 'meta-theoretical compatibilism'—backgrounding differences in the way people (including philosophers) value nature and the way they conceptualize the appropriate human relationship to nature and foregrounding their agreements on policy options.[8] For example, bird watchers, who believe in animal rights, and duck hunters, who want birds to shoot, can agree on a policy of wetland preservation for waterfowl habitat. Others have suggested that respect for democratic processes requires basing public environmental policy on the way people actually value nature and actually conceptualize their relationship with it.[9] This not only foregrounds values, despite the potential for divisiveness, but also implies value pluralism—a tolerance for multiple and often incompatible and competing values.[10]

Environmental pragmatists also recommend spatially scaling down from an abstract, universal frame of reference—the (unspecified) biosphere, the (unspecified) ecosystem, the (unspecified) biotic community inhabited by (unspecified) humans—to a more circumscribed, richly textured locale, inhabited by temperamentally, culturally, and socio-economically specific humans.[11] Environmental policy, pragmatists insist, should develop from the bottom up—from the biogeographical particulars of a place, its human inhabitants, their particular values and attitudes, and the challenges they face—rather than a one-size-fits-all formula imposed from the top down.[12] This 'abductive' (that is, neither deductive nor inductive) approach has been variously theorized by Charles Sanders Peirce and, under the rubric of 'situated knowledges', by Donna Haraway.[13]

Our study of biocomplexity in the Big Thicket exemplifies a pragmatic approach. It is specific in terms of locale, landscape, and human inhabitants and abductive as opposed to either deductive or inductive. As to the values driving human decisions, while the intrinsic value of local ecosystems may be espoused by some stakeholders, we are neither overtly nor covertly attempting to privilege such a value, certainly not to impose it. Nor do we hypothesize the existence of ecocentric intrinsic value among the denizens of the Big Thicket and use loaded-dice research methods in an effort to confirm such a hypothesis. Rather, primarily to parameterize and initialize our multi-agent, human-systems model, we empirically identify and quantify the values that drive the decisions that have an impact on local natural systems. Observation and consultation with people in the region indicate that the decision having the greatest impact in the Big Thicket is that by landowners to sell their properties for development. More particularly, because of restructuring in the timber industry and demand for residential properties, as the Beaumont–Port Arthur urban, suburban, and exurban area grows, the biggest changes are being wrought by big real estate companies acquiring large tracts of land for residential development put up for sale by big timber companies. The actual values of other stakeholders—various local government officials, the National Park Service, environmental organizations, other landowners—determine actions that either augment or impede the process of land-cover change from forest to lawns, roofing, and pavement.

Our approach to modeling decision processes is to identify the factors that stakeholders consider when taking a decision to sell their land, and the relative importance of these factors. For example, one factor contributing to a current landowner not selling his or her land may be that the property has been in the family for many years ('tradition value' we call it). However, this factor may be outweighed if prices increase. An objective of our work is to identify and encode these tradeoffs within a decision analysis framework. The hope is that when the actual Big Thicket stakeholders observe the outcomes predicted by our models they will revisit their current suite of values, reweigh them, and perhaps take actions more congenial to the BTNP and long-term environmental conservation of the region.

The Concept of Place in Geography and Philosophy

The importance of a place-based understanding of environmental attitudes and values has been emphasized not only by environmental pragmatists, but also by philosophers in the Continental tradition, bioregional theorists, and cultural geographers. Geographer Yi-Fu Tuan, classically (by now) distinguishes between place and space.[14] The former is one's immediate home range, familiar, with distinct and particular landscape features that are mentally mapped and named. Space is the more amorphous geographical field that surrounds one's place, the matrix in which place is located and in context of which place is defined. Place and space are hierarchically organized, not only such that places are located in spaces, but that the contextual space surrounding a place is in turn located in a larger space and so on up to the planetary scale. According to geographers R. L. Johnston, Derek Gregory, and Geraldine Pratt, place is 'A portion of geographic space. Space is organized into places often thought of as bounded settings in which social relations and identity are constituted'.[15]

The Big Thicket is sufficiently circumscribed to count as a place. It is located in east Texas, a space, in Tuan's terminology, which, in turn, is located politically in the state of Texas, but bio-culturally in the forested coastal plain of the Gulf of Mexico west of the lower Mississippi River drainage. Continental philosopher Edward S. Casey provides an expansive intellectual history of the concepts of place and space.[16] Geographer Nicholas Entrikin provides a more focused history of

20th-century thought about place, emphasizing the discrepancy between a 'decentered', 'objective', theoretical perspective and a 'centered' (or located), 'subjective', lived perspective.[17] Bioregional theorist Gary Snyder takes a more normative and aesthetic view of place. He urges people to select a place, set down roots there, learn the native flora and fauna and how past indigenous cultures had adapted their life ways to the biogeographical and ecological peculiarities of that place as a guide for 'reinhabiting' it.[18]

In addition to Casey, Continental philosophers Jeffery Malpas and Mick Smith provide rich and extensive phenomenologies, ontologies, aesthetics, and ethics of place.[19] Like Snyder, Smith's concern with place is normative, but his ethics of place emphasizes otherness and difference.[20] Bucking the tendency in Continental philosophy to regard everything, including nature, as a product of social construction, Casey argues that topography, climate, biology, and ecology play as significant a role in shaping the characters of places as do the human inhabitants.[21] On the other hand, human economies, structures, and cultures contribute as well to the characters of places. Indeed, the characters of places may be thought of as resulting from the complex and dynamic interactions between their natural and human endowments. Casey also argues that our identities as individual persons are in part reflections of the places we inhabit. As Malpas, even more emphatically and centrally puts it:

