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Chapter 3

Causes and Trajectories of Land-Use/Cover Change

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3.1 Introduction

One of the key activities of the Land-Use/Cover Change (LUCC) project has been to stimulate the syntheses of knowledge of land-use/cover change processes, and in particular to advance understanding of the causes of land change (see Chap. 1). Such efforts have generally followed one of two approaches: broad scale cross-sectional analyses (cross-national statistical comparisons, mainly); and detailed case studies at the local scale. The LUCC project applied a middle path that combines the richness of in-depth case studies with the power of generalization gained from larger samples, thus drawing upon the strengths of both approaches. In particular, systematic comparative analyses of published case studies on land-use dynamics have helped to improve our knowledge about causes of land-use change. Principally, two methods exist for comparative analyses of case studies. These methods are sufficiently broad geographically to support generalization, but at a scale fine enough to capture complexity and variability across space and time.

A first method is to organize *a priori* a set of standardized case studies, wherein a common set of variables is collected at a representative sample of locales, according to common protocols that can support inferential statistical modeling. These case studies are required to use a common structure and address a pre-set collection of factors or hypothesized causal mechanisms. This approach has been successfully applied to land-change questions aimed at exploring the relationship between population growth and agricultural change (Turner et al. 1993a), identifying regions at risk of environmental change (Kasperson et al. 1995), testing the relationship between population and urban as well as rural land-use dynamics (Tri-Academy Panel 2001), and examining broad types of forest ecosystems for their relationship with institutional arrangements, mainly (Turner et al. 2004; Sader et al. 2004; Moran and Ostrom 2005). Although comparative research has been widely touted as an important goal of research (Ragin 1987; Moran 1995), there are just a handful of synthesis efforts involving the systematic collection of data *in situ* across a variety of national boundaries using common data protocols, mainly because it requires a large investment to coordinate comparative research. Actually, there is no widely accepted protocol for carrying out field studies about land-use/cover change, despite long-standing calls for standardization. Researchers opposing standardization argue that each study site is unique and that results therefore cannot be extrapolated. Some view the human-environment processes under study as simply being too complex to support robust generalization. For example, some authors assert that desertification owes to multiple causative factors that are specific to each locality and time period, revealing no distinct patterns (e.g., Warren 2002; Dregne 2002). Likewise, proponents of complexity state that correlations between tropical deforestation and multiple causative factors are contextual, many and varied, again not exhibiting any distinct pattern (e.g., Bawa and Dayanandan 1997). Undeniably context matters, yet a systematic comparison of multiple case studies often reveals a limited and recurrent set of variables associated with major land-change processes.

A second method is the *a posteriori* comparison of case studies already published in the literature (Cook et al. 1992; Matarazzo and Nijkamp 1997), preferably at the sub-national scale. It can illuminate the factors that have been found important in case studies from different parts of the world but that share the same outcome (e.g., deforestation, agricultural intensification, desertification). It also identifies how theses factors have been studied at different times, in different regions, and from the perspective of different disciplines. This provides key information for the design of future research that will be even more amenable to comparative analysis (e.g., Guo and Gifford 2002; Parmesan and Yohe 2003; Root et al. 2003; Nijkamp et al. 2004; Misselhorn 2005). The bulk of the findings presented in this chapter are synthesized from three recent meta-analyses drawing upon case studies published in peer-reviewed literature, including reviews of tropical deforestation case studies (Geist and Lambin 2001, 2002), cases of dryland degradation (Geist and Lambin 2004; Geist 2005) and a review of agricultural intensification (McConnell and Keys 2005; Keys and McConnell 2005). Other comparative studies dealt with forest-cover change (Unruh et al. 2005), agricultural change (Wiggins 2000), and urbanization (Seto et al.

2004; Elvidge et al. 2004). All these studies produced insights into the causes of land-use change and their mode of interaction (Rudel and Roper 1996; Angelsen and Kaimowitz 1999; Petschel-Held et al. 1999). In total, the first three meta-analyses concerned approximately 400 cases at the sub-national scale, mainly in the tropics. In order to ensure a basic standard of quality, the cases were identified primarily from the Web of Science of the Institute for Scientific Information (ISI); in the case of agricultural intensification, some supplementary cases were drawn from other indexes such as JSTOR (http://www.jstor.org/, subscription required) and AGRICOLA (http://agricola.nal.usda.gov/), and books. Each of the cases were coded into databases recording the presence in the case study of each of a suite of social and biophysical factors found to be associated with the outcome of interest (e.g., deforestation). These databases were then analyzed to detect patterns of co-occurrence of causal and contextual conditions, using multiple cross-tabulation (Geist 2006a).

These meta-analyses have identified sets of underlying causes of land-use/cover change at a time scale of around 300 years from now (see Chap. 2). They are detailed in the following, for changes in tropical forests, drylands, areas of intensive agricultural production, and urban zones worldwide. They are clustered in terms of biophysical (Sect. 3.3.1), economic and technological (Sect. 3.3.2), demographic (Sect. 3.3.3), institutional (Sect. 3.3.4) and cultural factors (Sect. 3.3.5). These various groups of drivers are strongly interlinked across two or several levels of organization of human-environment systems. They were found to interact directly via feedbacks, and thus often have synergetic effects (Lambin et al. 2003; Steffen et al. 2004). It has also been argued that the many processes of globalization cross-cut the local and national pathways of land-use/cover change, amplifying or attenuating the driving forces by removing regional barriers, weakening national connections, and increasing the interdependency among people and nations (Lambin et al. 2001, 2002). Likewise, an integration of diverse, causal factors across temporal and spatial scales has been promoted by the concept of land-use transition or, more narrowly, forest transition (Mather et al. 1998, 1999; Rudel et al. 2000, 2002b; Mather 2004; Rudel et al. 2005).

Other important concepts are those of pathways or trajectories of land-use change, also referred to as spirals or "syndromes" (Moran et al. 2002; McCracken et al. 2002; Lambin et al. 2003; Mustard et al. 2004; Geist et al. 2006). Over the last decade, both place-based research and comparative analyses of land-use change studies identified some dominant pathways leading to specific outcomes. They are presented in this chapter as typical successions or dominant "stories" of causes and events of, for example, tropical deforestation. They vary substantially between major geographical entities and over time. Finally, from summarizing a large number of case studies, an attempt is presented to arrive at a limited number of fundamental, high-level causes of land-use/cover change (Lambin et al. 2003).

3.2 Explaining Land Dynamics

There are two fundamental steps in any study of land change, i.e., detecting change in the landscape, and ascribing that change to some set of causal factors. Establishing the change in the dependent variable is by no means simple, but advances in the acquisition, processing and interpretation of remotely sensed imagery over the past decade have made it much easier (see Chap. 2). This task pales in comparison, however, to that of explaining the observed change, i.e., identifying and assigning causal power to candidate factors. The research approach of detecting change in land cover and elaborating the causal and contextual factors responsible for that change bears little resemblance to classical experimentation, as understood and practiced in many other realms of global change research. Some study designs, however, may pretend to quasi-experimentation, for example in the case of so-called "natural experiments". In natural experiments, one identifies real-world situations that allow controlling for as many potential causal factors as possible, while looking for variation in one key factor that distinguishes the cases from one another. Transboundary situations, for example, permit comparative analysis of the implications for land use of contrasting macro-economic policies or land-tenure systems. In order to properly address the causes of land dynamics, it is important, first, to be clear on the distinction between land cover and land use (see Chap. 1), and, second, to broadly distinguish between proximate *versus* underlying causes.

3.2.1 Proximate Versus Underlying Causes

Identifying the causative factors requires an understanding of how people make land-use decisions and how various factors (including the biophysical setting and changes therein) interact in specific contexts at the local, regional, or global scale to influence land-use decision-making. The links between human activities and land-use/cover change, as adopted by the LUCC project, have been conceptualized by Turner et al. (1993a), and Ojima et al. (1994), among others – see Fig. 3.1. An important distinction is between proximate and underlying causes of land-use change (Turner et al. 1993a, 1996; Lambin et al. 2001). This framework has been widely applied (e.g., Nielsen and Zöbisch 2001; Xu and Wilkes 2004; Geist 2005; Misselhorn 2005).

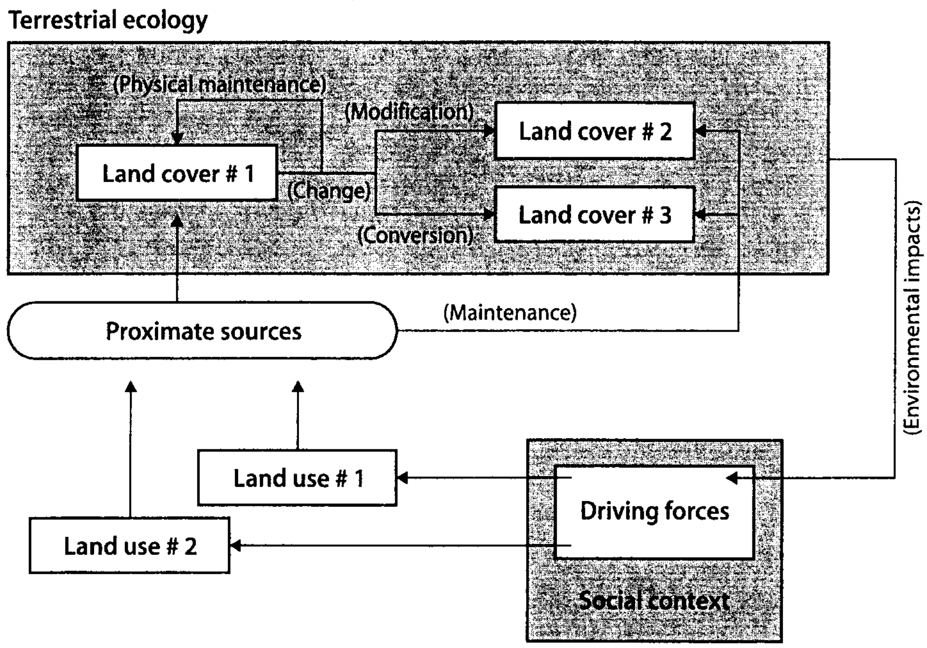

Fig. 3.1.
Links between human activities and land use and land cover.
Source: Ojima et al. (1994)

Land use is the sum of the proximate causes of land-cover change, i.e., human activities or immediate actions that originate from the intended manipulation of land cover (see Chap. 1). Proximate (or direct) causes involve a physical action on land cover and are usually limited to a recurrent set of activities such as agriculture (or agricultural expansion), forestry (or wood extraction), and infrastructure construction (or the extension of built-up structure). Proximate causes generally operate at the local level, for example, of individual farms, households or communities (Lambin et al. 2003; Mather 2006a). These are considered "direct drivers" of ecosystem change, along with other proximate factors such as species introduction or removal (see Chap. 4).

Underlying (or root, or indirect) causes are fundamental forces that underpin the more proximate circumstances. They operate more diffusely (i.e., from a distance), often by altering one or more proximate causes. Underlying causes are formed by a complex of social, political, economic, demographic, technological, cultural and biophysical variables (Brookfield 1999) that constitute structural (or systemic) conditions in human-environment relations. In contrast to proximate causes, underlying driving forces may originate from the regional (districts, provinces, or national), or even global levels, with complex interactions among levels of organization (Mather 2006b). A limited set of about half a dozen broad fundamental forces or root causes is consistently used in global environmental change research, i.e., technological, economic, political, institutional, demographic, and (socio)cultural factors. At the global scale, these fundamental forces influence the level of production and consumption of ecosystem services and collectively control the trajectory of (non)sustainable land or resource use (U.S. National Research Council 1999; Millennium Ecosystem Assessment 2003, 2005). Changes in any of these indirect drivers usually result in changes in one or more of the proximate factors, thus triggering land-use/cover changes. Especially in tropical zones, underlying causes are often exogenous to the local communities managing land and are thus difficult to control by these communities. Only some local-scale factors are endogenous to decision makers (Lambin et al. 2003).

In explaining land change, a web of factors thus needs to be considered that links the proximate and underlying levels (Kaimowitz and Angelsen 1998). Note that the proximate/underlying distinction depends on the spatial and temporal scales of analysis. Land-use decisions are made at a variety of scales (individual, household, community, nation and international environmental/trade agreements), and understanding is sought all the way from the very local to the global scale. Factors that appear quite distal and therefore exogenous for the purposes of a local case study (such as a government credit scheme) may be entirely endogenous to a national study aimed at assessing the effectiveness of that very policy.

One of the best examples where both the distinction between and the interaction among proximate and underlying causes can clearly be seen is tropical deforestation (Walker 2004). Based on the works of Ledec (1985), Angelsen and Kaimowitz (1999) and Contreras-Hermosilla (2000), among others, a meta-analytical framework was applied to identify the broad categories of proximate causes and underlying driving forces which were further subdivided into specific variables as found in a wide array of case studies from various regions of the world. At the level of proximate causation, the broad category of agricultural expansion, for example, falls into cropping and livestock activities with further subdivisions such as shifting cultivation and sedentary cropping, to be further subdivided into large-scale *versus* smallholder farming. Likewise, the broad category of wood extraction falls into commercial timber logging, fuelwood and polewood extraction for domestic uses, and charcoal production, with further subdivisions possible between clear-cutting, selective logging, state-run *versus* private company activities, etc. (Geist and Lambin 2001, 2002). At the level of underlying causation, the most prominent causal clusters are made up of economic factors, institutions, and national policies, with subsequent subdivisions (Geist and Lambin 2001, 2002).

3.2.2 The Context of Land Change: Slow Versus Fast, and the Role of Mediating Factors

It is useful to recognize that both anthropogenic and biophysical processes can be gradual, slow-moving and/or delayed, with long turnover times (e.g., the domestication of wild plants, tectonic forces), or they can work quite rapidly and be immediate, as trigger forces of land-cover change (e.g., violent conflict leading to mass movement of people, extreme weather events). Slow-intervening factors with long turnover times usually determine the boundaries of sustainability and collectively govern a land-use trajectory (such as the spread of salinity in irrigation schemes or declining infant mortality). However, fast variables or trigger events drive land-use changes as well. Generally, land-use dynamics are driven by a combination of factors or processes that work gradually and factors that happen intermittently (Lambin et al. 2001; Stafford-Smith and Reynolds 2002). Also, a random element can be important in several land-change situations, as discussed for Sudano-Sahelian land-use systems by Reenberg (2001).

The interplay between underlying and proximate causes may be shaped or modified by a number of mediating factors. In particular, underlying factors do not operate individually; rather they are themselves shaped by other factors. For example, population increase in a given area – often considered an underlying cause of land change – may be amplified or modulated by existing or changing social norms, and by fertility or resettlement programs, which may in turn be influenced by changes in knowledge and policy at national and international levels. It is helpful to recognize that some factors concern the motivation to change behavior, while others function in contextual ways, often filtering the effects of other factors (Turner 1989; Moran 2005).

A mediating factor – sometimes also labeled intermediate, filter or context variable – constitutes a biophysical or socio-economic causative factor which shapes, modifies or intervenes into the interplay between underlying driving forces and proximate causes. Often cited examples of mediating factors are gender, ethnic affiliation, class or wealth status (and thus power relations), and institutional arrangements regulating the access to land (e.g., privately-held, communally-held, and federal- and state-held forests), but also include biophysical properties (Turner 1989; Agrawal and Yadama 1997; Young 2002a, 2003; Tole 2004; Moran 2005). Researchers have found that demographic and economic factors in particular do not work in an unmediated fashion. For example, in the Mayan zone of the Yucatán peninsula, the presence of male population increases the probability of deforestation in a statistically significant manner, while the presence of female population decreases the same probability (Sader et al. 2004). This begs the question of the effects of mediating sociocultural and institutional factors.

