Land **2014**, *3*, 504-523; doi:10.3390/land3020504

OPEN ACCESS

land

ISSN 2073-445X

www.mdpi.com/journal/land/

Article

Evolutionary Mismatch as a General Framework for Land Use Policy and Politics

Russell C. Weaver [1,*] **and Jason Knight** [2]

[1] MS GIS Program, Department of Environmental Studies, University of Redlands, 1200 E, Colton Ave., P.O. Box 3080, Redlands, CA 92374, USA

[2] Department of Geography and Planning, SUNY Buffalo State College, 1300 Elmwood Ave., Buffalo, NY 14222, USA; E-Mail: knightjc@buffalostate.edu

* Author to whom correspondence should be addressed; E-Mail: russell_weaver@redlands.edu; Tel.: +1-909-748-8525; Fax: +1-909-335-5388.

Received: 14 March 2014; in revised form: 16 May 2014 / Accepted: 4 June 2014 / Published: 13 June 2014

Abstract: Patterns of human land use (LU) necessarily transform the land systems that sustain and contain them. Importantly, the impacts of such transformations are not isolated in space and time. LU management decisions that are made at a given geographic unit regularly impact both human and nonhuman well-being beyond the spatiotemporal boundaries of that unit. To superintend the conflicts that arise out of such circumstances, human LUs are generally subject to institutional regulations. As patterns of socio-ecological interactions change over time, these LU institutions require reform or replacement, as extant rules or LUs can become maladapted to new environmental conditions. The current paper defines this situation—in which a LU that was established in a given environment becomes dysfunctional when relevant environmental factors are changed—as a *LU mismatch*. It then develops a framework for studying the policy and politics of LU mismatches through the lens of evolutionary (mismatch) theory. The framework provides a means for understanding the origins and nature of LU mismatches, and, in turn, it implicates leverage points for public policy intervention. We conclude by exploring how the framework offers a relatively nonpartisan discursive frame for stakeholders to employ in LU mismatch planning and political arenas.

Keywords: land use; land use mismatch; evolutionary mismatch; land use policy

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1. Introduction

Human livelihoods are inextricably linked to the land [1]. Indeed, taking the concept to mean the physical material that makes up the Earth's crust, including the soil and all naturally occurring output thereof, one can defensibly claim that land supports and sustains all life [2]. For many human societies, however, land is conceptualized not only as a life-supporting substratum, but also as a dividable resource that possesses economic and noneconomic value [2–4]. The source and magnitude of this value depends on the functional relationship between humans and the land in space and time—that is, the ways in which humans use the land in specific environmental contexts [5].

Insofar as the physical geographies of land (*i.e.*, the natural characteristics that comprise the lithosphere, hydrosphere, atmosphere, and biosphere at particular locations) vary across space and time, the patterns of human settlement and land use (LU) that depend on these characteristics necessarily exhibit spatiotemporal variation. This variation in LU patterns plausibly reflects the efforts of humans to extract maximal value from the land in diverse environmental settings [6,7]. In this context, LU is not a static *property* of the land, but rather a dynamic *process* in which there are constant adjustments [5]. Ineludibly, these patterns of adjustment and readjustment transform the physical landscapes on which they operate [2,6–11].

It is essential to keep in mind that the environmental transformations just described are driven by human LU management at a given decision unit, but they almost always impact both human and nonhuman well-beings beyond the boundaries of that unit [2,10,12,13]. To superintend the conflicts that are generated by these external effects, human LUs are generally constrained by institutional regulations [14]. In his seminal model of "Land Use and Society" (LU&S), Platt [2,10] shows that such regulations are established when three geographic "data layers" interact in space. Namely, actions taken in (i) the human landscape, which are regulated by (ii) the institutional landscape, transform (iii) the physical landscape at a given geographic location. When human transformations of the physical landscape create hazards and risks that produce new LU conflicts in society, local institutions are reformed or replaced to manage the resulting issues.

The LU&S model therefore implies that as patterns of socio-ecological interactions change over time, extant LU institutions can become maladapted to new environmental circumstances. This conclusion closely resembles an outcome from the theory of evolution by selection, known as an *evolutionary mismatch*. An evolutionary mismatch exists when an organismal trait that adapted to some earlier environment survives, but does not make the same contributions to the host organism's welfare, in the present (changed) environment [15]. In the current paper, we define a *LU mismatch* to be a similar situation, in which a LU that was established in a given context becomes dysfunctional when relevant contextual variables are changed. We then develop a framework for studying the policy and politics of LU mismatches through the lens of evolutionary [mismatch] theory. The framework provides a means for critically analyzing situations of LU mismatch, and in doing so it implicates leverage points for public policy intervention. We conclude by exploring how this framework offers a relatively nonpartisan discursive frame for stakeholders to employ in LU mismatch planning and political arenas.

2. Land Use Policy Change and Politics

Implicit in our opening discussion of the land concept are at least four distinct land conceptions: (i) land as a physical substratum and location on which life can be supported; (ii) land as a dividable resource that can be owned, *i.e.*, land as real estate; (iii) land as a market commodity that has economic value; and (iv) land as a cultural commodity that has noneconomic value, *i.e.*, land as "place" [2]. Notwithstanding the differences between these conceptions, all share the view that land is a *fund* that provides *services* to environmental agents. Among other things, land provides: (i) ingredients for diverse species life at a given rate of production; (ii) property usage opportunities under given a set of institutions; (iii) a source of economic wealth in a given market arrangement; and/or (iv) a "sense of place" in the presence of a given culture or population [2–4,9,16–18].