> ... what we are as living, thinking, experiencing beings is inseparable from the places in which we live—our lives are saturated by the places, and by things and other persons intertwined with those places, through which we move, in which our actions are located, and with respect to which we orient and locate ourselves.[22]

Geographers John Agnew and Jonathan Smith provide an antidote to the tendency of some philosophers to romanticize places, such as the Big Thicket, by taking a hard look at the disparity between American ideals and the reality of various American places.[23]

Bounding the Big Thicket: An Exercise in Postmodern Geography

The Big Thicket is also certainly a place not only by virtue of its scale in relationship to the more amorphous space in which it is located, but also in respect to the way its natural and human endowments intertwine to form its character. Currently the heart of the Big Thicket and the location of the several units and connective corridors of the BTNP is bounded on the west by the Trinity River and on the east by the Sabine River, with the Neches River running through its eastern side. In addition to the Neches, a major river in east Texas, two of its smaller tributaries, Village Creek and Pine Island Bayou, drain most of the Big Thicket. The city of Beaumont sprawls at its southeastern extremity and the little crossroads village of Moss Hill stands at its southwestern extremity; the Steinhagen Lake reservoir on the Neches, the town of Woodville, and the Alabama–Coushatta Indian Reservation axis delimit its northern boundary. In this quadrant the towns

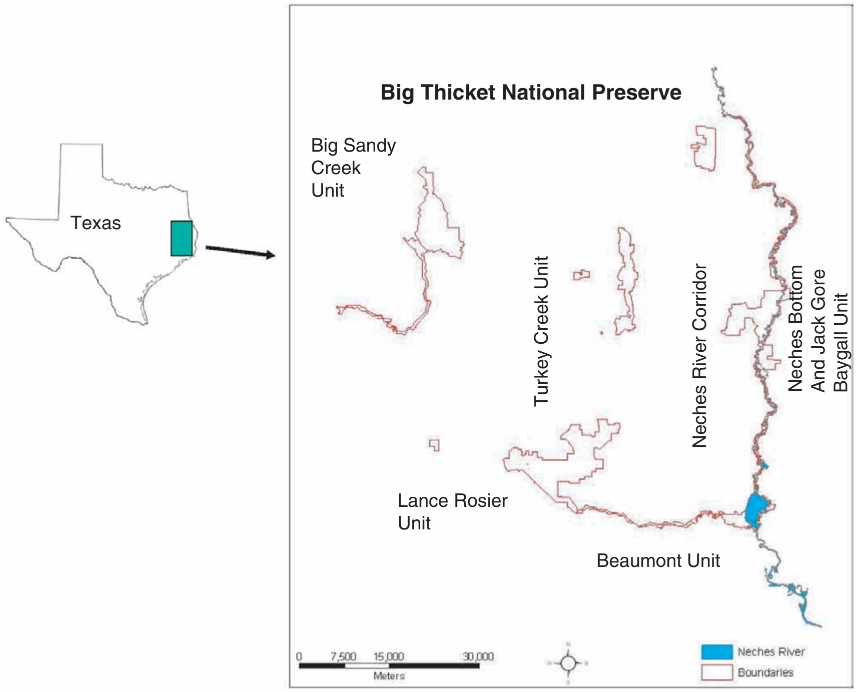

Figure 2. The Big Thicket National Preserve: location and units, illustrating fragmentation (from NPS Small-Scale Base GIS Data). *Source:* US National Science Foundation.

of Lumberton, Silsbee, Kountze, and Saratoga and the rural subdivisions of Wildwood and Ivanhoe are nestled.

Unlike the Great Basin in western North America, which is relatively well defined, the historic natural boundaries of the Big Thicket are ill-defined and contested. Scientific estimates of its aboriginal size range from 2 million to 3.3 million acres (800 000 to 1.3 million hectares).[24] Various criteria have been used to identify the Big Thicket in terms of phytogeography, ecology, geology, culture, and history.[25] The indefinite, fuzzy, and contested boundaries of the Big Thicket relate it to another strain of contemporary philosophy, postmodernism, in which reality is socially constructed from multiple points of view. According to historian James Cozine, in a 1970 article in the *Texas Observer*, a biweekly alternative newspaper, maverick journalist Hubert Mewhinney suggested that the Big Thicket, as such, is really non-existent and but ‘a gullible state of mind’.[26] The BTNP, however, certainly does exist and is more unambiguously definable, albeit fragmented. When created in 1974, it comprised nearly 85 000 acres (more than 34 000 hectares). The BTNP has since grown to more than 97 000 acres (nearly 40 000 hectares). Additional reserves in the Big Thicket include state parks and forests, a Nature Conservancy ‘sanctuary’, and the Alabama–Coushatta Indian Reservation. Thus roughly between only 2% and 5% of the aboriginal Big Thicket (depending on what estimate of its aboriginal size one accepts) is currently protected.

A Wilderness Condition

Since the early 1990s, the wilderness idea has been vigorously challenged.[27] The popular perception of the whole Western Hemisphere as languishing in a wilderness condition in the spring of 1492 has been thoroughly debunked. Current estimates of pre-Columbian indigenous populations have increased by at least 10-fold along with a better appreciation of the extensive environmental impact of their burning, hunting, and horticulture.[28] When English colonists displaced American Indians along the mid-Atlantic coast of North America during the 17th century, the landscape to which they immigrated was not, as they believed, a 'howling wilderness', but as much a cultural artifact as the one they left behind.[29] Of course, throughout North America tracts of wilderness were then interspersed with more or less intensely peopled places. The Big Thicket was one such true wilderness area. Historical records and archeological data indicate that American Indian tribes lived on the margins of the Big Thicket, only occasionally and infrequently penetrating it to hunt. The sandy soils of the Big Thicket were not fertile enough to amply reward the labor of clearing and cultivation, nor did its dense vegetation and low elevation make for an inviting place to live. Thus in the poetic words of the Wilderness Act of 1964, the aboriginal Big Thicket was 'an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain'.[30]