Biophysical factors conditioning land use include the properties of the landscape – its soils, terrain, climate, hydrology, as well as native flora and fauna, and location relative to human settlement, thus contributing to various degrees to land quality, in particular the condition of land relative to the requirements of a given land use (Pieri et al. 1995; Stone 1996; Dumanski and Pieri 2000). While these factors generally constitute the context within which land use takes place in the sense of initial conditions (or pre-disposing environmental factors), their dynamics – soil degradation and aridification, for example – can assume causal power. Thus, dramatic biophysical changes, such as increased aridity or drought, may be considered proximate causes, while they may be seen as contextual factors when operating gradually, shaping both natural (potential) land cover as well as land-use dynamics (Brookfield 1999). Similar is the dual character or role of institutions in causing and/or mediating land-use/cover change (Young 2002a, 2003).

At the proximate level, the conversion of tropical forests into agricultural uses, for example, is often found to be mediated by the unequal relations between large-scale farmers or corporate agricultural enterprises and smallholders eking out a living, thus creating "entrepreneurial" *versus* "populist" agricultural frontiers with rather distinct land uses (Turner 1920; Schneider 1995; Walker et al. 2000; Pacheco 2006a,b). Likewise, all categories of what has been called "agrodiversity" (Brookfield 2001) in settled agricultural zones – i.e., biophysical diversity, management diversity, agro-biodiversity, and organizational diversity – are shaped by factors that play out differently at various time and spatial scales. For example, crop choice and type of conservation practices often differ between poor and rich farmers, thus affecting the pattern of management diversity, and feeding back to enlarge differences in natural land quality (Brookfield et al. 2003; Xu and Mikesell 2003).

At the underlying level, mediating factors may severely alter the impact of similar demographic forces, shaping the trajectory of land change towards degradation or restoration. Whether or not increasing population is damaging or beneficial, for example, depends upon a variety of institutional, ecological, or technological factors. This implies that population growth can cause land degradation in the short term, but it can also spur innovation and agricultural intensification as well as the adoption of conservation techniques (Boserup 1965, 1975, 1981, 2002; Mortimore 1993a; Mortimore and Tiffen 1994; Tiffen and Mortimore 1994; Tiffen et al. 1994a).

Furthermore, mediating factors are crucial for the response of land managers to external forces, i.e., feedbacks are strongly mediated by local factors such as access to land, gender, education and institutional arrangements. In particular, institutions need to be considered at various scales to identify those local mediating factors that, together with peoples' adaptive strategies or responses to changing market opportunities, shape land-use change (Agrawal and Yadama 1997). Local participation in natural resource conservation, for example, is strongly mediated by a community's interactions with non-local actors such as national governments, transnational corporations, and international non-governmental organizations (Sundberg 2003). Seen together with other examples, these "conservation encounters" can shape landscapes and livelihoods in rather contradictory ways. In the Mayan zone, for example, local evidence of high deforestation can be found close to locations where exceptionally low rates of deforestation have occurred, with intervening institutional factors making the difference (Bray et al. 2004; Klepeis and Chowdhury 2004).

It is important to understand that, as land use is conditioned on the biophysical and social milieu, its effects cascade through the human-environment system, altering that milieu, and thereby changing the perception by land managers of the conditions for future land-use decisions. Thus, neither the social nor biophysical contexts are static. Quite the contrary, they reflexively shape, and are shaped by the collective actions of land managers (Lambin et al. 2003; Steffen et al. 2004). Therefore, a significant obstacle to the synopsis presented below is that factors that are crucially important in explaining change in one place may be irrelevant in other nearby places, and therefore not mentioned in a study of that other place. By the same token, a given factor (e.g., improved market access) may be implicated in opposite land-cover outcomes (e.g., increase/decrease in woody biomass). This happens for two reasons. First such factors are never identical from one instance to another (e.g., the particular incentives provided by a market to which access has been improved). In addition, even when the factor in question is quite similar, its effects will depend on the biophysical and socio-cultural context within which each land manager experiences it.

3.3 Synopsis of Broad Factors Affecting Land Change

3.3.1 Biophysical Factors

General Remarks

Biophysical factors – whether gradual processes, trigger events or filter variables – define the natural capacity or predisposing environmental conditions for land-use change, with the set of abiotic and biotic factors – climate, soils, lithology, topography, relief, hydrology, and vegetation – varying among localities and regions and across time (Lambin et al. 2001). The variability in biophysical factors and natural environmental changes interact with the human causes of land change. For example, biophysical limitations such as steep slopes and difficulty of access can provide considerable but not necessarily sufficient protection for a forest. From a wide array of case studies, it appears that institutional factors (see Sect. 3.3.4), in combination with biophysical limitations, play a major role in protecting limited forest areas from deforestation and erosion (Moran 2005).

Highly variable ecosystem conditions driven by climatic variations amplify the pressures arising from high demands on land resources, especially under dry to subhumid climatic conditions, whereas the role of climatic influences, for example, in temperate and humid zones is less pronounced (Lambin et al. 2003). Natural and socioeconomic changes may operate as synchronous but independent events. In the Iberian Peninsula during the 16th and 17th centuries, for example, the peak of the Little Ice Age occurred almost simultaneously with large-scale clearing for cultivated land following the consolidation of Christian rule over the region, which triggered changes in surface hydrology and significant soil erosion (Puigdefábregas 1998). In part because of human activities, the Earth's climate system has changed since the reindustrialize era, and is projected to continue to change throughout the 21st century – in terms of warmer temperatures and spatial and temporal changes in precipitation patterns, among others (see Chap. 4).

Natural variability may also lead to socioeconomic unsustainability, for example when unusually wet conditions alter the perception of drought risks and generate overstocking on rangelands. When drier conditions return, the livestock management practices are ill adapted and cause land degradation. This overstocking happened several times in Australia and, in the 1970s, in the African Sahel (Geist 2005). Land-use change, such as cropland expansion in drylands, may also increase the vulnerability of human-environment systems to climatic fluctuations and thereby trigger land degradation (Okin 2002).

Forest Change

In tropical forest zones, land characteristics or features of the biophysical environment – e.g., soil quality, low lying zones, flat and gently sloping areas, high density of marketable woods, and closeness to water – were found to be among causative factors of deforestation (in 14% of the cases reviewed) – see Table 3.1. Soil-related features clearly dominated in cases of forest-pasture conversion in Latin America (less so in cases of forest-cropland conversion) (Geist and Lambin 2001). However, this phenomenon can be related to both forests on fertile soils located on flat ground (i.e., most of the soil-related cases) and to forests on poor soils (i.e., in some of the cases), since meager soil endowment sets the context for accelerated clearing to put more land into cultivation (Hecht 1993). In addition, biophysical triggers – such as soil fertility collapse, drought, weed intrusion and forest fires – appeared in 18% of the deforestation cases (Geist and Lambin 2001). The impact of mostly natural fires on land cover in boreal regions has been well documented (Kasischke et al. 2002), mainly using remote sensing data (which is also true for the mostly anthropogenic fires in tropical regions; e.g., Pereira et al. 1999). In contrast to drylands, where increased aridity is a widespread factor in desertification, drought-induced forest fires are important so far only in the Amazon Basin or Indonesia. In Indonesia, for example, periodic El Niño-related droughts in the late 1990s lead to an increase in the forest's susceptibility to fires, with accidental fires becoming more likely under such conditions, leading to the devastation of large tracts of forests (Siegert et al. 2001). Forests that have been affected by forest fragmentation, selective logging, or a first fire subsequently become even more vulnerable to fires as these factors interact synergistically with drought (Siegert et al. 2001; Cochrane 2001; Csiszar et al. 2004). In general, fires as causative factors of land-use/cover change result from a combination of climatic factors (which determine fuel availability, fuel flammability, and ignition by lightning), and factors related to land-use/cover change that control fire propagation in the landscape and human ignition (Lavorel et al. 2005).

Dryland Change

In dryland zones of the world, soil conditions constitute key criteria in assessing the presence and severity of land degradation there, and in particular climatic factors are of overriding importance (in 86% of the cases reviewed) (Geist and Lambin 2004) – see Table 3.2. As underlying driving forces leading to increased aridity at the proximate level, climate factors can affect land cover in the form of prolonged droughts (Nicholson et al. 1998). Likewise, rainfall trends at meteorological stations in north-

Table 3.1.
Biophysical factors associated with forest conversion and modification in the tropics

	All	Asia	Africa	Latin America
Land characteristics (biophysical features)				
Soil quality	12	1	0	11
Slope, topography	7	0	2	5
Watercourse/water body	6	0	0	6
Vegetation	4	1	0	3
Biophysical triggers				
Soil-related	7	4	2	1
Water, climate	10	3	2	5
Vegetation-related	18	9	4	5

Total number of cases is 152; multiple counts possible. *Source:* Geist and Lambin (2001), p. 31.

Table 3.2.
Biophysical factors causing land degradation in drylands

	All	Asia	Africa	Latin America
Indirect impact (climatic variability)				
Higher rainfall deficit	37	3	24	1
Warmer, drier	34	23	5	0
Direct impact (on land cover/surface vegetation)				
Changes in fire regime	16	0	3	0
More oscillations of dry/wet conditions	12	0	0	6
Simple occurrence of droughts	42	17	20	2

Total number of cases is 132; multiple counts possible; not included are data for Europe, Australia and North America. *Source:* Geist (2005), p. 100.

western Senegal show a negative slope until the 1990s which is in congruence with all data from the West African Sahel (Gonzalez 2001). Climatic factors also operate indirectly, through changes in land use resulting from variation in rainfall (Nicholson 2002); rainfall changes at the landscape level, for example, can trigger significant shifts in soil type priorities (Reenberg 1994; Reenberg et al. 1998). Estimating from a wide array of case studies, the most widespread mode of causation by biophysical factors in drylands is reported to be climatic conditions operating concomitantly or synergistically with socio-economic driving forces such as technological changes.

Cropland Change

In zones of intensified agricultural production, biophysical factors figure prominently, namely precipitation, topography, presence and proximity of water bodies, and soil conditions (in almost 40% of the cases reviewed) (McConnell and Keys 2005) – see Table 3.3. Frequently, soil factors – mainly declining fertility, but also erosion – affected the specific location of different agricultural practices, for example when farmers adopt new practices to exploit micro-environments (e.g., bottom lands) (Kasfir 1993), often as a result of a change in access to land. Likewise, it has been shown that soil erosion on the Greek island of Lesvos was an important factor in the abandonment and reallocation of cereals in intense, mechanized agricultural systems during the 1886–1996 period (Bakker et al. 2005). Alternatively, choices about which lands to continue cultivating and which to let revert to forest regrowth have been observed to change over time, as settler communities learn about local environmental conditions in agricultural frontiers (Moran et al. 2002). Climatic factors, primarily changes in precipitation, were found in just over a quarter of the cases of agricultural intensification in croplands (McConnell and Keys 2005; Keys and McConnell 2005).

3.3.2 Economic and Technological Factors

General Remarks

Economic factors appear to play a strong role. This should not come as a surprise since global economic activity increased nearly sevenfold between 1950 and 2000 (while global population doubled in roughly the past 40 years), thus increasing the demand for many ecosystem goods and services (Millennium Ecosystem Assessment 2005). Available case studies highlight that, at the timescale of a couple of decades or less, land-use changes mostly result from individual and social responses to economic conditions, which are mediated by institutional factors (Agrawal and Yadama 1997; Lambin et al. 2001). Opportunities and constraints for new land uses are created by markets and policies and are increasingly influenced by global factors (see Sect. 3.4.3).

Economic factors (and related policies) encompass a number of distinct processes that require individual treatment. They define a range of variables that have a direct impact on the decision making by land managers, e.g., input and output prices, taxes, subsidies, production and transportation costs, capital flows and investments, credit access, trade, and technology (Barbier 1997). In particular, taxes and subsidies are important driving forces of land-use dynamics and related land cover and ecosystem changes. Currently, many subsidies substantially increase rates of resource consumption and negative externalities. It has been estimated that currently about 2 000 billion U.S.$ are spent in the form of "perverse subsidies" (Myers and Kent 2001) each year, which equals the annual income of the most impoverished 1.3 billion people on Earth (including agriculture, especially irrigation farming, and forestry, but also fishery, transport, and energy production). The 2001–2003 average subsidies, for example, paid to the agricultural sectors of member states of the Organization for Economic Cooperation and Development (OECD) were over U.S.$324 billion annually, encouraging greater food production and associated water consumption and nutrient and pesticide release (see Chap. 4). At the same time, many developing countries also have significant agricultural production subsidies. On the other hand, fertilizer taxes or taxes on excess nutrients, for example, provide an incentive to increase the efficiency of the use of fertilizer applied to crops and thereby reduce negative externalities (Millennium Ecosystem Assessment 2005).

Consumption ranks high among economic factors (Myers 1997; Kates 2000). The market demand for forest products and for agricultural output, including livestock-based products, not only encompasses basic needs (i.e., food crops for human and animal diets, fiber crops for clothing, timber for shelter), but also derived or relative needs (Keynes 1936; Maslow 1943) which go beyond the

Table 3.3. Biophysical factors associated with land-use dynamics in croplands

	Important	Not important	Absent
Precipitation variation	30	30	48
Watercourse/water body	23	35	50
Soil properties	43	27	38

Total number of cases is 108; multiple counts possible. *Source:* McConnell and Keys (2005), p. 334.

immediate satisfaction of fundamental livelihood requirements (e.g., exotic tropical timber and fruits, counterseasonal fresh agricultural produce) (see Sect. 3.3.5). Increasing demand affects both the expansion of cropland and pastures into forests (e.g., cattle, soya) and drylands (e.g., cotton, rice, vegetables), as well as various forms of intensification of existing farmland, including the planting of trees (e.g., coffee, fruit trees) (Geist and Lambin 2002; McConnell and Keys 2005; Geist 2005).

Available case studies highlight that the effects of local consumption on land-use patterns often is decreasingly important relative to external consumption (Tri-Academy Panel 2001). Be it in core agricultural lands or at tropical forest and dryland margins, much of the demand originates from nearby urban areas as well as from very distant (global) markets (McConnell and Keys 2005; Geist et al. 2006). Market demand exerts a "pull" on rural producers to engage in land-use practices beyond subsistence production. The possibility (or necessity) of purchasing goods or services constitutes a "push" factor. Of course, very few people are completely disengaged from markets, and even before subsistence demands are satisfied, rural producers are often prompted to commercialize at least some portion of their production. As they gain access to a wider range of products and services, and to information about lifestyles in other parts of their country, or the world, consumer aspirations rise (see Sect. 3.3.5). At the same time, government policies contribute to push factors as well, with market access remaining largely conditioned by state investments in transportation and other infrastructure (in fact there are few, if any, market factors that are free of the influence of the state).

Related to this demand-driven pattern are two global observations. First, subsistence croplands are decreasing in extent, while land under crops for markets is increasing, with a parallel increase in agricultural intensity, strongly driven by agro-technological measures of the Green Revolution since about the 1960s (see Chap. 2). And, second, local consumption has changed in response, with a shift in diets from traditional grains or starchy staples (such as rice, wheat, and potatoes) to diets including more fat (such as meat, dairy products, and fish) but also more fruits and vegetables (Tri-Academy Panel 2001; Millennium Ecosystem Assessment 2005). The former is true even for world regions with strong religious taboos on nonvegetarian food – see Box 3.1.