What is significant about so-called "fund-service" resources is that they suffer "wear and tear" during their production processes [16,19]. Wear and tear implies that one agent's extraction of a selected land service at a specific point in space-time diminishes the opportunities for (i) other agents to extract the same land service in that space-time; or (ii) other land services to be extracted from that site at that time [16]. In economic terms, the services that land provides are frequently *rivalrous*, or such that one land use (LU) precludes a separate, coterminous LU at a single geographic location [16]. Relatedly, the real estate services that land provides are frequently *excludable*, or such that landowners may consume all of the land services available from their holdings, while preventing others from consuming those services for the duration of their ownership [2,16].

When the qualities of rivalry and excludability are found in combination, land services ostensibly fit into the classification of *private goods* [20]. This is to say that land services can be consumed efficiently in private, free market transactions [20]. Crucially, though, land is spatially inter-connected [2,5,21–23]. Working through an analogy between real property usage and the laws of thermodynamics, Weaver [23] proffers as a "first law of urban dynamics" the notion that "in a given urban system, [land] is neither isolated in space nor constant in condition". Less formally, private consumption of land services at location i inexorably impacts environmental agents at neighboring locations j [2]. For instance, waste disposal LUs at landfill or dumping sites repeatedly affect the health of nearby residents [24]. The presence of such spillover effects (called *externalities*) in LU systems lead to conflicts between agents in the environment, or, alternatively, it exemplifies *market failure* [20]. Market failure occurs when free market transactions do not lead to efficient production and consumption patterns [20]. To mitigate the market failures brought about by LU externalities, decision-makers establish rules and regulations that govern how land may be used. In other words, as Platt suggests, the central problem of LU law is to minimize the harm that is done to third parties when land services are privately consumed [2].

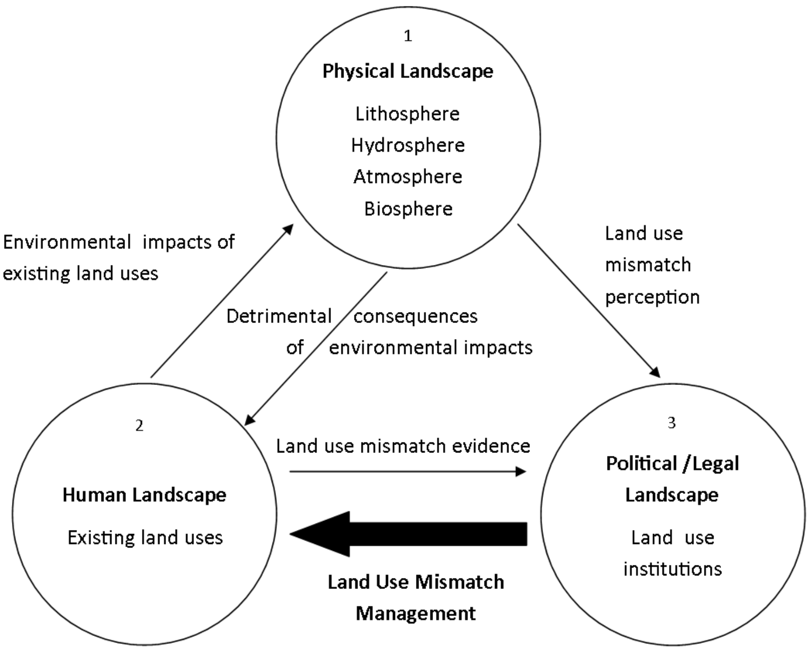
While correcting market failure is therefore of foremost concern to LU law, there is much more to be said about LU policymaking. Principally, LU systems are dynamic [5,7,9,17], whereas policies and political institutions tend to be rather rigid and persistent over time [22,25–27]. The implication is that inter-temporal changes within a regulated LU environment can render certain policies and institutions ineffectual, superfluous, or even injurious after they enter into service [28]. In this context, institutions originally set up to remove harmful externalities from the LU system can become sources of new externalities unto themselves. For example, the economic successes of the manufacturing and shipping industries in America's "Rust Belt" inspired some U.S. cities in the mid-20th century to "design [their LU systems] for trucks to serve…heavy industrial establishments" [29]. In the face of deindustrialization and the collapse of the U.S. manufacturing sector, however, these surviving institutions have left "large areas of vacant and/or underutilized land" in several cities [29]. Thus, instead of accruing benefits to the environment as intended, it can be the case that LU institutions decrease overall social welfare when relevant contextual variables are changed or removed [30].

Building off of this example, in general we define a *land use mismatch* (LUM) to exist when a LU institution that was constituted in a given prior environment becomes dysfunctional when the sets of contextual variables from the prior and active environments are nonequivalent. In plainer terms, a LUM occurs when the conditions that made a particular LU successful in the past are no longer available in the same qualities and/or quantities in the present. We distinguish this concept from the "nonconforming use" and "incompatible use" concepts found in the planning and LU law literature; for LUM is concerned not exclusively with the relationship between a LU and codified regulations at a specific point in time [22,31], nor only with the relationship between LUs in space at a specific point in time [21], but with the dynamic relationships between LU institutions and their environments across time. In this way the LUM concept is distinctively evolutionary in nature, as will be expanded upon in subsequent sections.