The Hasinai Indians lived in villages on the Trinity and Neches rivers north of the Big Thicket and subsisted primarily by horticulture. The Bidai Indians lived to the west of the region and also practiced horticulture. The Akokisa Indians lived on the Gulf coast to the south of the Big Thicket and derived most of their livelihood from the sea and riverine estuaries. By the early 20th century these groups had succumbed to smallpox and other epidemic diseases. Currently, the Alabama–Coushatta Indian Reservation abuts the Big Sandy Creek Unit of the BTNP. The Alabama tribe migrated into the region from the east, at first in response to English settlement of the place that now bears their name. After an extended stopover in Louisiana they eventually took up residence on the Neches River, the first people to permanently settle in the Big Thicket. The Coushatta also came from the eastern Lower Mississippi River drainage and settled north of the Big Thicket in the Trinity River valley. The Alabama received approximately 1300 acres (525 hectares) from the state of Texas in 1854 and, when the Coushatta's effort to acquire lands of their own failed, they joined the Alabama a few years later. In 1928 the federal government purchased an additional 3000 neighboring acres (1200 hectares) for the tribes, which was transferred to the state of Texas, as fiduciary, and consolidated into the reservation.[31]

After the European 'discovery' of the Western Hemisphere, Spain laid claim to the territory that is now Texas, as well as to the lands farther south. Alvar Nuñez Cabeza de Vaca probably wandered through the Big Thicket in 1528. The Spanish established no settlements or outposts anywhere near the region until it was claimed in 1685 by the French, who set up an ill-fated and short-lived settlement near Matagorda Bay, well away to the south and west. The French claim to the region, however tenuous, inspired the Spanish to establish a mission—San Francisco de Los Tejas—just north of the Big Thicket where the surviving French settlers had been living with the Hasinai Indians. Although it was manned by only three priests and three soldiers and lasted only three years, it set a precedent. Over the next century, in response to incidental and occasional French incursion, the Spanish established missions and presidios all around the Big Thicket, but never in it—because no Indians lived there. Spanish interest in east Texas, never great, waxed and waned in response to interest by the French, until Louisiana was purchased by the United States in 1803. After that the Spanish sought to maintain a sufficient presence in the region to discourage American incursion. However, after Mexico became independent of Spain in 1821, the new government pursued the opposite policy of encouraging Americans to settle Texas. Moses Austin and his son Stephen F. Austin were among the first of many 'empresarios' to contract with the central Mexican government to induce Americans from the United States to immigrate to Texas during the 1820s and 1830s. The growing population of Anglos became increasingly alienated from a distant government that was descending into corruption and tyranny. A Texas declaration of independence, a successful war of independence, and the creation of the Republic of Texas all occurred in 1836, followed by the annexation of Texas as an American state by mutual agreement between the Republic and the federal government of the United States in 1845.[32]

Because American immigrants flooded into Texas after it became first a part of Mexico, then a republic, and finally a state, good farm and ranch land become increasingly scarce and so the Big Thicket began to be settled—but only very sparsely—by honest agriculturists. Because it remained a virtual wilderness, rich in game resources for the resourceful sojourner, the Big Thicket served as a retreat for outlaws and fugitives from the southeastern states after it passed into American hands. One of the reasons that many American immigrants to Texas sought its separation from Mexico was because Mexico did not legally countenance slavery. When the institution of slavery in Texas was again threatened in 1860 by the election of Abraham Lincoln, an avowed abolitionist, the state of Texas seceded from the Union and joined the ranks of Confederate states in 1861. During the ensuing Civil War, the Big Thicket served as a hiding place for both abolitionist conscientious objectors and common draft dodgers.[33] Returning to the concept of place, the bio-cultural heritage of the Big Thicket is one of dangerous and dark mystery and romance.

Resource Extraction in the Big Thicket

The most plentiful resource in the Big Thicket wilderness was timber. However—lacking steady-flowing, well-channeled, deep rivers—to get it out was hard. Indeed it was so hard—and thus prohibitively expensive—that lumbering in the region was insignificant until an east Texas rail infrastructure began to develop in the last quarter of the 19th century. After the Lake State pineries were depleted in the mid-19th century, the Piney Woods of east Texas represented a relatively untapped timber source, ripe for rapid exploitation in the late 19th and early 20th centuries. The longleaf pine of the Big Thicket was especially prized for its size and strength and was the first to be cut over. Loblolly pine was cut next. Inconveniently located mostly in its floodplains, the Big Thicket's hardwoods were the last targets of the timber industry. Driven exclusively by short-term economic motives, extraction of virgin timber caused collateral damage to the soils and biota that was extensive and severe. Tram logging—in which steam skidders were used to yard timber—gouged and compacted the topsoil and damaged tree seedlings and understory vegetation; slash provided fuel for catastrophic fires. No reforestation or silviculture was undertaken until the beginning of the second quarter of the 20th century, when it became evident to all but the most recalcitrant operators that the woods of east Texas were not inexhaustible. After the initial logging orgy was spent, the forests began to regrow, either on their own or with the help of replanting efforts, but with a nearly complete shift in forest composition from longleaf pine to loblolly.[34]