Forest Change

In tropical forest zones, economic and technological factors are prominent underlying driving forces, found in a preponderance of the cases reviewed (Geist and Lambin 2001, 2002) – see Table 3.4. Among the economic factors, commercialization and the growth of national and international timber markets as well as market failures are frequently reported to drive deforestation. Economic variables such as low domestic costs (for land, labor, fuel, or timber), product price increases (mostly for cash crops), and the demands of remote urban-industrial centers underpin about one-third of the cases, whereas the requirement to generate foreign exchange earnings at a national level intervenes in a quarter of the cases. With few exceptions, factors related to economic development through a growing cash economy show little regional variation and, thus, constitute a robust underlying force of deforestation. Likewise, technological factors such as agrotechnological change – i.e., land-use intensification

Box 3.1. Land-use change in Haryana, India, during the 2nd half of the 20th century

Haryana, located in an arid to semi-arid environment in the northwestern part of India, comprises part of the wheat-growing "breadbasket" of the country, together with its northern neighbor state of Punjab. Major transformations of land cover into rice-wheat rotations – as in the rest of the Indo-Gangetic Plains – coincided with the introduction of Green Revolution technologies. Mainly initiated in the period 1967–1978, major aspects of the Green Revolution were the expansion of the cropland, the adoption of double-cropping systems (i.e., two crop seasons per year) and seeds that had been improved genetically (i.e., high-yielding varieties (HYVs) of wheat, rice, corn, and millet), and high inputs of fertilizer and water for irrigation. This attracted not only large numbers of migrants from other parts of India, but also made it possible that increased agricultural productivity kept pace with population growth, the rate of which is among the highest in India. During the state's high-growth period over the past three decades, the sectoral change in land use was rather small – i.e., the area devoted to croplands has remained fairly constant since 1971 at 81% of the total area (indicating that the potential for expansion of cultivation was already exhausted then) –, but farmers moved away from the production and consumption of traditional staple crops (such as maize, barley, gram, millet/bajra and pulses) and modified their farming systems toward income-producing cash crops (such as rice, wheat, and cotton). State policies amplified this trend by favoring the semiarid Green Revolution areas with infrastructural projects at the expense of the more arid western parts of Haryana. For example, public priority is given to large-scale investments (expansion of canals and pumping of groundwater for irrigation), state subsidies are provided for electricity (tube wells), credits and marketing facilities, price policies stabilize output prices (wheat) and favor cotton as well as oilseeds, and most of the (wheat) production surplus is procured by government agencies for sale through public distribution system networks in India. With continuation of the price support system for wheat and rice throughout the 1970s and beyond, rice-wheat crop rotations became a lucrative proposition for the farmers, and Haryana continues to be an important supplier of food for the country. In terms of food consumption, however, the share of cereal grains declined significantly in rural as well as urban areas from 1972 to 1993: milk and dairy products have replaced cereal grains as the now most important component of food expenditure, also fulfilling a sizable portion of the demand for livestock products in Delhi and several other urban centers (Vashishta et al. 2001).

Table 3.4.
Economic and technological factors of forest conversion and modification in the tropics

	All	Asia	Africa	Latin America
Market growth, commercialization	103	30	15	58
Sectoral market growth	(78)	(23)	(13)	(42)
Demand/consumption	(69)	(24)	(13)	(32)
Market failures	52	22	6	24
Urban-industrial growth	58	23	5	30
Foreign exchange	38	16	5	17
Special variables (low cost, price change)	48	9	5	34
Agrotechnological change	70	28	8	34
Poor timber/wood extraction techniques	69	39	8	22

Total number of cases is 152; multiple counts possible. *Source:* Geist and Lambin (2002), p. 148.

Table 3.5.
Economic and technological factors causing land degradation in drylands

	All	Asia	Africa	Latin America
Market growth, commercialization	64	37	8	9
Economic depression, impoverishment	48	22	9	8
Innovative developments, introductions	73	35	12	7
Deficiencies of technical applications	67	31	17	3

Total number of cases is 132; multiple counts possible; not included are data for Europe, Australia and North America. *Source:* Geist and Lambin (2004), p. 823.

as well as agricultural expansion –, and poor technological applications in the wood sector (leading to wasteful logging practices) have no distinct impact regionally (Geist and Lambin 2002).

Perhaps most striking in the analysis of economic and technological factors in forest zones is their multiple and sometimes contradictory effects (see Sect. 3.5.3). The most general pattern of economic effects follows directly from differences in the local abundance of forest resources. Forest-rich regions like the Amazon, insular Southeast Asia, and central Africa become the focus for large-scale logging and agricultural expansion, driven in part by a desire to capitalize on the store of natural resource value on the land, so in these instances economic incentives accelerate deforestation. Forest-poor regions like South Asia and peri-urban places in East Africa see very different trends. In these places, increases in the prices of scarce forest products induce afforestation, and both smallholders and the state respond to economic incentives by planting trees where there were none (Rudel 2005; Unruh et al. 2005).

Improved agricultural technology – while providing secure land tenure and giving farmers better access to credit and markets –, can potentially encourage more deforestation rather than relieving pressure on the forests. The differing impact of agricultural development on forest conversion depends on how the new technologies affect the labor market and migration, whether the crops are sold locally or globally, how profitable farming is at the forest frontier, as well as depending on the capital and labor intensity of the new technologies (Angelsen and Kaimowitz 2001b).

Dryland Change

In dryland zones, economic and technological factors were prominent underlying driving forces in about two-thirds of the cases of land degradation (or desertification) reviewed (Geist and Lambin 2004) – see Table 3.5. Economic factors are reported to underlie desertification in the form of a mixture of "boom" and "bust" factors, though with considerable regional variations. Boom factors relate to market growth and commercialization, mainly entailing export-oriented market production, industrialization, and urbanization. Farmers respond to market signals reflecting high external demands for cotton, beef, and grain, with mostly native grassland increasingly put under rain-fed or irrigated production. Bust factors relate to the overuse of land because of land scarcity, low investments, low labor availability, indebtedness, lack of employment in the formal nonagrarian sector, or poverty (Geist et al. 2006). In dryland zones of Asia, cases of desertification are mainly driven by remote influences such as urbanization and commercialization. For example, among the many drivers of land change in various regions of Syria, most prominent are those which are the result of individual decisions made for economic opportunity, supported by state planning (Hole and Smith 2004) – see Box 3.2. In many cases from Australia and Latin America, local farmers' response to an unfavorable economic situation, coupled with cycles of low rainfall, is reported to underlie desertification: declining prices in the export-oriented sheep sector, for example, cause farmers to go into debt when their farms are no longer economically

Box 3.2. Economic factors of steppe conversion in Syria during the 2nd half of the 20th century

Since the founding of the Syrian state in 1946 at the end of the French mandate, the socialist government created a series of Five Year Plans for overall economic and social development. From the standpoint of land use, the most important of these was to increase agricultural productivity to accommodate a rapidly growing population and increasingly affluent society. These plans gave rise to land reform, creation of agricultural cooperatives, economic incentives and subsidies for production, the building of reservoir and canal systems, grain silos and a first class road system. While production has never met the ambitious goals set in these plans, most of the potentially productive steppe land has now been transformed (Hole and Smith 2004).

viable, inducing the overuse of scarce natural resources, especially during droughts (Geist 2005).

Different from the regional variations in economic factors driving desertification, most of the technological factors are pervasive driving forces. Most strikingly, technological innovations are reported to be associated with desertification (but also deficiencies of technological applications). Innovations mainly comprise improvements in land and water management through motor pumps and boreholes (at the village level) or through the construction of hydrotechnical installations such as dams, reservoirs, canals, collectors, and artificial drainage networks (for large-scale irrigation schemes) – see Boxes 3.1 and 3.2. When applied, these developments are often coupled with high water losses due to poor maintenance of the infrastructure, especially in the Asian studies. In addition, they induce fundamental and often irreversible changes to the natural hydrographic network, altering hydrological cycles in most cases. The disaster of the Aral Sea is an extreme case of such perturbation (see Sect. 4.7). Technological applications associated with desertification also include transport and earthmoving techniques (trucks, tractors, carterpillar-tracked vehicles) and new processing and storage facilities (refrigeration containers on ships and trucks). These innovations can trigger rapid increases in production at remote sites (e.g., greater numbers of irrigated garden products or herds of sheep, both destined for distant markets). It should be noted though that some research, especially in Asia, is devoted to technologies that might be used to stabilize the sand that is threatening expensive highway, railroad, and irrigation infrastructure. Thus, technology may also make it possible to mitigate some of the adverse impacts of desertification (Geist and Lambin 2004; Geist 2005).

Cropland Change

In zones of high-intensity agriculture, market demand was reported in the case studies more often than population as a causal variable (McConnell and Keys 2005) – see Table 3.6. Improved market access, as a separate variable, was found to be important less frequently than market demand but showed regional variations and usually occurred concomitantly (cases where market access did not occur concomitantly with demand imply that there was improved access to a largely unchanged market in terms of demand). A related variable, standard of living, was important less often than market access but when present occurred almost always in conjunction with market access. A possible linkage was also discovered between market access and the availability of off-farm employment, which was judged important in less than one-third of all cases. Technological factors – such as agrotechnical change or the provision of water-related infrastructure – rank lower in core agricultural zones, implying that there was sufficiently developed infrastructure no longer triggering agricultural change (McConnell and Keys 2005).

In Sub-Saharan Africa, case studies from the 1970s to the 1990s, done at the village or district levels, confirm that demand from and access to a market is essential for agricultural development (which has been the single biggest idea in the policy reforms of the 1980s), but they also underline the importance of the detail of policy, i.e., in remedying failures in public investment in technology and in product, capital and insurance markets (Wiggins 2000). From an array of other, partly overlapping cases, explored by McConnell and Keys (2005), it could be seen that land-use intensification involved a change of cultivars and livestock without any explicit change in water management. Gains in productivity were seen to be coming from more frequent use of the land, that is, reduction in length of fallows. Land-use changes largely consisted of three dynamics. Farmers used farmland more frequently (decreasing fallow time); shifted from mainly consumption-oriented production of staple foods toward the adoption of cash crops like peanuts and cotton, and tree crops such as coffee, tea, palms, and vanilla; and switched from rain-fed production to small-scale irrigation, in the form of urban and kitchen gardening (Eder 1991; Mortimore 1993b; Drescher 1996). The adoption of high-yield varieties, particularly maize, was seen in several cases and resulted in increased output. Finally, changes in livestock practices, including replacement of grazing with cropping and intensive stabling (zero grazing), also were seen (Benjaminsen 2001; Bernard 1993; Carney 1993; Conelly and Chaiken 2001; Ford 1993; Goldman 1993; Gray and Kevane 2001; Kasfir 1993; Kull 1998; Laney 2002; Netting et al. 1993; Okoth-Ogendo and Oucho 1993; Tiffen et al. 1994b).

In Latin America, market-driven agricultural extension efforts were credited with the adoption of new crops, such as cocoa, rubber, coconut and improved pasture, as well as mechanical technology (e.g., tractors), credit (e.g., marketing cooperatives and soft loans), and infrastructure (e.g., roads and small-scale irrigation) (McConnell

Table 3.6.
Economic and technological factors causing land dynamics in croplands

[illegible]	Important	Not important	Absent
Market access	58	18	32
Standard of living	48	32	28
Market demand	69	11	28
Off-farm employment	30	28	50
Water provision program	16	0	92
Infrastructure program	33	10	65

Total number of cases is 108; multiple counts possible. *Source:* McConnell and Keys (2005), p. 333.

and Keys 2005). Specific government policies included fines for leaving fields fallow, such as in Peru (Wiegers et al. 1999; Coomes et al. 2000), and nature conservation and import controls (Taussig 1978). Likewise, nongovernmental organizations were credited with the provision of capital and knowledge (e.g., in limiting erosion on hillsides and green manure application). Changes in labor input play an important role, with reference, in some cases, to increased labor requirements associated with aging fields, and, in more cases, to new labor-intensive tasks such as those associated with terracing (McConnell and Keys 2005). In particular, there appears to be an issue of labor bottlenecks created in the adoption of news crops (e.g., chilies), or green manure application (Keys 2004). These arrangements are particularly problematic as Latin America is known for a variety of new, more labor-intensive crops soon to be widely introduced in the region (e.g., soybeans) (Hecht 2005; Jepson 2005). They may however, be foregoing the opportunity cost of their home-based labor for the perception of a much greater income in other locales (Schelhas 1996).

In Asia, which has the longest record of continuous large-scale irrigated agriculture, water management is an intricate part of the process of land-use/cover change (Brown and Podolefsky 1976; Abrol et al. 2002; McConnell and Keys 2005). While increased frequency of cultivation appears to be as strong as in other tropical regions, changes in cultivars seem much less frequent than in Latin America. In particular, the adoption of high-yielding rice varieties has often been accompanied by increased use of chemical inputs, demonstrating a most dramatic input of green revolution technologies (Leaf 1987; Turner and Ali 1995; Vashishta et al. 2001) – see Box 3.1. Other crops mentioned in Asian cases of agricultural change include beans, cotton, okra, Job's tears, maize, manioc, millet, mustard, peanuts, sesame, soybeans, squash, sweet potatoes, and taro. Notably, the intensification of forest-product collection and the adoption of agroforestry practices have been rather high, including bananas, cashews, coconuts, coffee, pepper, and rubber. Asian farmers, generally having secure land tenure and access to markets, manage non-timber forest products like crops, i.e., they grow them in plantations or manage them intensively in forests, and the families – usually not the poorest ones – specialize in a particular product and, indeed, get most of their income from it (Ruiz-Pérez et al. 2004). When information on market access and demand is present, access to nearby markets and changing urban market tastes has spurred notable changes in the types of crops farmed and the land-cover intensity of these crops (Leaf 1987; Eder 1991; Shidong et al. 2001b). Economic factors and related policies include direct agricultural policies such as import quotas, rice reserve requirements, and rice premiums, and the encouragement of soybean production, subsidies for market vegetables, and irrigation credits, but also nongovernmental organization programs as well as broad national or government policies such as China's Open Door policy, or tax policies favoring (agro)industrialization, market intervention, and even tax policy favoring coconuts and rubber over rice (George and Chattopadhyah 2001; Shidong et al. 2001a).

Urban Change

In major urban or peri-urban zones, economic changes together with technological and also demographic changes (e.g., growth of urban aspirations and urban-rural population distribution) have led to a greater integration of rural and urban economies. Farmers within city boundaries or in peri-urban lands have, in particular, been intensifying land use on sites which are themselves often in demand for residential or industrial development, mainly through adjusting crop types to satisfy urban food demand (e.g., Eder 1991; Guyer and Lambin 1993; Kasfir 1993; Gumbo and Ndiripo 1996; Godoy et al. 1997; Alves 2002a). As an example of one of the above-mentioned remote influences, urbanization affects land change elsewhere through the transformation of urban-rural linkages. Urban commodity demands, and, especially, the impact of rapidly growing cities, have been triggering considerable land-use/cover change (Tri-Academy Panel 2001), also affecting ecosystems goods and services, or the flow of natural resources in urban zones and well beyond in remote hinterland or watershed areas (Fox et al. 1995; Humphries 1998; Indrabudi et al. 1998; Mertens et al. 2000) (see Chap. 4).

Residential preferences for private houses in a "green" environment, and economic incentives provided by private land developers and/or the state to achieve this, drive the extension of peri-urban settlements primarily in but not limited to the developed world, fragmenting the landscapes of such large areas that various ecosystem processes are threatened. In turn, however, excessive urban sprawl (and, thus, ecosystem fragmentation) may be offset by urban-led demands for conservation and recreational land uses (Lambin et al. 2001). Economically and politically powerful urban consumers tend to be disconnected from the realities of resource production, largely inattentive to the impacts of their consumption on distant locales (Sack 1990, 1992; Heilig 1994) (see Sect. 3.3.5). For example, urban inhabitants within the Baltic Sea drainage depend on forest, agriculture, wetland, lake and marine systems that constitute an area about 1 000 times larger than that of the urban area proper (Folke et al. 1997) (see Chap. 2 and 4 for the related notion of ecological footprint).