For now, it is important to emphasize that cases of LUM often bring about LU policy changes [30]. Accordingly, Platt's [2,10] LU&S model, which describes the process by which LU policy is created, can be used to situate LUMs in the broader setting of human-environment-institution relations (Figure 1). Expressly, in a given geographic territory, the "physical landscape" (*i.e.*, the natural environment) is impacted by activities from within the "human landscape" (*i.e.*, society). Humans, for example, build infrastructure, mine raw materials, and emit pollutants during production and consumption. Human modifications to the physical landscape lead to tensions over LU, e.g., factory pollution causes neighboring residents to become ill, over-exploitation of local resources leads to import-dependency, *etc.* Such tensions are observed as hazards and risks by actors in both the human landscape and the separate "political/legal landscape". The notion that human-environment interactions create hazards and risks within an existing [regulated] LU system implies that adaptations within that system can become maladaptive [2,10]. Alternatively stated, the LU&S model essentially identifies cases of LUM [30]. Within the model, decision-making officials directly perceive LUMs from their positions in the political/legal landscape, and they receive indirect information about LUMs as feedbacks from society. Over time, the cumulative pressures from these direct and indirect information flows cause political decision-makers to adopt new or modify existing LU policies and regulations (Figure 1) [2,10].

Notably, the LU&S model depicted in Figure 1 presents readers with a "big" picture of LU policy change. Hence while the model has considerable utility for explaining LU policy *outcomes*, it is (intentionally) less interested in the competitive *political processes* that produce those outcomes [2]. Clearly, though, LU policymaking is a political endeavor that involves multiple competing interests and coalitions that possess uneven stocks of political capital [14,28,32–36]. Within such policy (political) arenas, interested parties frame LUMs in terms of their desired outcomes, and, in turn, their preferred strategies for arriving at those outcomes [37]. Very rarely do these frames share focal elements or visions of the relevant problems [32,37]. Consequently, LUM discourses regularly become contentious and are prone to political "turbulence" [5]. As Saint *et al.* [32] describe it, "all politics is local, (and) all land use is political". For the LU&S model this means that the information vector labeled "Land use mismatch evidence" in Figure 1 does not carry *the evidence* of a LUM; but *multiple evidences* that are packaged into a variety of politically constructed issue frames. In this regard, LU policies are the contested outputs of inter-group competition and political pressure [32–34].

Figure 1. The Land Use and Society (LU&S) model (adapted from [2]).



This political nature of LU policy makes it productive for LUM researchers and managers to acknowledge and maintain the "is-ought" distinction in LU policymaking processes, that is, to separate description from prescription in LUM discourses [24]. Evidence that a detrimental outcome is present in the context of a particular issue frame is not automatically evidence of a LUM, as framing is a normative process [38]. At the same time, evidence that an alternative outcome accrues higher collective welfare to an environment relative to an existing LUM outcome does not necessarily mean that society *ought to* pursue that exact alternative [24]. Instead, it is the task of decision-makers and affected stakeholders to sort through competing issue frames and understand the causes and consequences of a LUM, as well as the alternative states of nature that are possible. The LU&S model provides a birds-eye view for this sort of work. Namely, it challenges users to identify the evidence ("what is") that informs an observable policy outcome ("what ought to be"). But it is not intended to equip users with tools for deconstructing political issue frames or specifying the functional and mechanistic bases of LUMs ("why and how things come to be"). Conceivably, though, such knowledge leads to richer understandings of LUMs and adds greater transparency to political discourses [30]. For these reasons, we propose a framework for critically analyzing LUMs that actively seeks out these details and is at once motivated by and fully compatible with the LU&S model. In building this framework we draw heavily on evolutionary theory, chiefly for its: (i) utility for explaining changes in complex population systems [25,26,39]; and (ii) instructive work on identifying and managing "evolutionary mismatches" [15]. The next section briefly introduces these foundations.

3. Evolutionary Theory and Evolutionary Mismatch

Recent work in, among other disciplines, economics [39,40], the political and policy sciences [25,26], and human geography [41–44] is demonstrating the potential for evolution by selection to serve as a general framework for studying social phenomena. LU and urban planning have not been exempted from this trend. Namely, while evolution has for some time influenced thinking and analogies in the planning literature [45–47], more recent research is employing evolutionary theory as an analytical framework for LU policy and politics [30].

Likely among the reasons for this seemingly growing interest in evolutionary theory is its ability to explain so much with so few assumptions [48]. As Lustick [25] writes, "the defining characteristic of evolution is that, in relation to circumstances, patterns of change observed among units produce subsequent patterns of population change". That is, individual attributes vary across interacting members of a given population, and this variation has consequences for the survival of certain attributes in the overall environment [49,50]. Over time, less successful attribute varieties face selective pressures in competitive interactions and are gradually eliminated from the population. Meanwhile, relatively successful attributes are replicated and retained [39].

The logic and tenets of evolution have been used to explain phenomena as diverse as the macroscale question of human existence [48], and microscale issues of prosocial behavior in cities and neighborhoods [51]. The three conditions on which these and all other cases of evolution by selection rest are: (i) variation in a particular attribute; (ii) differences in "fitness" due to differences in the attribute of interest; and (iii) retention of that attribute in successive environments [49,52,53]. As discussed above, LU certainly varies across space, and, at any point in time, some LUs are more valuable (*i.e.*, "fitter") in their environment than others [9]. Moreover, LU tends to change incrementally, implying that LU during a given time period resembles LU during some prior period [22,30]. Thus, LU satisfies the aforementioned conditions, and, consequently, it is reasonable to assume that an evolutionary perspective can add value to LU research. That being said, although the preceding paragraph captures the essentials of evolution as a process, it does not represent the whole of evolutionary theory. Rather, reaching further down into the evolutionary toolkit offers researchers a wealth of concepts that can be adopted and interlocked to round out and enrich our understandings of why various traits exist in a particular environment [25,26,40]. Three such concepts are critical in developing a framework for studying the policy and politics of LUMs. They are: (i) "evolutionary mismatch"; and the locations of (ii) "local maxima"; on (iii) "fitness landscapes".