Nearly simultaneously with the timber boom came the oil boom in the Big Thicket. It started modestly in Saratoga in 1901. In 1903 oil was struck at Sour Lake, a therapeutic-spa town built around a series of ponds into which petroleum gases and fluids percolated from the subsurface and were believed to have salubrious virtues. The Sour Lake strike was spectacularly productive but ephemeral, followed, after several years, by rapidly declining yield. Meanwhile more wells were drilled near Saratoga and then Batson. The Big Thicket oil reserves tended to be close to the surface, easy to find—using salt dome mounds and surface ooze of gases and sludge as obvious clues—and rapidly depleted, with the productivity of most sites steeply declining after three or four years. The oil men were as little concerned about the environmental consequences of their industry as the lumber men. Oil violently blew out of the early drill holes, coated the surrounding biota, and seeped into the topsoil and groundwater; noxious gases polluted the air. Associated with petroleum deposits were equal measures of briny water, which was simply flushed into the nearest stream with devastating effects on both freshwater aquatic plants and animals, to say nothing of its effects on water quality for human consumption. In their first couple of years, the Big Thicket wells were so productive that there were not enough barrels available to store all the oil, so producers put it anywhere they could—in leaky wooden containers or simply pits dug in the ground. Just as the timber industry in the Big Thicket eventually reached a reasonable equilibrium with its resource base after the initial period of frenzied exploitation, so did the oil industry. New oil and gas deposits continued to be discovered in the Big Thicket and quietly developed throughout the 20th century and now into the 21st. Today, all over the region one sees new wells and pipelines being installed side-by-side with the rusting infrastructure of the first wave of oil extraction.[35]

Pleistocene Origins of the Big Thicket

Probably the most unambiguous approach to bounding the Big Thicket is by climatic and edaphic criteria. The climate is humid subtropical, with a mean annual temperature of about 70°F (21°C) and an annual average rainfall of about 53 inches (1350 mm); the steeply declining rainfall gradient defines the southwest boundary. Sea-level fluctuations during the Pleistocene periodically inundated the currently exposed coastal plain, leaving behind, each time, a band of sediments, sorted by size and mode of deposition (river floodplain silts, river outwash sands, lagunal muds and clays).[36] The Big Thicket lies within three such bands, the Beaumont, Lissie, and Willis formations.[37] Hence, when the current Holocene coastline stabilized, a mix of clayey and sandy soils covered the lower-lying area of the plain.[38] Being less fertile and more prone to desiccation during dry spells, and also flat and thus more prone to saturation during wet spells, it was less attractive to indigenous agriculturists than the better-drained and richer soils of the uplands and river floodplains to the north of the Big Thicket. The high rainfall, coupled with the poor drainage characteristic of low, flat terrain, resulted in extensive growth of wetland shrub bogs—dense thickets of mostly evergreen shrubs, now locally called baygalls—making human travel through the region difficult. Doubtless it was these plant associations that gave the place its name. Thus, thanks mainly to coastal geomorphic processes in a region of warm temperatures and high rainfall, the Big Thicket remained in a wilderness condition throughout most of the Holocene.

During the most recent Pleistocene glaciation the area was a refuge for many plant species and associations driven south by the ice and cold climate. The Big Thicket has been popularly characterized as the 'biological crossroads of North America' where forest species now typical of the northeast mix with xeric species typical of the southwest and where swamp species from Florida and the southeast mix with prairie species now typical of the Texas and Oklahoma plains to the northwest.[39] This construction was based on the apparent diversity of the Big Thicket and the supposition that when the climate warmed and the ice retreated, the fugitive species from the four winds once again extended their ranges, but also continued to propagate in their Ice-Age redoubt. This conception of the area played a significant rhetorical role in the political struggle to preserve remnants of the aboriginal Big Thicket and continues to be significant in the current effort to expand BTNP and protect it from the new challenges it now faces.[40] However, by far the predominant flora and fauna of the Big Thicket are characteristic of the warm, humid forests that stretch from east Texas to South Carolina.[41] And because such forests have been extensively logged and/or converted to other uses, any representative remnant is a worthy candidate for preservation, unadorned by any exaggerated (and undocumented) claims of biogeographical distinction.

Topographic and soil conditions also powerfully influence the local segregation of this rich concentration of plant species into distinctive plant communities. The longleaf pine ecosystem, one of the most threatened in North America and also one of the most diverse, occurs on three main landforms: (1) uplands that are dry because of coarse soils and relatively steep terrain; (2) especially dry deep sands of old river terraces (here, cacti, yuccas and other plants commonly thought of as desert plants are present with the pines, just as they are on deep sands across the southeastern United States); and (3) wet, poorly drained flats (here longleaf pine savannas occur together with a herb-rich ground layer of sedges and grasses). The longleaf pine ecosystem is fire-dependent, and so, with fire suppression, has disappeared from the well-drained, but not droughty uplands, being replaced by mixed forests of loblolly pines and hardwoods (post oak, southern red oak, upland laurel oak, water oak, and white oak), which were once more restricted in extent. In uplands and some stream bottoms with sandy-loam soils that are well-drained, but moist throughout the year, one finds magnificent stands dominated by southern magnolias and American beech. Sloughs and oxbows of river and creek floodplains are dominated by baldcypress and tupelo swamps. In floodplains along creek and river corridors bottomland-hardwood forests of oaks and gums are found.[42]

Biodiversity in the Big Thicket

The principal preservation value of the Big Thicket is its biodiversity. When conservation efforts in the Big Thicket began in the second quarter of the 20th century, the term 'biodiversity' had not been coined, nor would it be until the mid-1980s.[43] Thus it is a tribute to the prophetic foresight of the advocates for preserving the Big Thicket—going all the way back to the 1920s with the efforts of R. E. Jackson, a Santa Fe Railroad conductor from Silsbee. His early Big Thicket conservation efforts were conducted under the aegis of the Hardin County Cooperative Pasture and Game Preserve. He later formed the East Texas Big Thicket Association (ETBTA) in 1936—to lobby the state or federal government to set aside nearly 0.5 million acres (more than 200 000 hectares) as a wildlife sanctuary.[44] By the mid-1930s, the Big Thicket was attracting the attention of botanists who were beginning to discover its extraordinary variety of habitats and, as a consequence, the Texas Academy of Science lent its support to the ETBTA for some sort of preserve in the region. At the urging of the ETBTA, the National Park Service investigated the area as a location for a new national park in 1938. However, continued petroleum exploration and development in the Big Thicket during the late 1930s and early 1940s and increased demand for timber during World War II derailed the momentum toward preservation that the ETBTA had managed to generate.[45]

It may have been fortuitous that the National Park Service did not complete its study of the suitability of the Big Thicket for locating a national park in the 1930s or 1940s, for then the National Park Service was strongly oriented toward

Figure 3. Palmetto palm, hardwood community, Pine Island Bayou Corridor, Big Thicket National Preserve. Photo by Roy Hamric. Copyright: Pete Gunter.