In China, and to a lesser degree in some other developing or newly industrializing countries, urbanization usually outstrips all other uses for land adjacent to the city, including prime croplands (Shidong et al. 2001b; Seto et al. 2004). In many cases, prior occupants such as farmers or herders have been displaced into marginal dry land sites, resulting in land degradation (Geist 2005). However, cities also attract a significant proportion of the rural population by way of permanent or circulatory migration, and, given the fact that many new urban dwellers in developing countries still own rural landholdings, urban remittances to the countryside have contributed to economic growth and landscape changes in both close and distant regions (Browder and Godfrey 1997; Lambin et al. 2001). These changes often run counter to the effects of remote urban consumers in that urban remittances have relieved pressures on local natural resources. It has been shown, for example, that in a small island of Micronesia, international migration, foreign aid, and monetary remittances from family members living overseas in urban agglomerations have removed the pressures of economic crowding on mangrove forests, despite an increase in population and a decline in local government jobs (Naylor et al. 2002). Likewise, some regions in the tropics currently show signs of signification reforestation which can at least partly be traced back to urban remittances (Rudel et al. 2000). Perhaps most importantly, this urbanization changes ways of life fundamentally, associated with demographic transitions, increasing expectation about consumption and potentially a weakened understanding of production-consumption relationships which has so far been mainly noted in the developed world (Lambin et al. 2001).

For thousands of years, China was mainly rural but is becoming increasingly urban, with land-use changes there dominated by an urban transformation unprecedented in human history (nearly one quarter of the 488 major urban centers in the world are located in China; see Chap. 2). In the Pearl River Delta, which is one of the most economically vibrant regions in China, nearly all land-use changes can be attributed to an array of economic factors associated with remarkable growth and linked to respective policies supporting economic growth (as well as population mobility). For example, the establishment of three special economic zones (SEZs) in the 1980s (Shantou, Shenzen, and Zhuhai), and the formation of the Pearl River Delta (PRD) Economic Open Region in 1985, helped the area to attract foreign investment and transform itself into an export-oriented region. As a consequence, entrepreneurs from Hong Kong – due to geographic proximity and cultural ties – moved their operations into the area (accounting for almost 75% of foreign direct investments in 1996). Their overseas ventures have exerted a considerable impact on the pace and structure of economic and urban development in the PRD due to large investment flows, access to technological innovations, and managerial acumen (Seto et al. 2004).

Industrial Change

Industrialization – i.e., the transition, made possible by large-scale technological changes (coal, steam power, electrification), from agricultural society to an economy based on large-scale, machine-assisted production of goods by a concentrated, usually urban labor force (Krausmann 2006) – has driven – or gone hand-in-hand with – urbanization since the middle of the 18th century. The process has been accompanied by a surge in labor productivity in both industry and agriculture with fundamental implications for land use, expressed in terms such as those of an agrarian or "agricultural revolution" in today's developed countries (Jeleček 1995, 2006), and a "green revolution" in today's newly industrializing, less or least developed countries especially during the 1960s and 1970s (Ewert 2006).

In forest zones of the tropics, for example, more than a quarter of deforestation cases reviewed reported the growth of wood- and mineral-related industries as an underlying driving force steering economic demands stemming from the build-up of basic, heavy steel and iron industries in today's newly industrializing countries (Geist and Lambin 2002). This had also been true for historic processes of industrialization in Europe and in the eastern United States of America (Williams 1994, 2003). In drylands of the world, especially in Asia, industrialization is one of the remote influences – together with urbanization and commercialization (i.e., export orientation, market competition) – which combines with local factors such as agricultural intensification and crop choices in favor of agricultural cash produce to drive land-use changes and perhaps even degradation (Geist 2005).

Through large-scale processes of spatial specialization and concentration of population and production, industrialization has affected practically every region of the world, especially after World War II. It constitutes a global and still ongoing process which exerts effects not only on the overall economic and social structure, but is also related to land use and major biophysical transformation processes. In particular, the linkage of agriculture with the agricultural industry (e.g., sugar, tobacco, distilling, milk, and brewing industries) and with agricultural engineering (biotechnology) introduced an industrial character into agriculture in terms of the global agro-industry (see Sect. 3.4.3). It is also considered, in conjunction with social, political, and demographic changes, to be the major factor behind forest transitions worldwide (see Sect. 3.5.3).

3.3.3 Demographic Factors

General Remarks

At least since the classic essay by Malthus (1798), population growth and the pressure it puts on land use (and agricultural practices, in particular) have been central to thinking about the human-environment condition. A general agreement has developed, however, that not the sheer number of people but aspects of population composition and distribution, namely changes in urbanization and in household size, have become the most important characteristics of population aspects, acknowledging the importance of indirect or consumptive demands on the land by an increasingly urbanized population (Lambin et al. 2001). Also, it has long been recognized (but frequently overlooked) that it is "population in context" (Rindfuss et al. 2004a) that matters (see Sect. 3.2.2), i.e., any effect of population change – be it fertility, mortality, in- or out-migration – likely interacts with other factors as diverse as social organization (e.g., networks, institutional arrangements), technology (e.g., level of agricultural yields), lifestyle (e.g., income, diet pattern) and consumption patterns (e.g., staple food *versus* non-food crops) (Ehrlich and Holdren 1971; Jolly and Torry 1993; Heilig 1994). Usually, there is a complex of factors that determines the direction and extent to which population growth will lead, for example, to forests being converted to cropland, or *vice versa* (Waggoner and Ausubel 2001). The expansion of forest land between 1935 and 1975 across the southeastern part of the United States of America, for example, related to urbanization, industrialization and increased agricultural yields elsewhere (Rudel 2001). With global population having doubled in the past 40 years and increased by 2 billion people in the last 25 years (reaching 6 billion in 2000), demographic variables, and in particular, population growth must be expected to play a major role in explanations of land change (Millennium Ecosystem Assessment 2005). By and large, population growth rates in tropical countries have been – and continue to be – strongly positive, while European and North American populations approach stability or tend to be on a decline. However, there is an unprecedented diversity of demographic patterns across regions and countries, which does not allow for sweeping generalizations. For example, some high-income countries such as the United States of America are still experiencing high rates of population growth (mainly due to immigration), while some developing or newly industrializing countries such as China, Thailand, and North and South Korea have very low rates (Millennium Ecosystem Assessment 2005).

While population growth may underlie many land-cover changes (Bilsborrow and Okoth-Ogendo 1992; Cropper and Griffiths 1994), its effects are frequently manifest through migration (including temporary and/or circulatory migration) or displacement of groups of people, either spontaneously or with direct government support (Tri-Academy Panel 2001). At a given location under study, migration in its various forms clearly is the most important demographic factor causing land dynamics at timescales of a couple of decades (Geist and Lambin 2004; Angelsen and Kaimowitz 1999). Undeniably, high fertility in the areas of origin may be implicated, and it is also true that, once on the frontier, migrant families usually exhibit high fertility rates (Carr 2004). Nonetheless, migration operates as a significant factor with other nondemographic factors, such as government policies, changes in consumption patterns, economic integration, and globalization. Some policies resulting in land-use change either provoke, or are intricately linked with increased migration. From a wide array of case studies, some form of relocation was found in well over a third of deforestation cases (Geist and Lambin 2002), and in a quarter or more of desertification (Geist and Lambin 2004) and agricultural intensification cases (McConnell and Keys 2005). While spontaneous movements may often occur within a context of high density in the source region, in many instances specific triggers, such as drought, conflict, or major government (re)settlement programs were identified. Government programs to encourage settlement in the Brazilian Amazon (e.g., Moran 1981) and Indonesia (e.g., Fearnside 1997) are well-known, and other, smaller instances were seen where market demand and government incentives for the establishment of plantations also lead to relocation and subsequent land change in areas as different as Costa Rica (e.g., Schelhas 1996), Sumatra (e.g., Imbernon 1999a), and Zambia (Petit et al. 2001). In other cases, residents returning to a region after long absences initiated changes in local land use (e.g., Boyd 2001; Tiffen et al. 1994b). The creation of infrastructure, especially roads, is a crucial step in facilitating settlement and triggering land-use intensification in a region (e.g., Conelly 1992), and much road construction can be construed in this sense (see Sect. 3.3.4).

Thus, while population growth is clearly associated with a great deal of land change, there are always other factors that shape the expression of that growth: the location, timing and nature of the change, as well as who undertakes it, and who benefits from it. The treatment of demographic factors in land-change research is becoming increasingly sophisticated, and a population analysis of great nuance is required. For example, demographic factors go well beyond growth rates, density, or the shift from high to low rates of fertility and mortality (as suggested by the demographic transition) to include age and sex structure of the population, the characteristics of migration cohorts, and the demographic composition of households, among others (Moran and Brondizio 1998; Walker et al. 2000, 2002; Geist 2003a; Lambin 2003; Moran et al. 2003; Carr 2004). These life-cycle features arise from and affect rural as well as urban environments. They result from households' strategic responses to both economic opportunities (for example, market signals indicating higher crop profitability) and constraints (due to economic crisis conditions, for example). They shape the trajectory of land-use change, which itself affects the household's economic status. The longitudinal research of the Carolina Population Center in the United States and its partners, among others, is exemplary in its consideration of seasonal and permanent migration and the evolution of settlement patterns in shaping land trajectories in Nang Rong, Thailand (e.g., Entwisle et al. 1998; Rindfuss et al. 2003; Walsh et al. 2003).

Several concerted efforts have been undertaken to examine specifically the role of population growth in land-change processes. A set of commissioned case studies in high density areas of Africa, for example, was largely able to confirm the Boserupian hypothesis (Boserup 1965, 1975, 1981, 2002) linking population pressure on land to the transformation of agriculture (Turner et al. 1977, 1993a). Looking beyond tropical Africa, a set of case studies commissioned by a consortium of the National Academies of India, China and the United States of America described regions in those countries – i.e., Pearl River Delta and Jitai Basin in China, Kerala and Haryana Provinces in India, and southern Florida and Chicago in the United States of America – where agricultural production was increased without major detriment to the environment. This comparative analysis highlights the importance of economic and policy variables in shaping land-use practices, although initially it was assumed that population growth alone could be a significant driver of land-use change in many of the regions (Tri-Academy Panel 2001).

Another comparative study also wanted to address the role of population, seeking to examine a number of cases in three major types of forest ecosystems worldwide (i.e., temperate, tropical humid and tropical dry forests), and along a variety of institutional arrangements (i.e., privately held, communally held, and federal- and state-held forests), wherein could be tested the degree to which population density or its distribution is associated with loss of forest, or its recovery (Moran 2005). It has been found that the role of population not only varies by scale but is also often counterintuitive (Geist 2003a; Unruh et al. 2005), as in the case of the forest transition (see Sect. 3.5.3).

Forest Change

Case study evidence on land-use dynamics in forested tropical zones largely confirms the expectation that population plays a major, though complex role in the explanation of land change, with demographic factors implicated in almost two thirds of deforestation cases reviewed (Geist and Lambin 2001, 2002) – see Table 3.7. Among these factors, only in-migration of colonizing settlers into sparsely populated forest areas, with the consequence of increasing population density there, shows a notable influence on deforestation. This pattern tends to feature African and Latin American rather than Asian cases. While not denying a role of population growth in tropical deforestation (e.g., Allen and Barnes 1985; Amelung and Diehl 1992; Bilsborrow and Geores 1994; Pichón 1997a,b; Ehrhardt-Martinez 1998; Cropper et al. 1999; Carr 2005), most case studies fail to confirm the simplification "more people, less forest" in lieu of other more important, if complex forces (e.g., Anderson 1996; Rudel and Roper 1996; Barraclough and Ghimire 1996; Fairhead and Leach 1998) – see Box 3.3. Historical experience and current comparative research would suggest that there is no permanent, rigid or deterministic rule linking population and forest trends, but the role of population is located in a wider context, including agricultural and wider development trends, and concentrating on its role is perhaps to focus on the symptom rather than on the underlying condition or context (Mather and Needle 2000; Lambin et al. 2003; Geist 2003a). It has further been found that population does indeed show an association with deforestation at aggregate scales, but at local to regional scales it does not (Rindfuss et al. 2004a). Moreover, some of the most successful cases of forest management

Table 3.7. Demographic factors of forest conversion and modification in the tropics

	All	Asia	Africa	Latin America
In-migration	58	12	9	37
Growing population density	38	12	6	20

Total number of cases is 152; multiple counts possible. *Source:* Geist and Lambin (2002), p. 148.

occur at the highest population densities (Tri-Academy Panel 2001; Moran 2005; Unruh et al. 2005) (see Sect. 3.5.3).

Population increase due to high fertility rates is not a primary driver of deforestation at a local scale and over a time period of a few decades. There is no single common effect of fertility on land use, nor is one expected. The relationship between land-use change and fertility flows in both directions, and, as a review of the literature shows, the effect of fertility on land use varies from place to place and over time (Rindfuss et al. 2004a). Fertility intervenes in only 8% of the reviewed cases of land change (Geist 2003a; Geist et al. 2006), it is never a sole factor, but always combined with other, at least equally important factors (Angelsen and Kaimowitz 1999), and though it is significantly associated with deforestation at the global and regional scales, evidence for population links to deforestation at micro-scales – where people are actually clearing forests – is scant. For example, where tropical deforestation is linked to the increased presence of shifting cultivators, triggering mechanisms invariably involve changes in frontier development and policies by national governments that pull and push migrants into sparsely occupied areas (Rudel 1993, 2005; Mertens et al. 2000; Carr 2005). In some cases, these "shifted" agriculturalists (Bryant et al. 1993; Bryant and Bailey 1997) exacerbate deforestation because of unfamiliarity with their new environment; in other cases, they may bring new skills and understandings that have the opposite impact (Lambin et al. 2001) – see Box 3.4. This is not to deny empirical evidence that the link between high fertility and high deforestation can be shown at local scales for certain stages in the demographic cycle of settler households (e.g., Pichón 1997a,b; Carr 2005).

Box 3.3. Misreading West African forest landscapes

Many influential analyses of West Africa take it for granted, that old-growth forest cover has progressively been converted and savannized during the 20th century by growing populations. By testing these assumptions against historical evidence, exemplified in case studies from the forest-savanna transition zones of Ghana, Guinea and Ivory Coast, it has been shown that these neo-Malthusian deforestation narratives badly misrepresent people-forest relationships. They obscure important non-linear dynamics, as well as widespread anthropogenic forest expansion and landscape enrichment. These processes are better captured, in broad terms, by a neo-Boserupian perspective on population-forest dynamics. However, comprehending variations in locale-specific trajectories of change requires fuller appreciation of social differences in environmental and resource values, of how diverse institutions shape resource access and control, and of ecological variability and path dependency in how landscapes respond to use (Fairhead and Leach 1996; Leach and Fairhead 2000).

Box 3.4. Household dynamics and forest-cover modification in the Amazon

In humid forest frontiers in South America, the internal dynamics of traditional and colonist families, which are mainly related to households' capital and labor constraints, explain the microlevel dynamics of land-cover modification by forest types (Coomes et al. 2000), land quality (Marquette 1998), and gender division, as well as the changing social context of deforestation in the Amazon Basin (Pichón 1997a,b; Sierra and Stallings 1998; Perz 2002). Forest clearing is caused by a variety of actors, with differing effects (Rudel 2005): recent immigrants practice slash-and-burn agriculture, and their children's families shift to fallow agriculture, while long-settled families practize diversified production; small families have crop/livestock combinations (associated with high rates of forest losses), while large families employ perennial production modes (associated with low rates of forest losses); and small ranchers, large ranchers, or upland croppers are displaced by lowland ranchers (Humphries 1998; McCracken et al. 1999; Walker et al. 2000). As a rule, microlevel dynamics shape the trajectory of land-use change, in turn affecting the household's economic status (Walker et al. 1996; Sunderlin et al. 2001).