3.1. Evolutionary Mismatch

An *evolutionary mismatch* is a detrimental outcome or consequence that arises when a given trait or attribute has been selected for in one environment, but presently exists in another [15]. Put differently, an attribute (e.g., LU) that is successful in one context—its *ancestral environment*—can be unsuccessful, or even downright harmful, in a different combination of space, time, and society. Examples of mismatch abound in the social and behavioral sciences and include, for instance, negative outcomes associated with setting up certain neoliberal institutions in some developing nations [54], and unhealthy levels of fat consumption by modern humans, which derives from high rewards for fat intake early on in human development [25].

Importantly, several ingredients are needed to demonstrate a case of evolutionary mismatch. First, following the logic, notation, and terminology used by Lloyd *et al.* [15], a particular trait (T) must be unpacked in the context of the ancestral environment (E1) in which it adapted. Specification of T requires an explicit identification of the population in which it is found. Unpacking T within E1 then involves explicating the *function* or purpose T serves in E1 (its *ultimate cause*), as well as the E1 *mechanism*(s) that facilitated its development (its *proximate cause*). Finally, it is critical to present evidence that T is maladaptive, or "correlated with detrimental outcomes" [15], in its present environment (E2). This step demands explication of the relevant environmental factors found in E2, the mechanism in E2 that links T to a detrimental outcome therein, and the means by which T was transmitted to E2 from E1. When the above information requirements are satisfied, decision-makers are relatively well-prepared to design and establish environmental interventions that mitigate the harms associated with an evolutionary mismatch [15]. We argue below that the same is true for LUM management.

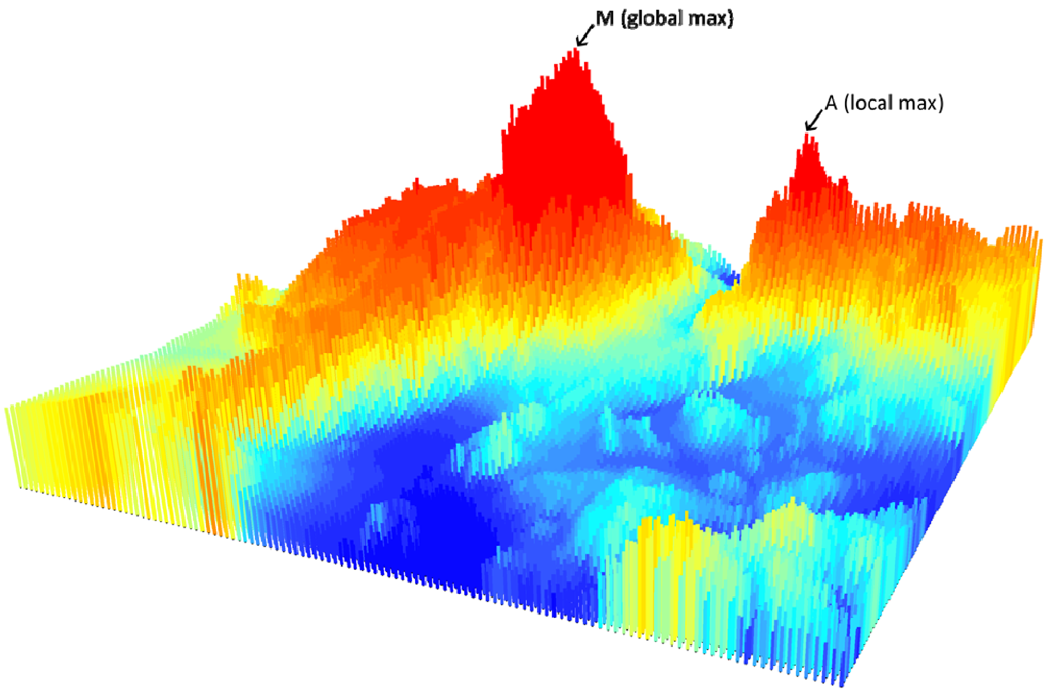
3.2. Fitness Landscapes and Local Maxima

Applications of evolutionary theory, and, by extension, studies of evolutionary mismatch, are concerned with some set of units that make up a population or institution [25,26,55]. Furthermore, each unit in the set of units can take on any of a number of traits. Relying on abstract terms for a brief illustrative moment, let S_i be the set of possible traits that unit i can take on, and let s_i be the trait that unit i does take in a given environment, where $s_i \in S_i, i = 1, \dots, N$. For all [N] units in the population (e.g., all tracts of land in a LU system), the observed *attribute profile* or *outcome* is defined as, $s = (s_1, \dots, s_N)$.

The set of all possible attribute profiles forms the *outcome space*. Every outcome in the outcome space is associated with a particular level of *fitness*, or welfare, in the environment. The universe of all outcome-fitness combinations forms what evolutionists refer to as the *fitness landscape* [25,26], which tends to be rather rugged [56]. Very rarely, if ever, is the terrain of the fitness landscape known to actors in the environment. Rather, individual-level interactions lead the population to a particular outcome. This outcome depends on the population's starting point and all successive interactions that occur thereafter. When any one outcome is realized, its associated value from the fitness landscape accrues to the environment. Once this information is revealed to and processed by actors in the environment, their further interactions can cause the population to migrate to nearby, marginally "fitter" outcomes over time [25,26].