Figure 4. Palmetto palm, hardwood community, Lance Rosier Unit, Big Thicket National Preserve. Photo by Roy Hamric. Copyright: Pete Gunter.

Figure 5. Cypress swamp, Turkey Creek Unit, Big Thicket National Preserve. Photo by Roy Hamric. Copyright: Pete Gunter.

Figure 6. Bottomland hardwood community, Village Creek Corridor, Big Thicket National Preserve. Photo by Roy Hamric. Copyright: Pete Gunter.

scenic characteristics and the Big Thicket is decidedly unscenic.[46] The vision of R. E. Jackson for a wildlife preserve in the Big Thicket was revived by Governor Price Daniel who was impressed by the number of tourists he saw attracted to Yellowstone National Park when he himself toured it in 1960. Governor Daniel proposed a Big Thicket State Park and Game Preserve, oriented toward tourism and outdoor recreation, hoping it might boost the perennially depressed economy of east Texas. He favored the public-forest rather than the national-park model, in order to allow regulated hunting, fishing, and lumbering—and to keep the federal government from taking control of land in the region, when 'states' rights' was a hot-button political issue. John Connally succeeded Daniel as Governor and only tepidly promoted his predecessor's scheme for a Big Thicket State Park during the mid-1960s. Nevertheless a reemerged Big Thicket Association (BTA) continued the campaign for some sort of preserve. It turned for political support to one of the US senators from Texas, Ralph Yarborough, and to a campaign for federal rather than state administration. A trip to the Big Thicket by Supreme Court Justice William O. Douglas in 1966 fueled the effort for a federal preserve. Douglas was outraged by the lumbering practices he saw and added his eloquent and authoritative voice to the call for federal action.[47]

In 1966, Senator Yarborough introduced a bill to establish a Big Thicket National Park without much specificity about its exact location. For the rest of the decade his proposal was explored and refined by the National Park Service and countered by alternative proposals for a smaller-scale state park offered by functionaries of the state government in collaboration with the Texas Forestry Association, which represented the interests of the big timber companies in the region. By 1970 all parties to the discussion agreed that a preserve of one sort or another should be established in the Big Thicket—some enthusiastically, some reluctantly—the questions were how big, where located, and by whom administered. Nowhere in the region remained an unroaded, unlogged, or otherwise unfragmented block of forest big enough to set aside as a consolidated park–reserve. Furthermore, an extremely large area would have been required to capture the major forest types of the Big Thicket in one unit. Therefore, a 'string-of-pearls' concept was endorsed by most interested parties—that is, a series of units (pearls) connected by riparian corridors (strings).

The gradual shift in the logging industry from long-rotation timber harvesting of mixed species to short-rotation pulpwood harvesting of single species grown in row-crop plantations added urgency to the preservationists' cause. Over the next four years the BTA and the newly formed Big Thicket Coordinating Committee (led by Pete Gunter), the Texas Forestry Association, the Save Our Homes and Land Committee (a Big Thicket homeowners' association), the shifting Texas Congressional delegation (Yarborough had been defeated by Lloyd Bentsen and Charles Wilson newly represented the Congressional District in which the Big Thicket was located), the National Park Service, and the chairmen and members of the House and Senate committees and subcommittees through which such bills must flow to become law, wrangled over the question where to locate and how big to make a reserve, and what sort of reserve to make it. The Big Thicket did not meet the National Park Service criteria for a park; nor if it were a park would hunting, regulated timber extraction, and oil exploration be permitted within its boundaries. In all, between1966 and 1974 28 Big Thicket bills had been introduced. Finally in late 1974, after painstaking negotiations and compromises, the last of them passed both houses of Congress creating an 84 550 acre (34 216 hectare) BTNP consisting of eight units and four stream corridors.[48] In the 30-year interval between 1974 and 2004, the BTNP itself has grown in size and has been complemented by other preserved land owned and managed by such entities as the Nature Conservancy and the state of Texas.[49]

Shifting Alliances in the Big Thicket

In the mid-century battle for a BTNP, the big timber companies and BTA were bitter enemies. By the time the BTNP was established, however, the timber industry was evolving from a cut-down/get-out philosophy to one of sustainable forestry. During the last quarter of the 20th century, many big timber companies in the region began to practice conservation on their holdings (however imperfectly), in the tradition of Gifford Pinchot. Thus, since the BTNP has been established, the major land-use philosophical tension has been internecine to the American environmental movement—that between the preservationists and the conservationists.[50] Not long after the establishment of the BTNP a threat emerged—not just to the wilderness remnants of the region, but to its overall forested character: exurban development. Just west of Beaumont, on the southern fringes of the Big Thicket, Bevil Oaks and Pinewood, two upscale exurban subdivisions, were built, imprudently, at the confluence of Pine Island Bayou and Little Pine Island Bayou, the latter draining the largest 'pearl' of BTNP, the Lance Rosier Unit, and itself a corridor unit. These watercourses are subject to periodic flooding during the tropical storms that occasionally come ashore from the Gulf. After episodes of particularly severe flooding the well-to-do and politically well-connected residents of these communities demand flood control works on the bayous—which would at a minimum involve clearing and straightening their channels and, more drastically, additional upstream impoundment of the Neches River into which they flow. In opposition to such schemes—which engineering assessments deemed to be ineffectual in any case—the National Park Service was joined by the big timber companies, whose forest holdings would be adversely affected. After rising and receding with the floodwaters, the issue finally came to a head in 1998 when a referendum to create a flood-control district was put to the vote. It lost by about a four-to-one margin—one suspects less on its environmental demerits than aversion to the taxes that would have been imposed on the subdivisions' residents and non-residents alike.[51]