Dryland Change

As in other types of land change, case study evidence largely confirms the expectation that population plays a major role in the explanation of dryland change, with demographic factors implicated in over half of the cases of land degradation – see Table 3.8. However, and thus repeating the pattern found for forest zones, closer inspection reveals that even when population growth is an important explanatory factor, the archetypal process of a burgeoning population expanding into virgin lands is rare in the case study literature. For example, it has been found that population increase due to high fertility rates among impoverished rural groups, at a local scale and over a time period of a few decades, is not a primary driver of dersertification, appearing in just 3% of the cases reviewed (Geist and Lambin 2004). More important are family or life-cycle features that relate mainly to labor availability at the level of households, which is linked to migration, urbanization, and the breakdown of extended families into several nuclear families. As an example of the latter phenomenon, the splintering of family herds in the West African Sudan-Sahel zone over the past 25 years (due to increases in nuclear households and the transfer of livestock wealth from herding families to merchants, agriculturalists, and government officials) led to increased investment in crop production, reduced labor availability among pastoral households, lower energy and skills applied to livestock husbandry, and reduced livestock mobility, which increased the risk of land degradation (Turner 1999, 2002, 2003). Fuelwood demand by households in Africa differs between nuclear family units and larger consuming units; the latter are generally more energy efficient. Small consuming units thus cause more forest degradation, especially in peri-urban environments (Cline-Cole et al. 1990).

Demographic factors in dryland degradation show distinct regional clusters, with Asian and African cases of desertification most commonly cited as reflecting human population dynamics – see Table 3.8. Most widespread are cases in which (remote) population growth, overpopulation or population pressure is reported as a driver. The growth or increased economic influence of urban population often triggers migration of poor cultivators or herders from high-potential, peri-urban zones into marginal dryland sites. Consequently, the sometimes rapid increases in the size of local human populations in drylands are often linked to the in-migration of cultivators into rangelands or regions with large-scale irrigation schemes, or of herders into hitherto unused, marginal sites, resulting in rising population densities there (Geist 2005). Prominent examples of migration-driven desertification stem from ancient or historical irrigation (oasis) sites in Central Asia, such as the Tarim and Hei River Basins or the Aral Sea region. Until recently, traditional irrigation farming practices in these regions had a relatively small impact on dryland ecosystems. Only in the second half of the 20th century did advances in hydrotechnical infrastructure combine with population influx from remote zones, likewise driven by outside economic demands and related policies, i.e., attaining self-sufficiency in food and clothing, so that cotton monocultures and irrigated food crops became key crops in areas of rapid settlement. In the period 1949 to 1985 alone, population in the Hei River Basin of northern China almost doubled, from 55 million to 105 million people, with the total irrigated area tripling from 8 to 24 million ha and the number of reservoirs increasing from 2 to 95 in the same period of time (Sheehy 1992; Genxu and Guodong 1999; Yang 2001; Feng et al. 2001; Lin et al. 2001).

Cropland Change

Case study evidence also confirms the expectation that population plays a major role in the explanation of land dynamics in agricultural intensification zones, with demographic factors implicated in almost two thirds of the reviewed cases, though not working in a universal, or unmediated fashion – see Table 3.9 (McConnell and Keys 2005). As for other land-change classes, it has been found that population, usually together with national economic policy, plays an important role in regional studies as explanatory variable of change. However, at the village level, it may become clear that features of the household life cycle are more important (Vance and Geoghegan 2004). For example, it has been shown that the effects of population change in northeastern Thailand, when expressed as a change in household size, had a larger impact on the conversion of land for use in upland crops (e.g., cassava, corn, sugar cane) than when expressed as counts of individuals (Rindfuss et al. 2003). Likewise, historical demography is a powerful way to bring attention to the fact that a complete explanation of ecosystem change in agricultural core zones must include the actual sequence and timing of events that produce an observed structure or function. The age-gender structure of human populations is a summation of their historical experience and can provide powerful ways to examine land change in light of the changing structure of households (Netting 1986; Butzer 1990; Batterbury and Bebbington 1999; Redman 1999).

Urban Change

Today, about half the people in the world live in urban areas, up from less than 15% at the start of the 20th century. High-income countries typically have populations that are 70 to 80% urban. Some developing-country regions (e.g., parts of Asia) are still largely rural, but Latin America (at 75% urban) is indistinguishable from high-income countries in this regard (Millennium Ecosystem Assessment 2005).

Urban populations are not randomly scattered across the globe, but are commonly located at transportation break points and places of opportunity, with highest population densities at low coastal elevations and in topographic basins adjacent to mountain ranges (see Chap. 2). Rural-urban migration stories are not simple, and they involve both pull (facilitating) and push factors. There is an important life cycle aspect to how households use land, and timing of fertility is an important

Table 3.8. Demographic factors associated with land degradation in drylands

	All	Asia	Africa	Latin America
Population growth, increases in size	42	31	4	2
In-migration, rising population densities	33	15	14	0

Total number of cases is 132; multiple counts possible; not included are data for Europe, Australia and North America. *Source:* Geist and Lambin (2004), p. 823.

Table 3.9. Demographic factors associated with land dynamics in croplands

	Important	Not important	Absent
Population numbers, density	70	22	16
Population composition	8	12	88
Settlement, migration	34	41	33

Total number of cases is 108; multiple counts possible. *Source:* McConnell and Keys (2005), p. 333.

aspect. For urban migrants, push factors at the place of origin historically often include population pressure as a legacy of prior fertility levels. Rural-urban migration will transfer part of the impact of rural fertility to urban places and play a role in the conversion of land to urban uses. The longer-term effect would involve increased rates of household formation, and, although fertility has declined in most parts of the world (especially in urban zones), a legacy of high levels in the past is a continuing growth in the numbers of young people coming of age, forming their own households, and using land for dwelling units and for some type of productive activity. Thus, even though reduced fertility leads to diminished growth of the base (ages 0–4), the legacy of past fertility leads to substantial increases in the numbers of men and women entering their 20s and 30s many years after the decline in fertility, known as "population momentum" (Rindfuss et al. 2004a). On the other hand, turnarounds in forest-cover change have been widely associated with urbanization and industrialization, and the processes facilitating reforestation likely includes urbanization (Rudel 1998; Mather and Needle 1998) (see Sect. 3.5.3).

With the rising affluence commonly associated with the transition from agricultural to urban-industrial societies, a shift has occurred to smaller household sizes, i.e., the number of individuals living in a household, for which there is a variety of reasons (McKellar et al. 1995). Other things being equal, declines in fertility will lead to smaller household sizes. Also, many countries have experienced increases in divorce, especially in urban zones, and this often turns one household into two. And, in some countries of the industrialized world, a stage in the life course has emerged wherein children leave the parental household but have not yet formed their own family, frequently resulting in the creation of an additional household. Likewise, when rising affluence permits mobility from multi-generational households (or extended families), splitting into smaller units is typical. In sum, declining household size affects urban land use through a variety of mechanisms. There is demand for more housing units, and typically these units will spread horizontally across the landscape, contributing to urban sprawl. More dwelling units usually leads to more demand for building materials, etc., and smaller household size commonly also translates into less efficient use of various resources (Rindfuss et al. 2004a).

3.3.4 Institutional Factors

General Remarks

The preceding presentation of demographic, economic and technological factors makes it clear that it is also important to understand institutions (political, legal, economic, and traditional) and their interactions with individual decision-making (Agrawal and Yadama 1997; Ostrom et al. 1999; Young 2002a, 2003). In particular, government policy plays a ubiquitous role in land change, either directly causative or in mediating fashion (see Sect. 3.3.2). In the last case discussed in the preceding section, for example, governments intervene to reduce fertility and encourage transmigration (thus influencing demographic factors), while in the economic realm they control prices, subsidize inputs, provide credit, promote industrialization and export, and provide and maintain infrastructure. Throughout history and throughout most major regions of the world, the expansion of agricultural land has often served as a tool of population redistribution and has also played a key role in the formation and consolidation of nation states (Richards 1990; DeKoninck and Dery 1997). In the latter case, access to land, labor, capital, technology, and information is structured (and is frequently constrained) by local and national policies and institutions (Batterbury and Bebbington 1999). Also, crucial issues of property rights lie clearly in the institutional domain, and land managers have varying capabilities to participate in and to define these institutions. Relevant nonmarket institutions are, for example, property rights regimes, decision making systems for resource management (e.g., decentralization, democratization, and the role of the public, of civil society, and of local communities in decision making), information systems related to environmental indicators as they determine perception of changes in ecosystems, social networks representing specific interests related to resource management, conflict resolution systems concerning access to resources, and institutions that govern the distribution of resources and thus control economic differentiation (Lambin et al. 2003).

Probably the most closely scrutinized realm of policy influence on land dynamics is economic policy. National governments exert a huge influence on land-use decisions through economic and finance policy. Broad policy factors, often associated with structural adjustment (e.g., market liberalization, privatization, currency devaluation), were cited in all types of land-use change reviewed (Kaimowitz et al. 1999; Mertens et al. 2000; Sunderlin et al. 2001). Specific policies, including the provision of credits, price supports and subsidies, as well as the imposition of tariffs and taxes, were detected in a third of the cases of agricultural intensification, where subsidized inputs and price supports enabled farmers to profitably adopt new crops (McConnell and Keys 2005). More examples of policies that influence land-use change are state policies to attain self-sufficiency in food (Xu et al. 1999), decentralization (Becker 1999), (low) investments in monitoring and formally guarding natural resources (Agrawal and Yadama 1997), resource commodification (Remigio 1993; Deininger and Minton 1999; Sohn et al. 1999; Tri-Academy Panel 2001; Keys 2004), land consolidation (Imbernon 1999b; Pfaff 1999), and nationalization or collectivization (Xu et al. 1999; Tri-Academy Panel 2001) as well as privatization (Watts 1989, 1994, 1996). Credits and subsidies for the forest sector played strong roles in over a quarter of the deforestation cases reviewed (Barbier 1993; Pichón 1997a,b; McCracken et al. 1999; Deininger and Minton 1999; Hecht 1993, 2005), while such factors appear to be somewhat less important in cases of desertification (Geist 2005).

Forest, Dryland and Cropland Change

As mentioned above, the linkage between infrastructure expansion and deforestation has long been recognized and debated, and the meta-analyses of land-use dynamics bear this out. Overall, government-sponsored migration (resettlement) schemes exert an overwhelming influence in deforestation in certain cases, such as the Brazilian Amazon and Indonesia (Geist and Lambin 2002). While the most frequently cited form of infrastructure facilitating forest settlement is transportation, this was much less prevalent in prompting agricultural intensification, occurring in barely one quarter of the cases (McConnell and Keys 2005), and even more rarely associated with desertification (Geist and Lambin 2004). By contrast, the provision of water resource infrastructure (reservoirs, dams, canals, levies, boreholes and pump stations) was seen as an important causal factor in over a third of the desertification cases, and played a crucial role in agricultural intensification involving irrigation (Johnson 1986; Hopkins 1987; Ewell and Merill-Sands 1987; Carney 1993; Shively 2001). In their studies on land-use change in Punjab and Haryana, the Indian heartlands of green revolution applications, Leaf (1987) and Vashishta et al. (2001) both find that the two most crucial public policies were regionally biased infrastructure development (roads as well as irrigation infrastructure) and the pricing of crop inputs and outputs by the state, which is widely supported by other case study evidence (e.g., Deininger and Minton 1999; Tri-Academy Panel 2001) – see Box 3.1.

Direct government participation in extractive industries, such as agricultural or forestry plantations, can have locally powerful consequences. Likewise, the state's encouragement of energy and mineral resources development has led to pressure on water resources, triggering desertification. As a general rule, it appears as if land degradation is more prominent when macropolicies, either capitalist or socialist, undermine local adaptation strategies (Geist and Lambin 2003). In particular, "perverse subsidies" for road construction, agricultural production, forestry, and so forth are thought to be one of the biggest impediments to environmental sustainability (Myers and Kent 2001) (see Sect. 3.3.2).

The flip side of the influence of government policy is its failure, i.e., ill-defined policies and weak institutional enforcement. This can involve the lack of access to government services by particular groups (e.g., highlanders, ethnic minorities), as well as more widespread inability, for example, to provide extension services, or to enforce land-use regulations. In some instances, such failure is seen to result from simple lack of resources, while in others, authors assert that clientelism and other forms of corruption are to blame. In Indonesia, for example, widespread illegal logging is linked to corruption and to the devolving of forest-management responsibilities to the district level (Jepson et al. 2001). In the Brazilian Amazon, significant examples of policy failure are the widespread disrespect of the limits to clear cut determined by the federal Forest Code and the difficulties of implementing prescribed land-zoning programs (Alves et al. 2003; Mahar 2002). On the other hand, recovery or restoration of land is also possible with appropriate land-use policies (Tri-Academy Panel 2001; Mather 2006c). Also, war, insurgency, and violent conflicts over land lead to the disruption of land management, thus triggering dryland degradation, for example (Geist 2005).

Clearly one of the most important sets of factors influencing people's actions on the landscape is their rights to use, alter and extract resources from the land. In much of the tropics, property rights have been quite dynamic over the past few decades, as traditional community tenure systems cede to increasingly private, individualized regimes, generally in the context of colonial and post-colonial influences. In fact, the delineation of colonial territory by the European powers was often purposely designed to subdivide the territory of ethnic groups, and the legacy of this continues to be cited as an important factor shaping land dynamics. These shifts in access to and control over land resources have of course been experienced differently by different groups within any country, and even within localities (see Sect. 3.2.2). At the same time, states have exerted – and have sometimes subsequently relaxed – ownership of all or part of their national territory (e.g., forest lands). An important recent manifestation of this is the creation of biodiversity conservation areas, which entails denying or restricting access to lands considered crucial to existing livelihoods. At the same time, consolidation of land resources in the hands of few has been an important process, and the redressment of this through land reform (redistribution) has had major consequences (Bebbington 2000; Coomes et al. 2000).

Not surprisingly, then, property rights issues emerge as important factors in almost half of the deforestation cases reviewed (Geist and Lambin 2002) – see Table 3.10. Of particular relevance in this domain are logging concessions, liberalization of land markets, easy transfer of public lands for private use, state regulations favoring large land holdings, tenure insecurity, and malfunctioning customary tenure regimes. Though much discussed as a robust cause of deforestation (e.g., Deacon 1994, 1995,

Table 3.10. Institutional factors associated with forest conversion and modification in the tropics

	All	Asia	Africa	Latin America
Formal deforestation policies	105	46	7	52
on land development	60	28	5	27
on economic growth	51	22	5	24
on credits/subsidies	39	11	1	27
Property rights issues	67	33	5	29
Policy failures	64	31	1	32
Mismanagement	38	13	1	24

Total number of cases is 152; multiple counts possible. *Source:* Geist and Lambin (2002), p. 148.

Table 3.11. Institutional factors associated with land dynamics in croplands

	Important	Not important	Absent
Property regime	65	34	9
Government/NGO policy	55	24	29
Income affecting program	36	14	58
Infrastructure program	33	10	65

Total number of cases is 108; multiple counts possible. *Source:* McConnell and Keys (2005), p. 333.

Table 3.12. Institutional factors associated with land degradation in drylands

	All	Asia	Africa	Latin America
Malfunctioning common property regulation	42	21	8	6
New land tenure, land zoning measures	37	19	11	1
Agricultural development policies	35	27	7	0

Total number of cases is 132; multiple counts possible; not included are data for Europe, Australia and North America. *Source:* Geist and Lambin (2004), p. 823.