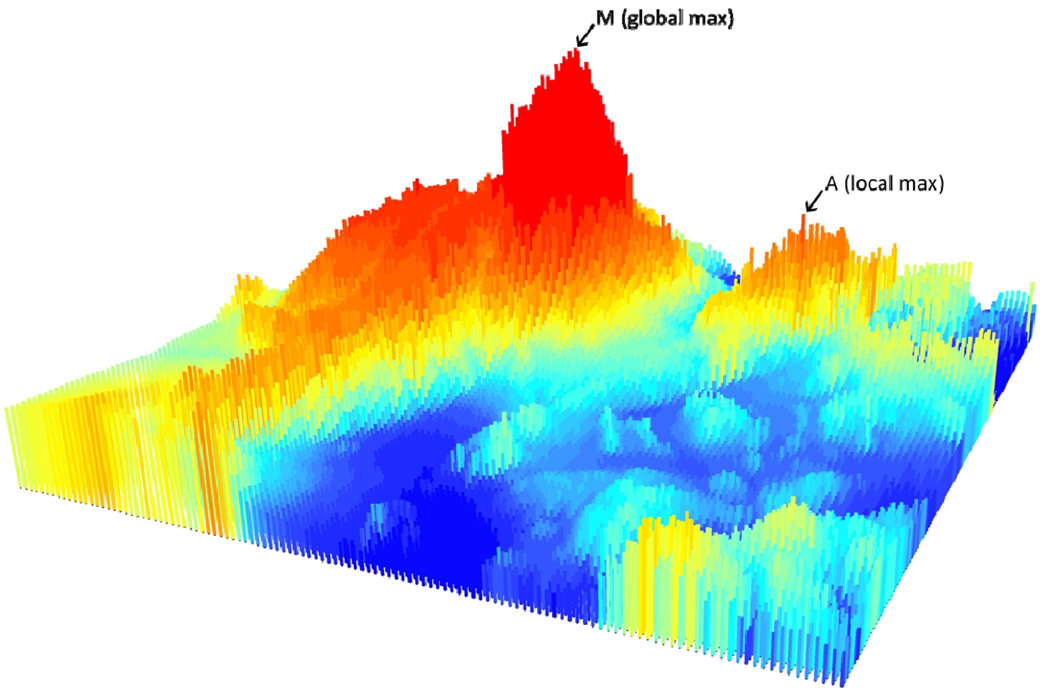
Notwithstanding this tendency toward fitter outcomes, populations often find themselves locked-in to disadvantageous or relatively unfit states of nature. This is frequently the result of an evolutionary mismatch [25] in which the outcome from the ancestral environment (E1) is a *local maximum* on the fitness landscape [26]. This situation is illustrated graphically in Figures 2 and 3, where a hypothetical fitness landscape is spatialized for two environments: E1 and E2, respectively. Suppose that in the ancestral environment (E1), interactions between individuals, and between individuals and their environment, gradually lead society to outcome A (Figure 2). Outcome A is a local maximum on the fitness landscape, meaning that all nearby (accessible) outcomes accrue lower welfare to the environment than A. This is visualized with comparatively short vertical bars surrounding point A. Once again, the overall terrain of the fitness landscape is unknown to members of the population, and, given the context of E1, the population interprets A to be the fittest possible outcome at the time it is realized. This is a reasonable conclusion in the short run, for moving off of point A (a local maximum) in any direction triggers immediate losses in welfare [25,26].

Figure 2. Hypothetical fitness landscape and outcome in the ancestral environment (E1).



Consider now an environmental change (e.g., deindustrialization) that causes the fitness landscape to change in one or more places. Such a scenario is illustrated in Figure 3 for environment E2. Observe that point A in E2 remains a local maximum, as all nearby outcomes are still associated with lower fitness levels. However, the environmental change causes A to be less fit in E2 than it was in E1. The associated welfare loss that accompanies the change, given by the decrease in the vertical height of point A from Figure 2 to Figure 3, makes the population worse off relative to E1. Such welfare losses are likely to disquiet actors in the environment. Nevertheless, moving off of outcome A in any direction means even greater losses in current welfare [25,26]. If decision-makers are unwilling to bear these additional costs, then outcome A remains the "best" short run solution. In this manner society becomes locked-in to outcome A. Even though "better" outcomes are available on the fitness landscape, including the *global maximum* at point M, they are not immediately *accessible* from society's current position. Accessible outcomes refer to those that incrementally deviate from the status quo, where inaccessible (especially fitter) outcomes represent transformational societal changes. As such they are difficult to achieve when political leadership is not sufficiently far-sighted, or interested in welfare beyond the near term (e.g., during the electoral cycle). In other words, the inaccessibility of "better" states of nature works to "trap" society on a local maximum [26].

Figure 3. Hypothetical fitness landscape and outcome in the changed environment (E2).



The fitness landscape and local maximum concepts are fundamental for understanding not only the challenges of LUM management, but also the difficulties of using policy instruments to move toward "better" outcomes at a much broader level [25,26]. To wit, these conceptual devices illustrate an important source of built-in political resistance to non-incremental change [26]. They show that only by absorbing (potentially significant) short term welfare losses can a trapped population reach "better" outcomes than a local maximum (Figures 2 and 3). For understandable reasons, political decision-makers, especially those whose power depends on being elected to office, might be averse to trading off welfare in the short term for the expectation of long term welfare gains. This is feasibly why political institutions, including LU institutions, tend to be persistent over time [25,26].