As the 20th century gave way to the 21st, the evolution of the business models of the big timber companies made their role as the conservation complement to biodiversity preservation in the Big Thicket more problematic. Taking everyone in the region quite by surprise, Louisiana Pacific and International Paper began to divest themselves of 'unproductive assets' by putting approximately 1.5 million acres (607 500 hectares) of east Texas timber lands up for sale. Some of those acres in the Big Thicket have been acquired by developers and real-estate speculators. And the probability of accelerating exurban sprawl in the region is likely to be greatly increased by plans to widen US Highway 69, which runs north from Beaumont to Woodville through the heart of the Big Thicket—entraining new subdivisions, strip malls, box stores, churches, and all the other construction that spills out around highway arteries in Texas.

The Big Thicket is also threatened by water-impoundment schemes. East Texas water supplies come from surface waters. There is but one natural lake in all of Texas—Caddo Lake—which itself was created by a logjam on the Red River and is now maintained by a dam. More water for east Texas consumption thus implies building more dams on east Texas rivers. Thus as the human population grows, demand for water increases, and new dams are envisioned by the US Army Corps of Engineers. Rockland Dam proposed for the upper Neches River would have adversely affected the several BTNP units on the lower Neches. Authorized in 1974, it was deauthorized by an amendment attached by Congressman Wilson to a 1990 omnibus House bill, only to have the state revive the project a decade later. Subsequently, with the help of Jim Turner, who succeeded Wilson as Congressman, and with the support of residents of the Neches River watershed, 33 000 acres (13 355 hectares) of prime timber land were purchased from International Paper by a consortium of philanthropists, for later purchase by state and federal agencies, as a wildlife refuge, effectively blocking further dam-building plans. However, the Lower Neches Valley Authority is floating a plan to elevate the Town Bluff Dam to increase the storage capacity of Steinhagen Lake, thus inundating upstream forests, a state park and wildlife management area and adversely affecting downstream discharge.[52]

Rising to the Challenge of Biodiversity Preservation in the Big Thicket

Fragmented into scattered units, tenuously connected by riparian corridors, lying squarely in the path of urban, suburban, and exurban sprawl, the BTNP was identified in 2003 by the National Parks Conservation Association as the most endangered of all the lands under the jurisdiction of the National Park Service.[53] Ongoing preservation of biodiversity and wild land in this string of pearls will depend on the land-use/land-cover dynamics of the privately owned matrix in which it is located. Those dynamics will unfold in time as the human agents in the region interact with the vegetation and ecosystems of the Big Thicket. What will happen as forested land goes up for sale? Who will buy it and what will become of it? What role, if any, will the state and federal governments and non-governmental organizations (NGOs)—like the Nature Conservancy and the Conservation Fund—play in the Big Thicket real-estate market? What role will state, county, and municipal governments play in encouraging or discouraging real-estate development through infrastructural support (or the lack thereof) and land-use restrictions? If forest land cover is converted to residential use—pavement, roofing, and lawn land cover—how will ecosystem processes (and services) respond?

Our models enable us to answer the last of these questions with some degree of confidence. The behavior of human agents is much more difficult to predict because human agents are less driven by innate developmental dynamics than are natural systems and are also able to react intelligently to changes in their surroundings. Above all, human agents exercise choice. Our study will enable human agents in the Big Thicket—both corporate and individual landowners and governmental entities—to visualize probable effects of their value-driven choices on the forested landscape and ecosystem processes and then reconsider those choices in the light of how our models project their consequences into the future.

The Models in General

In accordance with the abductive logic of our study, beginning with the situated knowledge we gain in the Big Thicket and with that garnered in our sister study areas, we can generalize our methodology across landscapes and cultures. Precisely because the study sites in Texas and Venezuela are culturally and ecologically very different, successful application of the models in each of them will validate the generality of this approach to understanding the biocomplexity embodied in coupled human and natural systems. The drivers of land-use change in both the Big Thicket and in north Texas are now largely related to rapid urbanization, while those in Venezuela are largely related to conversion of forested land to farmland and pasture. Although these are very different forms of human impact on natural systems, at bottom they both represent anthropogenic land-use/land-cover changes. Thus analytically comparing the dynamics of such changes—simulated in models—can reveal commonalities among them applicable throughout the world.

To develop interacting models that couple forested landscape dynamics and associated ecosystem processes and functions to human decision making is our biggest technical challenge. The landscape models are hierarchically arrayed, following a consistent scaling methodology.[54] That is, they begin with the dynamics of tree growth and distribution (based on the FACET model) and scale up to a patch transition landscape model (MOSAIC).[55] Cell to cell interactions are determined in the Venezuelan models using a cellular automata approach and in the Texas models using the cell interaction rules of MOSAIC.[56] Changes in forest cover affecting ecological processes and functions are passed to a distributed hydrological model that simulates changes in water quantity and quality. Changes in forest cover are also subject to calculation of fragmentation metrics in order to assess the effects on habitat quality for wildlife species.