1999; Mendelsohn 1994; Mendelsohn and Balick 1995), it appears as if property rights issues are mainly a characteristic of Asian cases and tend to have ambiguous effects upon forest cover, i.e., insecure ownership, quasi-open access conditions, maladjusted customary rights, as well as the legalization of land titles, are all reported to influence deforestation in a similar manner (Geist and Lambin 2002). Virtually all of the agricultural intensification cases reported some information on property regimes. The information was part of a still larger set of nonmarket institutional variables that emerged as frequently as other important causes, with policies and programs of the government or non-governmental organizations somewhat less frequently reported than property regimes. The latter were particularly important in those cases involving the adoption of tree crops, which often imbues the owner with a greater degree of control over the land (McConnell and Keys 2005) – see Table 3.11. Among the institutional and policy factors that underlie about two-thirds of reported cases of desertification, modern policies and institutions are as much involved as are traditional institutions (or, in other words: the failure of traditional land-tenure regimes under circumstances of other pressures such as aridification or market integration). It appears that the failure of institutional aspects of traditional land tenure (e.g., equal sharing of land and splintering of herds because of traditional inheritance law) are as important in driving desertification as are growth-oriented agricultural policies (including measures such as land distribution and redistribution), agrarian reforms, modern sector development projects, and market liberalization policies. Both traditional and modern institutions and policies thus reduce flexibility in management and increase the pressure on constant land units. The introduction of new land-tenure systems, whether under private (individual) or state (collective) management, is another factor associated with land degradation in drylands (Geist 2005) – see Table 3.12.

Underlying the institutional arrangements for land management and property rights regimes are broad sociopolitical factors that encompass, among others, the amount of public participation in decision-making, the groups participating in public decision-making, the mechanisms of dispute resolution, and the role of the state relative to the private sector. Over the past 50 years, there have been significant changes in these forces. The changes include, among others, a declining trend in centralized authoritarian government (but also in the importance of the state relative to the private sector), an increased involvement of non-governmental and grassroots organizations in decision-making processes (expressed, for example, in the worldwide recognition by the Norwegian Nobel Prize Committee of Wangari Maathai and the Green Belt movement in Africa, linking women's rights, democracy, ecological restoration, and grassroots activism in favor of sustainable development), and an increase in multilateral environmental agreements such as the United Nations Convention to Combat Desertification (UNCCD) (Millennium Ecosystem Assessment 2005). With increasingly interconnected market forces and the rise of international conventions, the impact of institutional drivers moves from the local to the global level (Taylor et al. 2002a). It can be expected that many of the rules used for making land-related policies will continue to be relevant factors. This will be important because in the history of human-environment relations there has often been a widespread mismatch between environmental signals reaching local populations and conventional macrolevel institutions (Redman 1999; Tri-Academy Panel 2001), and any changes should help to ensure that local users are able to better influence resource-management institutions (Poteete and Ostrom 2004). These institutions need to be (re)considered at various scales, to identify the local mediating factors and adaptive strategies and to understand their interactions with national- and international-level institutions (Klepeis and Chowdhury 2004; Mather 2006c).

Urban Change

A prime example of economic and related policies associated with the growth of urban zones is China. On the one hand, beginning in the late 1970s, urban regions benefited from national reform policies in the agricultural sector (price reform, elimination of collective farming), which triggered increased crop yields and a surplus of agricultural workers available for urban economic sectors. On the other hand, decentralization policies allowed provincial and local city governments more autonomy to devise and implement their growth-oriented development strategies (e.g., incentives to stimulate investment, economic development and conversion into urban-industrial zones) (Seto et al. 2004). A land reform in 1988 further allowed the transfer of land-use rights through negotiation, auction, or bid, with the consequence that both individuals and collectives can rent or lease their land to local and foreign ventures (Sharkawy et al. 1995). Movement to cities was made possible through reforms, which have relaxed the so-called *hukou* and reduced the importance of the *danwei* systems, both limiting population mobility, especially from rural to urban areas. *Hukou* has been a household registration system which determined the residency status of an individual, while the work unit, *danwei*, was an important provider of basic goods and services such as housing, health care, food ration tickets, and education, with both systems controlling internal migration and urbanization before 1978 (Mallee 1996; Smart and Smart 2001). At the national scale, again beginning in the late 1970s, the central government initiated a series of sweeping reforms that included the promotion of township and village enterprises (TVEs) which had originally been agricultural collectives. Urban TVEs in China turned into veritable pillars of economic growth, since they were built upon low labor costs due to rural surplus labor and relative freedom from state or bureaucratic control, thus becoming attractive partners for foreign investments (Putterman 1997).

3.3.5 Cultural Factors

General Remarks

Numerous cultural factors also influence decision making on land use, and it is important not to divorce these cultural conditions and trends from underlying political and economic conditions, including political and economic inequalities such as the status of women, ethnic minorities and resource-poor households, that affect resource access and land use (see Sect. 3.2.2). The ways in which people frame land-use choices represent an important set of proximate factors that influence decision-making, but these framing practices in turn influence and are influenced by the other driving forces discussed in this chapter. Land managers have various motivations, collective memories, and personal histories, and it is their attitudes, values, beliefs, and individual perceptions which affect land-use decisions, for example, through their perception of and attitude toward risk (U.S. National Research Council et al. 1999). Understanding the mental models (i.e., cognition, volition, will, etc.) of various actors may thus help explain the management of resources, adaptive strategies, compliance with or resistance to policies, or social learning, and therefore social response in the face of land-use change (Lambin et al. 2003).

Forest Change

In tropical forest zones, cultural factors are reported to underlie mainly economic and policy forces in the form of attitudes of public unconcern towards forest environments, and these factors also shape the rent-seeking behavior of individual agents causing deforestation (e.g., Deininger and Binswanger 1995) – see Table 3.13. Most notably the so-called cattle complex, or the high status accorded cattle ranching in Latin America, explains some important variations in regional patterns of land use, i.e., pasture creation for cattle ranching as a striking cause of deforestation reported almost exclusively for humid lowland cases from mainland Latin America (Geist and Lambin 2002). The cultural preference for cattle ranching stems from colonial Iberian experiences in the

17th and 18th century in the Americas. This common cultural legacy explains in part why cattle ranching is so prevalent in land poor Central America as well as in land rich South America. When penetration roads were built through these regions during the 1960s and 1970s, this cultural preference catapulted cattle ranching into one of the key driving forces behind tropical deforestation in the Western Hemisphere (Shane 1986; Hecht 1993). These cultural preferences also have spillover effects, spreading from majority to minority groups in a society. Some of the most populous and acculturated indigenous peoples in Latin America became cattle ranchers during the 1970s in an effort to secure titles to what had been forested land. Some indigenous peoples reverted to more culturally familiar patterns of shifting cultivation after they obtained formal land tenure, but others remained cattle ranchers (Rudel et al. 2002a).

Dryland Change

In drylands affected by land degradation, public attitudes, values and beliefs are as frequently associated with cases of desertification as are individual or household behavior, but there are regional variations – see Table 3.14. In Asia, land-use change leading to desertification is sometimes driven by public encouragement of a frontier mentality and by efforts to improve living standards and attain self-sufficiency in food. An example of the former cultural complex is the official support for land consolidation in the northern and, especially, northwestern territories of China (Jiang et al. 1995; Genxu and Guodong 1999; Feng et al. 2001; Lin et al. 2001; Jiang 2002). Such land-use change is very often linked to the belief that water is a "free good" and that grazing is "inefficient" when compared with grain production. In particular, water has always been regarded as a common good to be used freely, and there is usually little incentive to conserve when the cost of irrigation from individual wells is only the cost of extraction, and when costs for water drawn from canals is a low annual fee independent of volume and frequency of use (Hole and Smith 2004). Contrasting with this pattern are the Latin American cases, in which desertification seems to be predominantly driven by the individual responses or motivations of ranchers, and the Australian cases, in which a frontier mentality is not explicitly promoted by the state but seems to reflect a private attitude (Geist 2005). In Africa, ethnicity can have a strong bearing on adaptive land-use strategies (Reenberg and Paarup-Laursen 1997).

Cropland Change

In agricultural core areas with settled farming practices and pronounced land use intensification, religion, ethnicity and education have been identified as factors shaping land use decisions. These include strong preferences for staple crops, or for particular cropping practices (McConnell and Keys 2005) – Table 3.15. In addition, cultural and religious factors often shape restrictions (i.e., taboo) on the use of certain parts of the landscape, for example, reserving the hillsides surrounding family tombs for cultivation only in special circumstances in respect of the founders of the village (McConnell 2002).

Table 3.13.
Cultural factors associated with forest conversion and modification in the tropics

	All	Asia	Africa	Latin America
Public attitudes, values and beliefs	96	45	5	46
Public unconcern	66	25	3	38
Missing basic values	55	33	2	20
Individual/household behavior	80	38	6	36
Situation-specific (esp. rent-seeking)	74	36	5	33
Unconcern by individuals	48	20	4	24

Total number of cases is 152; multiple counts possible. *Source:* Geist and Lambin (2002), p. 148.

Table 3.14.
Cultural factors associated with land degradation in drylands

	All	Asia	Africa	Latin America
Public attitudes, values and beliefs	52	30	10	5
Violent land conflicts, war	10	3	6	0
Perceptional issues	12	7	0	0
Individual and household behavior	53	18	10	9
Indifference	13	4	5	3
Perceptional issues	9	4	0	0

Total number of cases is 132; multiple counts possible; not included are data for Europe, Australia and North America. *Source:* Geist and Lambin (2004), p. 823.

Table 3.15. Cultural factors associated with land dynamics in croplands

[illegible]	Important	Not important	Absent
Religion/ethnicity	7	41	60
Education	21	11	76

Total number of cases is 108; multiple counts possible. *Source:* McConnell and Keys (2005), p. 333.

Urban Change

The influence of cultural preferences includes landscapes of consumption as well as landscapes of production. Urbanization, for example, very likely changes ways of life fundamentally, with increasing expectations about raised consumption and potentially a weakened understanding of production-consumption relationships (see Sect. 3.3.3). Demands originating from urban-industrial zones often exert remote influences on rural and marginal sites, and urban entrepreneurs are often cited as being responsible for what has been called "speculative cultivation" outside the built-up zones, affecting property rights regimes there. In the humid forest zones of mainland Latin America, for example, pasture creation by large ranchers and absentee landlords is often reported as an unproductive, profit-seeking activity to add value to land, thus raising the value of land for speculation purposes and driving "speculative deforestation" (Hecht 1993; Walker et al. 2000). Likewise, it has often been reported that in the wake of rising prices of irrigation key crops (such as cotton and rice) urban entrepreneurs start investing in land, tractors and combine harvesters to cultivate large tracts of what had previously been rangelands (Geist 2005). As in the case of felling old-growth forest trees for pasture, steppe could be claimed by plowing it. Enormous areas of marginal land were thereby brought under speculative cropping, mostly funded by urban investors, such as in the semi-arid Syrian Khabur Region between the Tigris and Euphrates Rivers (Hole and Smith 2004). Cultural factors also shape land-use dynamics within urban zones. The English preference, for example, for lawns contributed to suburban sprawl in North America after World War II, and more recently, the preference for suburban landscapes of consumption has spread from North America to South America and shows signs of spreading to disparate other world regions (Leichenko and Solecki 2005).

3.4 Causation Revisited

3.4.1 Factor Interaction and Conjunctural Causation

This presentation of causal factors highlights several issues. First, any given factor can have multiple and often contradictory effects, depending on its specific nature, and on the context in which it occurs. For example, an increase in world coffee prices may cause farmers in Central America to clear forest land to make way for coffee groves, while at the same time in East Africa, land may be converted from field crops to coffee groves (Goldman 1993; Kasfir 1993; Okoth-Ogendo and Oucho 1993). The net effect on woody biomass at the two sites will be quite different. Likewise, the effects of globalization (see Sect. 3.4.3), in the sense of the geographical expansion of free trade, have had dramatically different effects in different regions: increasing pressure on forest resources in forest-rich regions like the Amazon, while reducing pressure in forest-depleted regions like West Africa or South Asia (Rudel 2005).

In addition to the ambiguous effects of a given causal factor, as noted above, no objective framework exists for the classification of factors into broad groups; rather the framework applied depends on the analytical lens of the researcher. The construction of roads, for example, can be analyzed according to the resulting difference in farm gate prices, or as part of a government policy to encourage transmigration, which itself may be seen as an outcome of rapid population growth. In fact, it has been argued that roads can only facilitate land change, but are themselves insufficient in the absence of price incentives, and that inputs must also be in place (Angelsen and Kaimowitz 1999) – see Box 3.5 and Fig. 3.2.

The strongest finding emerging from the meta-analyses of case studies is a resounding rejection of single-cause explanations of land-use change. No factor ever works in isolation. While some factors, such as population growth, may be very widely implicated in land change around the world and through time, their effects depend not only on their particular nature, but also on the specific biophysical and social contexts in which they occur. Given the impossibility of carrying out classical experimentation, isolation of the "independent" effects of any factor is fruitless. Thus, the focus should be causal synergies or the interaction of factors, rather than the individual factors or groups of factors (sectors). For example, a recurrent combination of interacting factors associated with desertification entails a change in precipitation combined with government policy promoting growth in the agricultural sector, along with the introduction of new technology, in the context of an inflexible tenure regime ill-suited to these new circumstances (Geist and Lambin 2004).

Different patterns or modes may represent the interactions between the various causes of land change (Young 2002a; Lambin et al. 2003). First, while no key factor operates in isolation, one cause may completely dominate the other cause, assuming that land use in a given locality is influenced by whatever factor exerts the greatest

> **Box 3.5. Debating the role of roads in deforestation**
>
> As illustrated by the case of roads and deforestation, the direction of causality may be difficult to establish, even at short timescales. For example, 81% of the deforestation in the Brazilian Amazon between 1991 and 1996 occurred within 50 km of four major road networks (Lele et al. 2000; Alves 2002a). Is it the national demand for land and the (high) agricultural suitability of some forest areas that lead to policy decisions to expand the road network in these areas, which then gives access to the forest for migrants who clear land? Or is it the expansion of local logging or agricultural activities in some forest areas that then justifies the construction of new roads to link these active production areas to existing markets? Or does the construction of a road for reasons unrelated to land use in the forest (e.g., to connect major cities) induce new deforestation by its mere presence, through a spatial redistribution of population and activities? Or, in the latter case, does the road simply attract to a given location a preexisting demand for land that would have led to deforestation elsewhere if the road had not been built? In this case, are there other intervening factors like the creation of forest reservations or a more strict enforcement of existing land appropriation regulations? In other words, is a road an endogenous or exogenous factor in deforestation and does it affect just the location or also the quantity of deforestation in a given country? The likely answer to these questions is that, in most cases, national demand for land, policies to develop the forest frontier, capital investments in logging and agricultural activities, population movements, commodification of the economy, the development of urban markets, and infrastructure expansion are highly interdependent and co-evolve in close interaction as part of a general transformation of society and of its interaction with its natural environment (Lambin et al. 2003).

constraints. Second, factors driving land-use/cover dynamics can be connected as causal chains, i.e., interconnected in such a way that one or several variables (underlying causes, mainly) drive one or several other causes (proximate causes, mainly). Third, different factors can intervene in concomitant occurrence which describes the independent but synchronous operation of individual factors leading to land change. Finally, and the modes of interaction might not be exhausted herewith, different factors may also intervene in synergetic factor combinations, i.e., several mutually interacting variables driving land-use change and producing an enhanced or increased effect due to reciprocal action and feedbacks between causes (see Sect. 3.4.2). In meta-analyses of case studies of tropical deforestation (Geist and Lambin 2002) and dryland degradation or desertification (Geist and Lambin 2004), the proportion of cases in which dominant, single, or key factors operate at either the proximate or underlying level was low (ca. 5 to 8%); concomitant occurrence of causes was more widespread (ca. 25%); and the most common type of factor interaction was found to be synergetic factor combinations (in ca. 70 to 90% of the case studies reviewed).