On this backdrop, it is plain to see why in practice LU policy change is often marginal or resemblant of the status quo: outcomes nearer to the status quo are readily accessible (*i.e.*, politically and technologically attainable) from society's current position on the fitness landscape [22,25,26]. Nonetheless, major institutional change does occur, and societies trapped in LUM situations on local maxima do reach fitter outcomes. While it is unmanageable to attempt to identify and generalize over all such cases, we assume that issue *framing* plays a major role in them [37]. Section 4 thus combines the concepts and tools defined hereinbefore into a LUM framework that simultaneously helps users to: (i) comprehend the evolutionary history of a LUM; and (ii) adopt a relatively nonpartisan discursive frame for debating LUM issues and policy alternatives in the political process. The latter of these features employs the fitness landscape concept to articulate the idea that welfare losses triggered by moving off of local maxima are recurrently in the best long-run interests of trapped societies.

4. Bringing It All Together: The Land Use Mismatch (LUM) Framework

Just as an evolutionary mismatch is a "particular type of dysfunction that results from evolution in changing environments" [15], we have so far defined a *land use mismatch* (LUM) to be an outcome in which a previously functional LU or LU institution becomes dysfunctional in response to environmental changes. It should be somewhat apparent, then, that we see a LUM as a form of evolutionary mismatch specific to LU systems. As a consequence, the information requirements for demonstrating a case of evolutionary mismatch extend to cases of LUM. Table 1 lists and details these requirements, which are set forth in a recent call for a "back to basics" approach to managing evolutionary mismatches [15].

Table 1. Information requirements for demonstrating a case of land use mismatch (LUM).

Requirement	Description
Population	The collection of units whose interactions generate LUMs ***Examples***: *all tracts of land in a given geographic territory; all LU regulations in a given jurisdiction*
Trait (T)	The attribute of interest that varies across units in the population, where unit-level variation therein has population-level consequences ***Example***: *a selected land service, i.e., a given type of LU*
E1 context	The set of contextual factors that existed when the relevant LU institution was established (the ancestral environment) ***Examples***: *the economic base of a jurisdiction; the demographic or socioeconomic profile of a geographic territory*
E1 function	The adapted role that the relevant LU institution served in the context of E1 (the ultimate cause) ***Examples***: *services the economic base of a jurisdiction; provides benefits to landowners and tax revenues to municipalities*
E1 mechanism	The mechanism that led to the establishment of the relevant LU institution in E1 (the proximate cause) ***Examples***: *public or private investments; permits for certain types of LUs or land service extractions*
E2 context	The set of contextual factors that exist in the active environment to which the relevant LU institution is poorly suited ***Examples***: *deindustrialization; post-natural disaster*
E2 problem	The detrimental outcome associated with the LUM in the active environment ***Examples***: *vacant or underutilized land; pollution; habitat or property destruction*
E2 mechanism	The mechanism linking the relevant LU institution to the problem or detrimental outcome in E2 ***Examples***: *durability of built structures; land contamination*

4.1. Demonstrating a Case of LUM

Seeing as the contents of Table 1 were unpacked in Section 3.1, we eschew repeating that discussion here. Rather, there is greater utility in clarifying these ideas through a quick application. Take the recent case of the Cypress Freeway replacement project in Oakland, CA, USA [57,58]. While a comprehensive review of this case goes well beyond the scope of the current paper, and readers should therefore look elsewhere to find such information [57,58], for our purposes a handful of relevant details demonstrate that the case satisfies the aforementioned LUM diagnostic requirements (Table 1). First, the Cypress Freeway, an automobile-oriented transportation LU (**Trait**) occupying significant tracts of land in West Oakland (**Population**), was constructed in the 1950s during a time of growth and sprawl in northern California (**E1 context**). At that time there was little connectivity between downtown San Francisco, residential sprawl communities in the region, and the industrial employment centers on Oakland's waterfront (**E1 context**) [58]. The Cypress Freeway filled that role (**E1 function**), though in doing so it divided several [predominantly minority] neighborhoods in West Oakland. This disruption expectedly brought about opposition to the Freeway; but, the wide-reaching regional benefits associated with the transportation improvements—combined with rising dependence on the automobile as a primary means of mobility [59]—ostensibly outweighed these localized costs in the eyes of public decision-makers [58]. As such, the Freeway was constructed with the help of significant public funding and political salesmanship (**E1 mechanism**) [59].

Several decades later, in 1989, a 7.1 magnitude earthquake struck northern California and caused portions of the Cypress Freeway to collapse, thereby rendering the roadway unusable (**E2 mechanism**). Consistent with the LU&S model from above [2,10], this hazardous human-environment interaction was a focusing event for LU policy change. A nonoperational roadway that consumes vast swaths of land is undeniably mismatched to its environment and requires intervention (**E2 problem**). Nevertheless, when a plan surfaced to rebuild the Cypress Freeway at its original scale and in its original location, it was met with powerful resistance [57,58,60]. To understand why, it is important to consider the context of the 1989 environment. Notably, by this time a diversity of (post-1950s) transportation options were available for intra-regional travel [58,61]. These options reduced the demand for any single roadway (**E2 context**). Thus the Cypress Freeway was not performing the exact function in the 1989 environment (**E2**) that it performed when it was first constructed (**E1**) [61]. On top of that, the U.S. environmental justice movement had recently gained political traction, and the disparate siting of highways in minority neighborhoods was being challenged by civil rights leaders (**E2 context**) [60]. In this sense, both the lessened role of the Freeway in the 1989 regional transportation environment (**E2 mechanism**) and the increased resistance to locating highway infrastructure in predominantly minority neighborhoods (**E2 mechanism**), created opposition to rebuilding the Freeway in its original form and location.