We simulate human behaviors with multi-agent models. The Texas models are based on decision analysis whereas the Venezuela models are logic-based.[57] We link the multi-agent models to the forest landscape and hydrological models in two ways. First, in the Texas cases, the agents provide input in the form of changes in land use and land cover and they receive feedback about the effects of agents' aggregate actions from the forest landscape and hydrological models. Second, in the Venezuela cases, the agent-based model is coupled to the cellular automata model by linking computational tools, without explicit conceptual distinction between action and feedback. In the Texas cases, we obtain information about the values driving human decision taking by means of empirical research, including focus groups, survey questionnaires, and conjoint analyses. In the Venezuelan cases, the agents' decision rules are derived from existing literature that provides analyses of empirical sociological data.

We execute these models using a variety of computational platforms—from single low-end personal computers (PCs) to high-performance dual-processor machines to PC clusters. Mathematics is used throughout to build the models and analyze output, but in addition we analyze the dynamics of simplified versions of coupled natural and human systems mathematically to identify complex dynamic behavior and to provide guidance to the simulations.

Multi-agent-based Models and Their Application to the Study of Biocomplexity

Multi-agent-based models have become useful tools for simulating human behavior at the individual, group, and society levels. Multi-agent-based models have also become useful tools for the analysis of land-use and land-cover change, together with more traditional tools such as systems analysis, spatial econometrics, and cellular automata.[58] The fact that agent-based models make explicit consideration of human actions has enabled them to contribute to the incorporation of complex anthropogenic disturbance in land-use change models. Because multi-agent-based models have application to modeling land-use change, they have therefore been especially interesting to geographers, whose academic discipline often requires integration of human and natural systems.[59] Interest in multi-agent-based models has spread from geography to ecology and other disciplines. Multi-agent-based models have attracted attention especially for their potential contribution to understanding land-use change in forest environments—for example, in the study of deforestation and afforestation in south-central Indiana and in that of deforestation processes in Brazil.[60] The approach we take in our biocomplexity studies is similar to many other multi-agent-based models: we are more interested in explaining emergent phenomena from simple relations than in accurately predicting the state of a socio-ecological system at a certain moment of the future.[61] However, we are attempting to endow the models with both descriptive and predictive power by basing them on empirical data about the human values motivating agents' actions.

Our multi-agent methodological framework condenses as much behavior as possible into a few simple agents. More agents and more complicated behavior will be added as we evaluate model results progressively. We implement this framework using two different approaches. In the Texas study areas, we use a decision-theoretical method. In the Venezuela study sites we use a logic-based approach: that is, behavior is represented by rules written in programming logic, without using explicit mathematical functions. The same qualitative information about agents' values and their assumptions for taking decisions can be expressed in both the utility-function and logic-based modeling approaches. Also, utility functions and programming logic are both effective for the purposes of value representation and weighting. In the former, the model establishes a total order of utilities by computing a value for each action. In the latter, values can also be represented by partial order sets, allowing for pairs of actions that are not related.[62]

The Critique of Economic Reductionism in Environmental Philosophy

We use utility functions for quantifying agents' values instead of expressing them in a monetary metric because a perennial target of criticism in the literature of environmental philosophy has been valuation in the economic sense of the word. No critic of economism has been more unrelenting than Mark Sagoff.[63] Sagoff, however, has been by no means alone in criticizing economic reductionism: he has been joined by, among many others, Eugene C. Hargrove, Holmes Rolston III, and Bryan G. Norton—the latter two, it may be worth noting, on diametrically opposed sides of the intrinsic-value-in-nature debate.[64]

The crux of Hargrove's complaint about economic valuation is that it reduces the rich and complex variety of human values—aesthetic, moral, and spiritual values—to but one kind: economic value.[65] Economists reply that they are misunderstood. They too recognize a multitude of kinds of value, but—for purposes of quantifying them, comparing them, and making rational choices among them—such values must be expressed in a common metric: money.[66] A car, for example, represents several disparate kinds of value—aesthetic value, status value, lifestyle value, transportation value, safety value. These various values are bundled together and reflected in its price, which isn't an additional economic value, but an aggregation of the other values that a car represents.

Things that are not traded in markets, among them many environmental amenities, can be 'shadow priced' by a variety of methods.[67] For example, the Grand Canyon may be shadow priced by the 'travel-cost method', which calculates the amount of money people spend on transportation, lodging, food, entrance fees, burro rides, memorabilia, and such to harvest its recreational, aesthetic, and spiritual values. Some economists also add its 'existence value' to the mix of non-market values represented by the Grand Canyon.[68] That can be calculated by the contingent-valuation method, according to which economists survey people's hypothetical willingness to pay to preserve the Grand Canyon, even if they never plan to visit it.[69] The value of the Grand Canyon as a public environmental amenity can then be compared with its potential value as, say, a Colorado River reservoir.

Its reservoir value may be calculated by estimating the income that would be generated from selling water and electricity, minus the costs of building and maintaining a dam, a hydro-electric plant, and an infrastructure for water and power distribution. To that number its value as an aquatic recreational resource for fishing, swimming, boating, and the like should be added. Expressing the various values of the Grand Canyon in its unaltered state in the monetary metric enables us to quantitatively compare those values with the value of the Grand Canyon converted into a reservoir.