Quantitative social science has long recognized the implausibility of the assumption of complete independence among so-called "independent" variables, and a great number of sophisticated techniques have been proffered to accommodate – that is, to remove the effects of –

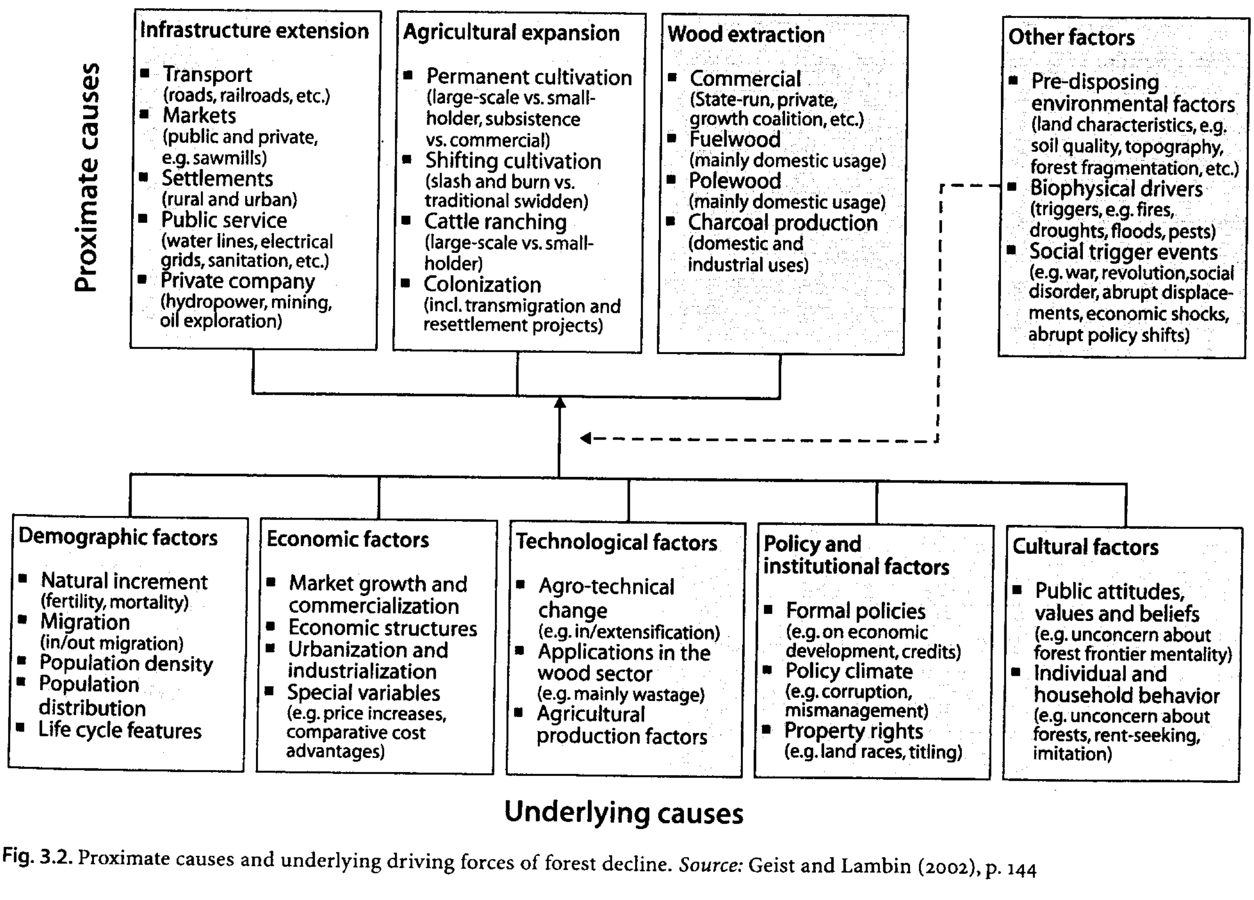

Fig. 3.2. Proximate causes and underlying driving forces of forest decline. *Source:* Geist and Lambin (2002), p. 144

such interaction (e.g., York et al. 2003). A different approach is to reject the notion that individual variables have independent effects, and can be substituted one for another in causing an outcome, and instead embrace these interactions as the heart of explanation (Ragin 1987). This approach seeks to identify how suites of interacting factors work in conjunction with one another, and to identify typical, or recurring causal clusters. Case studies of land-cover change underline the importance of meso-level variations in land-cover change in which different rain forest regions exhibit distinct clusters of causes that together drive land-use change. For example, Geist and Lambin (2002) identify distinct continental clusters surrounding cattle ranching in Latin America, smallholder agriculture in Africa, and a logging-smallholder tandem in Southeast Asia. Rudel (2005) finds variations in causal clusters between regions with large forests (Amazon, Central Africa, and Southeast Asia) and regions with small forests (Central America, West Africa, East Africa, and South Asia): well financed landowners and corporations drive deforestation in regions with large forests, while villages and smallholders are important actors in places with small forests.

3.4.2 Feedbacks, Thresholds, Endogeneity, and Co-Evolution

The patterns of causation discussed above are in most cases simplifications that are useful for communicating about particular environmental issues or for modeling (see Chap. 5). In reality, however, there are functional interdependencies in reality between all the causes of land change, both at each organizational level ("horizontal interplay"), and between levels of organization ("vertical interplay") (Young 2002b). Thus, the relationship between causes and outcomes is neither linear nor unidirectional (Mather 2006b). Anthropogenic land change invariably alters all aspects of the biophysical system to some degree (and extent), and as those alterations become sufficiently great, they are detected by the land users (or by their neighbors or regulating bodies), and this detection eventually leads to a change in behavior. When the reaction exacerbates perceived negative consequences on the system, the result is degradation; when the reaction moderates such negative effects, the result may be remediation or rehabilitation. In other words, amplifying mechanisms (or "positive" feedback loops) lead to an acceleration of change, in some cases triggering a rapid degradation of ecosystems and the impoverishment or even collapse of the societies using these ecosystems (Diamond 2005). By contrast, attenuating mechanisms dampen the human impact on the environment, in some cases leading – in the form of institutional and technological innovations, for example – to "negative" feedback loops associated with a decrease in the rate of change or even a reversal of the land-cover change trend (see Sect. 3.5.3). Thus, feedback is an important system property associated with changes in land use that can impact the speed, but also intensity and mode of land change (Lambin et al. 2003).

Adding to the system properties of land-use/cover dynamics are thresholds (hidden points or "break points"), that steer fundamental, but reversible changes. Sudden, abrupt and irreversible shifts from one land use into another (or into collapse) can occur at control (or switch and choke) points (Steffen et al. 2004). Often, biophysical and socioeconomic factors tend to operate in what could be called "multiple thresholds", governing the trajectory towards degradation or remediation in conjunction with feedback mechanisms, occasionally in an event-driven manner (Reenberg 2001). In dryland areas, for example, common examples of multiple thresholds are dry climate conditions (limiting water provision for cropping and determining germination conditions), critical minimum soil depths, the regenerative capability of vegetation to develop back to dense growth, and the degree of flexibility among rural societies for informal arrangements to cope with these factors (Geist 2005).

As a matter of co-evolution, many factors driving land-use/cover change – such as new economic policies or technological developments in agriculture – appear to be exogenous forces (thus largely out of control by local land managers), but as the timescale of analysis expands, all causes – from demographic changes to technological innovations (including new environmental policies) – become endogenous to the human-environment system and are affected in some degree by land dynamics. Actually, the changes in ecosystem goods and services that result from land-use/cover change (see Chap. 4) lead to important feedback on the drivers of land dynamics. These changes affect the availability and quality of some of the natural resources that are essential to sustain livelihoods, create opportunities and constraints for new land uses, induce institutional changes at the local to global levels in response to perceived and anticipated resource degradation, modify the adaptive capacity of land managers (by affecting their health, for example), and give rise to social changes in the form of income differentiation (when there are winners and losers in environmental change) or increased social complexity (e.g., by increasing interactions between urban and rural systems) (Lambin et al. 2003).

3.4.3 Globalization

Globalization – i.e., the worldwide interconnectedness of places and people through global markets, information, capital flows and international conventions, for example – is a process that underlies the driving forces discussed above. Global markets, in particular, increase complexity and uncertainty, raising concerns about risk from the global-local interplay of driving forces. Examples include forces of globalization that underlie processes of tropical deforestation (e.g., through an expansion and liberalization of the markets for forest products), rangeland modifications (e.g., by the application to dryland regions of inappropriate land-management systems designed elsewhere), agricultural intensification (e.g., through domestic and international capital flows leading to agricultural specialization), and urbanization (e.g., by the diffusion of urban culture and the increasing disconnection of the sources of demand from the location of production) (Lambin et al. 2001). For example, the depletion of accessible stocks of tropical hardwoods in Southeast Asia has prompted Asian buyers and companies to investigate and begin purchasing old growth timber from other continents, most recently from the Central African and Amazon-Orinoco forests; at the same time, these firms closed down their operations in already depleted areas like peninsular Malaysia or Thailand (Rudel 2005).

The various processes of globalization accelerate or dampen the impact of drivers of land change, i.e., they cross-cut the local and national pathways of land-use/cover change, and they therefore attenuate or amplify the driving forces by removing regional barriers, weakening connections within nations, and increasing the interdependency among people and between nations. Throughout the history of land transformation, rapid land-use changes often coincide with the incorporation of a region into an expanding world economy such as in the process of European colonization of the New World (Richards 1990). In an increasing manner, global forces replace or rearrange the local factors determining land use, building new, global cause-connection patterns in their place, such as contract farming schemes and global agro-food chains (Watts 1996; Goodman and Watts 1997; Fold and Pritchard 2005). On the other hand, globalization also affects land change indirectly. Examples are eco-labeling and global organic food networks, information technologies leading to better forecasts on weather or market prices for farm management, or land monitoring using earth observation satellites that provide control and global sanctioning such as in the case of forest fires in Indonesia (in 1998). In particular, international institutions – be they organizations within the United Nations system or nongovernmental organizations – can be instrumental in promoting and funding policies aimed at combating environmental degradation, setting political agendas, building consensus, and creating constraints and incentives for sustainable land management (Lambin et al. 2002).

It appears as if globalization, in the sense of trade liberalization and the spread of neo-liberal macroeconomic policies, is particularly important in countries or areas with fragile ecosystems (e.g., semiarid lands and mangrove forests). In Ghana and Mexico, for example, land-use/cover changes during the 1980s and 1990s were identified as the immediate and principal impact stemming from economic liberalization and globalization, mostly trade liberalization and reforms to open up the agro-industrial sector. Increased agricultural productivity directly triggered forest conversion and increased land degradation from unsustainable production methods, and, indirectly, agro-industrial development displaced the landless and rural poor, who were then pushed to marginal agricultural lands or to the forest frontier (Barbier 2000a).

Globalization also has a cultural component that most visibly affects consumption landscapes in expanding urban areas. The spread of recreational norms embodied in games like golf leads to the construction of golf courses and second homes in seemingly unlikely settings in newly industrializing, prosperous nations (Leichenko and Solecki 2005). Although the MacDonaldization thesis refers to a form of bureaucratic rationality within enterprises (Ritzer 1998), one could appropriate the term and use it to describe the common element that makes emerging urban landscapes in the more affluent and newly affluent parts of the world look so similar.

3.5 Syndromes, Pathways, and Transitions

3.5.1 Syndromes of Land Change

Case study comparisons revealed that not all causes of land change and all levels of organization are equally important. This prompted an attempt to reduce the complexity of the analysis of causes by identifying a limited suite of processes and variables which makes the problem tractable at aparticular scale. For any given human-environment system, a limited number of causes are essential to predict the general trend in land-use/cover change (Stafford-Smith and Reynolds 2002; Reynolds et al. 2006). This is the basis, for example, for the syndrome approach, which describes archetypal, dynamic, co-evolutionary patterns of human-environment interactions (Petschel-Held et al. 1999; Petschel-Held 2004). A taxonomy of syndromes links processes of degradation to both changes over time and status of state variables. The approach is applied at the intermediate functional scales that reflect processes taking place from the household level up to the international level. For example, the "over-exploitation syndrome" represents the natural and social processes governing the extraction of biological resources through unsustainable industrial logging activities or other forms of resource use. Policy failure is one of the essential underlying driving forces of this syndrome (e.g., lobbyism, corruption, and weak or no law enforcement) (Petschel-Held et al. 1999). The typology of syndromes reflects expert opinion based on local case examples, and the overall approach aims at a high level of generality in the description of mechanisms of environmental degradation.

Summarizing from a large number of case studies (Geist and Lambin 2002, 2004), the authors found that land change is driven by a combination of the following fundamental high-level causes (or "syndromes"), making a difference between "slow" and "fast" variables – see Table 3.16 (Lambin et al. 2003):

- resource scarcity leading to an increase in the pressure of production on resources,
- changing opportunities created by markets,
- outside policy intervention,
- loss of adaptive capacity and increased vulnerability, and
- changes in social organization, in resource access, and in attitudes.

Some of these fundamental causes are experienced as constraints. They force local land managers into degradation, innovation, or displacement pathways. The other causes are associated with the seizure of new opportunities by land managers who seek to realize their diverse aspirations. Each of these high-level causes can occur as slow evolutionary processes that change incrementally at the timescale of decades or more, or as fast changes that are abrupt and occur as perturbations that affect the land system suddenly. As may be seen from the cases collected by Puigdefábregas (1998), only a combination of several causes, with synergetic interactions, is likely to drive a region into a critical trajectory. In short,

land use = f (pressures, opportunities, policies, vulnerability, and social organization)

with

pressures = f (population of resource users, labor availability, quantity of resources, and sensitivity of resources);
opportunities = f (market price, production costs, transportation costs, and technology);
policies = f (subsidies, taxes, property rights, infrastructure, and governance);
vulnerability = f (exposure to external perturbations, sensitivity, and coping capacity); and
social organization = f (resource access, income distribution, household features, and urban-rural interactions),

with the functions f having forms that account for strong interactions between the causes of land change.

Table 3.16. Typology of the causes of land change

	Resource scarcity causing pressure of production on resources	Changing opportunities created by markets	Outside policy intervention	Loss of adaptive capacity and increased vulnerability	Changes in social organization, in resource access, and in attitudes
Slow	Natural population growth and division of land parcels Domestic life cycles that lead to changes in labour availability Loss of land productivity on sensitive areas following excessive or inappropriate use Failure to restore or to maintain protective works of environmental resources Heavy surplus extraction away from the land manager	Increase in commercialization and agro-industrialization Improvement in accessibility through road construction Changes in market prices for inputs or outputs (e.g., erosion of prices of primary production, unfavourable global or urban-rural terms of trade) Off-farm wages and employment opportunities	Economic development programs Perverse subsidies, policy-induced price distortions and fiscal incentives Frontier development (e.g., for geopolitical reasons or to promote interest groups) Poor governance and corruption Insecurity in land tenure	Impoverishment (e.g., creeping household debts, no access to credit, lack of alternative income sources, and weak buffering capacity) Breakdown of informal social security networks Dependence on external resources or on assistance Social discrimination (ethnic minorities, women, lower class people, or caste members)	Changes in institutions governing access to resources by different land managers (e.g., shift from communal to private rights, tenure, holdings, and titles) Growth of urban aspirations Breakdown of extended family Growth of individualism and materialism Lack of public education and poor information flow on the environment
Fast	Spontaneous migration, forced population displacement, refugees Decrease in land availability due to encroachment by other land uses (e.g., natural reserves or the tragedy of enclosure)	Capital investments Changes in national or global macro-economic and trade conditions that lead to changes in prices (e.g., surge in energy prices or global financial crisis) New technologies for intensification of resource use	Rapid policy changes (e.g., devaluation) Government instability War	Internal conflicts Illness (e.g., HIV) Risks associated with natural hazards (e.g., leading to a crop failure, loss of resource, or loss of productive capacity)	Loss of entitlements to environmental resources (e.g., expropriation for large-scale agriculture, large dams, forestry projects, tourism and wildlife conservation), which leads to an ecological marginalization of the poor

Source: Lambin et al. (2003), p. 224.