This is where political process and framing begin to enter into the LUM framework. Whereas the LU&S model fittingly predicts that a LUM instigates a new LU policy decision, its central focus on observable outcomes takes some attention away from the multiple varieties of evidence that flow from society to decision-makers through politically constructed frames (refer to Section 2). Drawing on the "is-ought" distinction discussed earlier, the LU&S model explains a given policy intervention ("what ought to be") in terms of available evidence that human-environment interactions created some hazard or risk ("what is"). From an evolutionary perspective, however, there is more to this story. Namely, recall that stakeholders in society package evidence of hazards and risks into frames that are used to advocate for their preferred LUM policy interventions [37]. These frames are the keys for understanding a given stakeholder's perceived causal history of a LUM ("why and how things are as they are").

In the Cypress Freeway case, several prominent frames emerged during the political process. For instance, a *status quo frame* advocated for restoring the Cypress Freeway to its original state [58]. A *new urbanism frame* called for deconstructing the Freeway and replacing it with an at-grade boulevard [62]. An *environmental justice frame* called on decision-makers to relocate the Freeway from the minority neighborhoods it divided decades earlier [58]. While these frames are drastically simplified for illustrative purposes, they roughly problematized the Cypress Freeway LUM as, respectively:

(i) damaged infrastructure in need of repair; (ii) obsolete infrastructure in the context of changing transportation patterns and values; and (iii) unjust LU patterns that were under fire elsewhere, and therefore rising on the political agenda [60]. Of utmost importance, then, is the notion that adherents to all three of these frames shared the view that the collapsed, post-earthquake Cypress Freeway was a LUM that required intervention; yet in spite of this agreement, the desired intervention—to rebuild, remove, or relocate the Freeway—varied markedly between frames. Crucially, the LUM framework facilitates critical analysis of LUM frames in ways that can explain this variation, and, by extension, pinpoint the LUM information requirement (*i.e.*, the element from Table 1) that is tendentially responsible for political competition over LU alternatives.

Observe from above that at least three separate phenomena were proffered as "E2 mechanisms" that caused the Cypress Freeway to be maladaptive in the 1989 environment. These three phenomena correspond to the three problem definitions enumerated in the preceding paragraph. The upshot is that *in situations of LUM, the mechanisms linking E1 LUs or LU institutions to detrimental outcomes in E2 are leverage points for public policy intervention*. As recent tutorials on the subject suggest, this is true for evolutionary mismatches at a much broader level [15]. Unlike cases of evolutionary mismatch in the physical sciences, though, E2 mechanisms in LUMs, like those cited for the Oakland case, are socially constructed through political frames [37]. This means that intervening in LUMs involves evaluating competing evidence within a conflictive political arena [30]. Such a task is severely complicated when problems are framed in terms of different concepts, or when different frames define relevant concepts differently. That being said, deconstructing frames into the elements from Table 1 can aid stakeholders in addressing these challenges and initiating comparative analyses. Indeed, explicitly teasing out, for each frame, the information required to demonstrate a LUM can reveal either: (i) whether or not critical diagnostic information is missing from a frame, thus indicating that the frame does not fully capture the evolutionary dynamics of the relevant LU issue; or (ii) the E2 mechanism that the frame perceives to proximately cause a given negative outcome, thus highlighting a strategic leverage point for policy intervention.

It should be clear that deconstructing frames via the LUM information requirements (Table 1) is not on its own an evaluative exercise. In other words, it does not equip decision-makers with empirical evidence to support one policy intervention over others. It does, however, help lay the foundations for asking empirical questions that are evaluable with appropriate data and methods. More precisely, *when all the elements that factor into a LUM diagnosis are explicitly specified, the purported proximate cause of a LUM becomes transparent to all actors in the policy arena*. Thus, implementing the LUM approach transforms a complex political problem into an arguably more informed debate about the relative explanatory power that alternative mechanisms have over a specific LUM. For example, has the demand for the Cypress Freeway declined to such a point that it can be replaced by an at-grade boulevard? Did siting the Freeway in minority neighborhoods impact some citizens disproportionately relative to others? What harmful externalities are generated by each of these problems in the current LU system, how can these effects be measured, and for which problem are they greater in magnitude? Answers to such questions are essential inputs into policy interventions, and they are made increasingly possible by the systematic application of the (nonpartisan) LUM information criteria to the alternative problem definitions that exist in a LUM political discourse [30].

Prior to completing our explication and application of the LUM framework, a preliminary point needs to be made about the preceding discussion. Namely, observe that there is a dialectical relationship between *environmental contexts* and *traits*. That is, while the focus of the LUM framework is on the process by which a given LU or LU institution (*i.e.*, *trait*) becomes maladapted to its current environment (*i.e.*, *context*), it is essential to keep in mind that human, physical, and institutional systems *coevolve* in space [2,10,63]. This observation is a key to understanding why multiple mechanisms can be linked to a single detrimental (LUM) outcome in a current environment, as in the Cypress Freeway case. Indeed, the environmental conditions that give rise to, for instance, a Freeway, are subsequently reshaped by that Freeway [64]. Recall from the example that construction of the Cypress Freeway was motivated largely by the tendencies toward sprawl in Northern California, and the resultant desire to connect emergent communities to downtown San Francisco and the Oakland waterfront [58]. By performing this *function*, however, the Freeway facilitated additional sprawl in the ancestral environment. These (reshaped) ancestral environmental conditions led to the production of diverse new options for intra-regional travel, which, in turn, began to decrease the functional role of the Freeway [61]. Accordingly, by 1989 the Freeway became maladapted to the present environment. The reason for making this point clear is that, even though the LUM framework follows recent calls for a "back to basics" approach to handling evolutionary mismatches [15], it is fully consistent with modern perspectives on coevolution and urban morphogenesis [63–65]. We submit that this is because the LUM framework is a meta-approach to critically analyzing frames from LUM discourses, and it is not intended to be a standalone theory of LU change. That being said, we can now finalize our presentation and illustration of the LUM framework.