Would Americans be willing to sell the Grand Canyon to a corporation that would turn it into a reservoir if a benefit–cost analysis indicated that that would be worth more than to keep it as is? Sagoff thinks not. He argues not that economists reduce the rich and complex variety of human values to economic value, but that they reduce all values to preferences.[70] One may well prefer chocolate to vanilla ice cream or Coca Cola to Pepsi, but one does not merely prefer justice to injustice or honesty to dishonesty or the Grand Canyon to a reservoir. In addition to preferences, we share values that transcend preferences and these values often clash with our preferences. For example, a parent, of an evening, might prefer watching television, going out for a drink with friends, or surfing the internet to helping a child with homework—and yet choose to help with homework in service to what are popularly known as family values. According to Sagoff, the market is the proper arena in which a society's collective preferences are expressed; in democratic societies, the legislative body (Congress, Parliament, Duma, or Diet) is the proper arena in which transcendent values are expressed.[71] We are at once consumers and citizens, Sagoff claims. As consumers we 'vote' with our dollars for the things we prefer. As citizens we literally vote for ballot initiatives that express our transcendent values and for politicians who will represent those values in legislative bodies.

Just as preferences change, so a society's transcendent values change. Sagoff argues that the outrage the majority of us feel at the prospect of the Grand Canyon converted to a reservoir or the Arctic National Wildlife Refuge to an oil field reflects a shift in American environmental concerns from the domain of preferences to the domain of transcendent values. When such a shift occurs the legislative process often attempts to protect emergent transcendent values by taking the things expressing those values out of the market arena. Legislation prohibits trafficking in human beings, in addictive narcotics and mind-altering drugs, in sex, and in human organs. The Convention on International Trade in Endangered Species of Wild Flora and Fauna and the US Endangered Species Act attempt to remove listed species from the market and free their conservation from dependence on economistic benefit–cost analysis. As Sagoff says, echoing Immanuel Kant, an 18th-century philosopher of enormous influence in modern moral philosophy, 'some things have a price, others a dignity'.[72] Therefore, shadow-pricing things that have a dignity improperly conflates transcendent values with preferences, on Sagoff's account.

A Non-monetary Way to Quantify Values

Nevertheless, economists reply, in the real world of scarcity we have to trade one thing off against another.[73] And, as noted, values and preferences sometimes conflict—some transcendent values with others, some preferences with others, and some transcendent values with some preferences—forcing us to choose between them. How can we make rational choices unless the things between which we must choose can be expressed in commensurable terms? More particularly for our research, how can we model agents' decision making unless we can quantitatively express the values driving choices among alternative courses of action? Mindful of the environmental-ethics critique of economic reductionism, we quantify values and preferences for purposes of comparison and rational choice not in terms of money but by means of utility functions. A Big Thicket landowner might feel uncomfortable putting a dollar figure on the tradition value of his property, just as he or she might feel uncomfortable putting a dollar figure on the intrinsic value of a grandchild or the family dog. Economists may persuasively counter Hargrove's allegation that they reduce all values to economic value by insisting on the metric function of money in their valuation exercises, but an ordinary landowner must consider trading something that might be fraught with all kinds of transcendent value for a sum of money. The lived experience of selling land that has been in the family for, say, 150 years—land cleared and worked by the landowner's great-great-grandparents who are buried there—may well be Kantian. It may feel like inappropriately putting a price on something that should have only a dignity. But when an offer to buy the property is received the price must somehow be compared with tradition value and perhaps intrinsic value. And just as all preferences are not equal, neither are all transcendent values. The tradition value of a piece of land may weigh much less than the intrinsic value of human life or liberty. If the current landowner is not otherwise wealthy, tradition value might be subordinated to the value of money as a means of satisfying preferences, such as a long-dreamed-of vacation to Europe, or of investing in other transcendent values, such as education for children.

In our models, agents represent a variety of interacting human stakeholders, including municipal governments, state and federal agencies, land developers, landowners of large tracts of undeveloped land, homeowners, and NGOs. Faced with making a decision, agents select their actions from a specified set of available alternatives. Agents select the action that best realizes their values. As noted, these values are quantified within a statistical decision analysis framework.[74] This framework encodes the value tradeoffs and uncertainties inherent in stakeholder decisions. More specifically, agents evaluate the worth of each available action according to a multi-attribute utility function and then select that action with the highest expected utility. A utility function evaluates the worth of each action with respect to each factor important to the stakeholder (e.g. tradition value and wealth). These partial utilities for each factor are then weighted by the relative importance of the factor and summed to give the overall worth or utility of the action. Stakeholder agents' utility functions are derived from quantitative and qualitative surveys. The surveys attempt to identify both the factors influencing a stakeholder decision and their relative importance.

More mathematically, faced with making a decision, agents first define the set of possible consequences, $\{c_1(A), c_2(A), \ldots, c_m(A)\}$, and their respective probabilities, $\{p_1(A), p_2(A), \ldots, p_m(A)\}$, for each available action A. The value of consequence $c_i(A)$ is expressed by an additive multi-attribute function of the general form $U(c_i(A)) = k_1 U_1(c_i(A)) + \cdots + k_n U_n(c_i(A))$. The functions $U_j(\cdot)$ represent the partial utilities of value attributes associated with the decision. The constants $k_1, k_2, \ldots, k_n \geq 0$ indicate the relative value that the agent places on the respective attributes. Following standard practice, the partial utilities functions take values between 0 and 1, and $k_1 + k_2 + \cdots + k_n = 1$. The expected utility of action A is $E[U, A] = \sum_{i=1}^{m} p_i U(c_i(A))$. Agents select the action $\hat{A}$ such that $E[U, \hat{A}] = \max_A E[U, A]$.

The decision analysis framework provides a consistent structure for adapting the model to other study areas where stakeholders may have different available actions and value structures. It is not uncommon to observe that elicited value models and the resulting decisions prescribed by a decision analysis model may differ from the decisions actually taken—people are not always rational decision makers. However, the models provide important benchmarks for investigating the effect of growth management strategies on land-use dynamics, and for evaluating the sensitivity of these dynamics to variations and temporal changes in the elicited value structures.

Notes

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[33]See Cozine, *Saving the Big Thicket* for a detailed discussion.

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