Some of the fundamental causes triggering land change are mainly endogenous (such as resource scarcity, increased vulnerability and changes in social organization), even though they may be influenced by exogenous factors as well. The other high-level causes (such as changing market opportunities and policy intervention) are mainly exogenous, even though the response of land managers to these external forces is strongly mediated by local factors (see Sect. 3.2.2).

3.5.2 Typical Pathways of Land-Use/Cover Change

The various drivers of land change discussed above are strongly linked within and between levels of organization. They interact directly, are linked via feedback, and thus often have synergetic effects. Any land manager also constantly makes trade-offs between different land-use opportunities and constraints associated with a variety of external factors (Geist et al. 2006) (see Chap. 7). Moreover, various human-environment conditions react to and reshape the impacts of drivers differently, which leads to specific pathways of land dynamics (Lambin et al. 2001). As noted above, despite of the large diversity of causes and situations (or contexts) leading to land change, the complexity of causative factors giving rise to land dynamics can be greatly reduced. Thus, the critical challenge is to identify dominant pathways or trajectories, which also illuminate associated risk factors for each trajectory (Lambin et al. 2003).

This is the basis, for example, of the approach to study "regions at risk" and environmental criticality by Kasperson et al. (1999). Several case studies of regions under environmental degradation were described qualitatively by their histories. These qualitative trajectories were represented in terms of development of the wealth of the inhabitants and the state of the environment. A "critical environment" was defined as one in which the extent or the rate of environmental degradation precludes the maintenance of current resource-use systems or levels of human well-being, given feasible adaptation and the community's ability to mount a response (Kasperson et al. 1995). Different typical time courses of these variables were identified and interpreted with respect to more or less problematic future development of the regions. The Aral Sea, for example, was unquestionably a critical region after a few decades of Soviet-sponsored, ill-conceived large-scale irrigation schemes (Glazovsky 1995). Assigning a particular case (e.g., the present situation and the history in a specified region) to one of these classes should allow for a restricted prognosis of its possible future development, which is a prerequisite for mitigation or adaptation (Kasperson et al. 1995).

In summary, and drawing the information from Table 3.16, there are some generalizable patterns of change that result from recurrent interactions between driving forces, following specific sequences of events. Even though, at the detailed level, these sequences may play out differently in specific situations, their identification may confer some predictive power by analogy with similar pathways in comparable regional and historical contexts (Lambin et al. 2003).

Trajectories of dryland degradation (or desertification), for example, are quite distinct on different continents (Geist and Lambin 2004; Geist 2005). In Central Asia, two central pathways of partly irreversible desertification are the expansion of grain farming into steppe grazing land, triggering soil degradation and overstocking, and the invasion of large-scale hydraulic agro-industries into desert ecosystems that historically supported only localized, traditional oasis farming. The most spectacular outcome, notably in low-lying sea region basins (such as the Aral Sea) and northern China, is a widespread increase in desert-like sand cover, which is linked to the exceptionally strong impact of socioeconomic driving forces such as centrally planned frontier colonization and (sometimes forced) population movements. In contrast, a typically African pathway of desertification involves the spatial concentration of farmers and pastoralists, very often as a result of national sedentarization policies, around infrastructure nuclei and water resources. This local, sometimes forced concentration of population results in overgrazing, intensive fuelwood collection, and high cropping intensities, ultimately leading to degraded vegetation and declining soil productivity during periods of drought. "Beefing up" of drylands, with little or no involvement of cropping, frequently characterizes the desertification pathways of Australia and of North and South America. Historically, these rangeland zones typically shared common patterns of land use, such as the rapid introduction by European settlers of exotic livestock species and commercial pastoralism into ecosystems that had not undergone these uses before. Since about the 1950s, however, these trajectories diverged. In Australia, the livestock industry and its complex of related infrastructure developed sufficient flexibility to counterbalance droughts and avoid spectacular desertification, and in the U.S. Southwest, principal land uses shifted away from cattle ranching to meet urban-driven aspirations. In contrast, Patagonia and northern Mexico suffered from a lack of advanced technologies and alternative land uses or diversification options to deal with the vagaries of oscillating natural resource productivity. Local farmers find themselves with no viable alternative but to continue raising livestock, often under conditions of impoverishment and deprivation. Consequently, dryland degradation in these areas is not just a historical phenomenon, but continues to advance (Geist and Lambin 2004; Geist 2005).

Likewise, some typical pathways can be identified for tropical humid forest regions, and deforestation notably (Rudel and Roper 1997; Lambin and Geist 2003b). In some frontier regions, however, determining prevailing land-use/cover change pathways may be difficult due to complex, rapidly changing dynamics over time. In the case of the Brazilian Amazon, for example, unsustainable cattle ranching appears to have evolved to market chains to satisfy local and national demand for cattle-based products (Hecht 1993; Faminow 1997; Veiga et al. 2004). Thus, a trajectory of land-cover change for the Amazon may start with rubber extraction for the world market (from end of 19th to mid-20th century), which was followed by integration of forested regions into national economic development, mainly through pasture creation (2nd half of 20th century). More recently, cattle ranching that depended heavily on subsidies and land speculation in the 1970s and 1980s evolved into intensified land uses for (semi)urban markets, relying upon well-developed transport and other infrastructure to satisfy local as well as national demand for cattle-based products (Alves et al. 2003). More recently, there are indications that global market demands regain power in local land-use decisions to convert forests for soybean (increasingly) and beef (again). Thus, what appears to be a typically homogenous agricultural frontier pathway in the land-use history of forested mainland South America, related to individual colonists' land-use decisions, is indeed driven by local urban as well as remote economic influences, with strong oscillations and overlaps between poverty- and capital-driven land-use dynamics (Perz 2002; Pacheco 2006a,b).

What has been lacking so far is the development of an integrative framework that would provide a unifying theory for the insights on causes and these pathways of land change, as well as a more process-oriented understanding of how multiple macrostructural variables interact to affect micro agency with respect to land (Lambin et al. 2003). The concept of land-use transition represents a first step in this direction.

3.5.3 Land-Use Transitions

Land-use dynamics have been construed as constituting about a dozen processes. In particular in tropical zones, which are the focus of this chapter, these processes are:

- urbanization (or the increase of built-up areas),
- conversion of forest to cropland (classic expansion, but virtually always intensification),
- conversion of grassland to cropland (classic expansion, but virtually always intensification),
- change of crop on existing cropland (will always entail change in intensity),
- more intensive use of croplands (decreased fallow – up to and beyond double cropping –, change of cultivar, terracing, irrigation, use of chemical and mechanical technology),
- incorporation of trees into cropland (usually considered intensification, when it is an economic species such as coffee, tea, cocoa, or vanilla),
- conversion of cropland to forest (considered disintensification, if abandonment; or intensification if for economic gain),
- conversion of forest to pasture (often cropland as an intermediate step),
- conversion of cropland to pasture (may appear less intensive, but yield higher rewards),
- more intensive use of pasture (usually through increased inputs),
- incorporation of livestock into cropland, and, finally,
- conversion of pasture to cropland.

In the following, we do not provide an integrative or unifying framework for all these land-change processes, but attempt to detail some of the aspects only as laid out above. Even considering just a small number of broad land-use/cover states, a large number of land-change processes are possible. This is illustrated in a very simplistic form in Fig. 3.3. The figure considers just two broad natural land-cover types (forest and grassland), and two broad land-use types (cropland and pasture). Changes among these four classes yield a minimum of twelve possible transitions (only some shown for simplicity). Quite different processes, however, may account for a given transition, yielding a much greater array of land-change processes. For example, cropland may begin to look more like forest because of forest succession due to fallow or farm abandonment, or because farmers replace field crops with arboreal species, i.e., practice agroforestry.

Through a series of transitions, land-use change is associated with other societal and biophysical changes (Raskin et al. 2002; Mustard et al. 2004). A transition can be defined as a process of societal change in which the structural character of society (or a complex subsystem of society) transforms. It results from a set of connected changes, which reinforce each other but take place in several different components of the system. Multiple causality and co-evolution of different sectors of society caused by interacting developments are central to the concept of transition. Transitions in land use must be viewed as multiple and reversible dynamics. They are not set in advance, and there is substantial variability in specific causes and situations (or contexts). There is thus a strong notion of instability and indeterminacy in land-use transitions (Lambin et al. 2003). Transitions should be viewed as possible development paths where the direction, size, and speed can be influenced through policy and specific circumstances (Martens and Rotmans 2002).

The concept of transition has been applied in land-change studies at different spatial and temporal scales. In the early 1990s Alexander Mather began using the term "forest transition" as a shorthand way of summarizing the historical changes in forest cover that occurred in

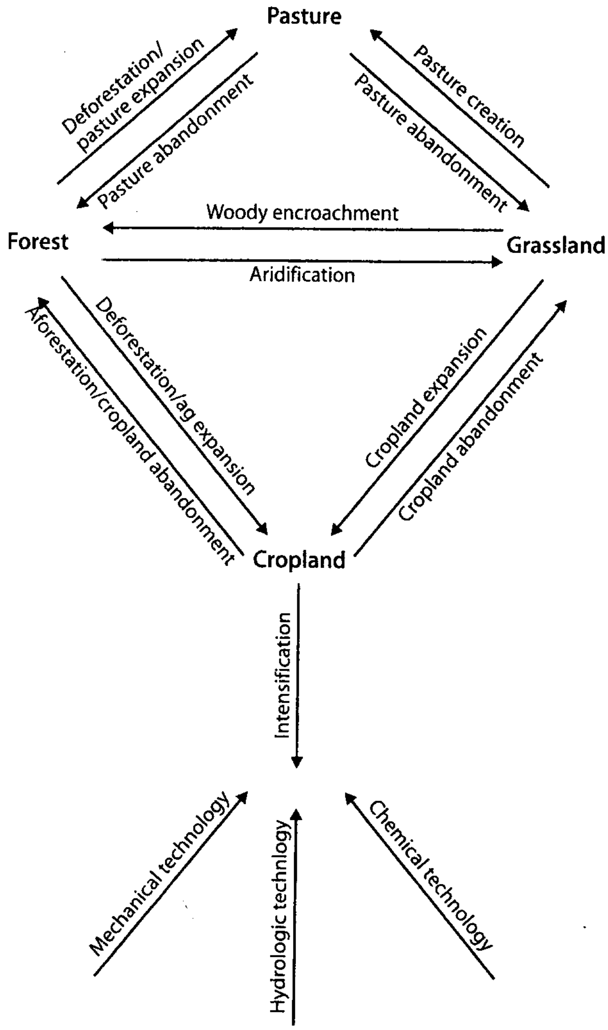

Fig. 3.3. Potential transitions between two land-use/cover states (pasture/cropland, forest/grassland)

Europe during the past two hundred years as European societies underwent industrialization and urbanization (Mather 1992; Mather and Needle 1998; Mather 2001). He saw a series of mainly northern European societies undergo deforestation as rural populations grew during the 18th and 19th centuries. Beginning in the 19th century, the creation of industrial jobs and amenities in cities induced widespread rural-to-urban migration. The departure of rural residents for cities led to the abandonment of the most marginal agricultural lands, and some of these lands reverted to forests. As the extent of abandoned lands grew, a transition in forest cover trends occurred, with net forestation rather than net deforestation coming to characterize these countries (Mather 2006d).

Analyses of forest cover trends during the 1990s suggest that forest-cover transitions take two somewhat different forms. In the more affluent European and American societies labor scarcities in agriculture continue to drive land abandonment and aforestation. In the poorer Asian and African contexts forest product scarcities brought about by the widespread destruction of natural forests induce landholders to plant trees and, on a larger scale, plantations. The increase in the extent of these replanted areas largely explains why forestation rather than deforestation now characterizes forest-cover trends in these countries (Rudel et al. 2005).

3.6 Conclusions

This chapter presents a synthesis of the suite of social and biophysical factors that have been associated with land-use change and, thus, land-cover dynamics. At first glance, there seems a universe of land-change studies that presents an effectively unlimited number of land-cover changes, and of associated human and biophysical factors. In general, synthesis of these factors is inherently a process of simplification, and of establishing some order among these factors (e.g., Brookfield 1962; Turner et al. 1977; Petschel-Held et al. 1999). Further examination, mainly by reviewing meta-analytical studies, reveals a limited suite of recurrent core variables of land change or variable configurations, which are detailed above. As a result, the richness of explanations has greatly increased over the last decade, but this has often happened at the expense of the generality of explanations, and no general land-change theory is yet in sight (see Chap. 1).

Nonetheless, over the last decade, research on the causative factors (or causal clusters) has largely dispelled simplifications or "myths" such as that only the growth of the local population, aggregated to a global level, and, to a lesser extent, its increase in consumption were thought to drive the changes in land conditions. Thus, our understanding of the causes of land change has moved from simplistic representations of two or three driving forces to a much more profound understanding that involves situation-specific interactions among a large number of factors at different spatial as well as temporal scales (Lambin et al. 2001, 2003). Concerning the latter, it is well known that explanations for processes vary by the scale at which they are studied. Thus, specificity of scale is essential, but also, ideally, the results of each causative factor analysis should be scaleable, both up and down, from the original scale of analysis (see Chap. 5 and 6). Such improved understanding also helps to account for the growing human capacity to transform vast areas of the land surface through agriculture, the building of roads and dams, and the rise of cities with vast impervious areas (see Chap. 4). For example, for the monasteries in Western Europe it took several centuries to deforest a substantial portion of the landscape in the early to late Middle Ages. By the 19th century, in contrast, it was possible for homesteading farmers to move across the forested lands of North America and cut down most of the existing forests in less than one century. Today, comparable deforestation is possible in a matter of decades – because of much greater technological capacity, favor-able government policies, and much larger populations acting simultaneously to make forests into agropastoral and urban areas (Moran 2005). Likewise, one thousand years ago, a postulated combination of factors including population growth, political instability and warfare, environmental degradation and climate change may have led to the collapse of the ancient Mayan Civilization (Diamond 1997, 2005; Turner et al. 2004), a situation threatening to repeat itself in today's forests in southern Mexico, Belize and northern Guatemala (the largest contiguous tropical moist forest remaining in Central America) with its current inhabitants, in spite of a much lower population and a much shorter time frame (Sever 1998; Sader et al. 2004).

The synopsis presented in this chapter relies upon case study material, and while the breadth and depth of that literature is to be celebrated, its idiosyncrasy is a major impediment. The meta-analyses by necessity depend on *ex post* operationalization of variables, which will be inherently unsatisfactory. Greater success may be expected from case studies undertaken with comparative analysis in mind from the outset. Now that a more coherent set of relevant factors has been codified, this should be increasingly likely.

While the causes and trajectories of certain land-change processes are commonly analyzed (e.g., deforestation), there is no consensus on specific definitions. These depend upon the observational perspective used, which in turn depends on the observer's analytical purpose. Likewise, the optimum organization of causal and contextual factors depends on their intended use. A researcher whose objective is a critique of existing land-related policy will likely call upon a different theoretical framework than one interested in generating a model capable of predicting spatio-temporal trends in net primary productivity. In part, these are issues of differing spatial and temporal scales of analysis, but it is important to remember that land change in and of itself is generally an intermediate analytical outcome. Since changes in land cover reverberate throughout the ecosystem, the impacts are many (see Chap. 4), and different causal and contextual factors are likely relevant. It must be recognized that with multiple stakeholders come multiple sets of values. Different stakeholders have values that are often not part of how scientists study land change, and even individual stakeholders may have internally inconsistent values (see Chap. 5 and 6).