4.2. Rounding out the LUM Framework: Navigating the Fitness Landscape

Subsequent to the 1989 earthquake in northern California, the California Department of Transportation (Caltrans) quickly sought to address the Cypress Freeway LUM by rebuilding the roadway in its original place [58]. Responding harshly to this proposal, a coalition of community stakeholders in West Oakland devised what they called the "clean air alternative" to the Cypress Freeway [60]. The alternative came out of the environmental justice frame discussed earlier, and it proposed to relocate the Cypress Freeway for the purpose of wholly reuniting the minority neighborhoods that were dislocated or torn apart when the Freeway was constructed in 1957 [58,60]. The alternative was drafted with meaningful community input and public participation, and it had the strong political backing of the NAACP Legal Defense and Education Fund [60]. Thus it became highly influential in the political process [57,58,60]. Nonetheless, while the environmental justice frame "changed the course of the freeway", the clean air coalition was "not able to get (its) plan implemented" [60]. In the end, the adopted plan maintained an intrusive part of the Freeway's original footprint in southwest Oakland, which continued to divide a predominantly minority neighborhood in that part of the city. By contrast, the clean air alternative pushed for the Freeway to be sited west of all the West Oakland residential communities in order to correct past mistakes and minimize exposure to future risks [57,58].

Critically examining LUM cases through the evolutionary lens of this paper suggests a reason as to why a large-scale, transformational LU policy intervention like the clean air alternative might fail to be implemented in a given institutional arrangement. Using terminology defined in a previous section, the outcomes associated with such interventions are inaccessible from society's current position on the fitness landscape [25,26]. Pursuing (immediately) inaccessible outcomes is likely to make society worse off in the short run, and this realization often means that such actions are politically nonviable. For the Oakland case, the plan initially recommended by Caltrans—to rebuild the Cypress Freeway in its original place—was readily accessible on the fitness landscape, and this is perhaps why the agency was eager to pursue it. Rebuilding the Freeway would have returned society to its pre-earthquake status quo, which, due to past investments and traffic patterns, was plausibly a local maximum on the region's fitness landscape. It was only through the influence of the environmental justice frame in the political process that stakeholders successfully convinced decision-makers that the proximate cause of the LUM went beyond infrastructure damage sustained in an earthquake. These efforts resulted in a policy intervention that, while not fully in accord with the clean air alternative, dramatically decreased the Cypress Freeway's impacts on West Oakland's residential communities [60,62,66].

Imperatively, to arrive at the environmental justice-influenced outcome it was necessary for society to navigate the rugged terrain of the fitness landscape [56]. The project lasted for nearly a decade [57] and consumed over one billion dollars, making it "the most expensive strip of highway in California history" [58]. It is easy to imagine that time lags, large public expenditures, and traffic impacts during this lengthy construction process reduced society's welfare in the short term. But within the wider (evolutionary) picture, the project eventually set off patterns of LU adjustments that led to positive changes and long term welfare improvements, including landscaped boulevards, additional green spaces, and the provision of non-auto-dependent transportation options such as bicycle lanes [58,61]. Cervero and his colleagues have made similar findings for several other cases of urban freeway removal within and beyond the U.S. [66–68]. Expressly, despite the long time delays and cost overruns that are often involved in such projects [62], they repeatedly trigger patterns of LU change that yield "net positive benefits without seriously sacrificing transportation performance" [66].

In this context, it is evident that societies "stuck" on local maxima in LUM situations are not necessarily "trapped" for the duration of their existence. Reaching "better" outcomes on the fitness landscape is highly achievable, both in terms of evolutionary theory and in light of empirical evidence [25,26,66–68]. Having said that, the process by which such outcomes are realized involves, almost by definition, trading off short term welfare for the expectation of long term gains [25,26]. That immediate welfare losses can translate into negative political consequences for elected decision-makers putatively explains the incremental nature of many LUM management decisions. Indeed, for Oakland the management decision initially preferred by institutional actors was decidedly incremental. It proposed simply to rebuild the Cypress Freeway as it existed prior to the earthquake, thus returning society to its pre-disaster status quo [58]. Climbing off of the local maximum required a well-researched evolutionary history of the Cypress Freeway LUM (the environmental justice frame) that specified the E2 mechanism responsible therefor. It further mandated that this environmental justice frame be articulated and defended for years, both in political and legal arenas by a coalition of informed stakeholders [57,58,60]. Once those pieces were firmly in place, the environmental justice frame substantively altered the course of action in the Cypress Freeway LUM [60]. At a broader level, this experience suggests that a frame in which all of the necessary LUM diagnostic criteria are well-specified, in addition to public and political understanding and acceptance of the likely costs and benefits associated with navigating the fitness landscape, are vital components for accomplishing long term transformational change in LUM cases.

5. Conclusions

In this paper we advanced a framework for investigating situations in which previously functional LUs or LU institutions become dysfunctional in response to environmental changes. We termed such situations *land use mismatches* (LUMs) for their similarities to the concept of *evolutionary mismatch* from the theory of evolution by selection [15]. To begin constructing this framework, we first noted that LU in fact meets the three conditions for evolution by selection [49,50,52,53]: (i) it is a trait that varies across units (tracts of land) in a population (LU system); (ii) these variations have consequences for how successful a tract of land is in its environment; and (iii) it changes incrementally, meaning that LU at any given time tends to represent or derive from LU at a previous point in time [22,30]. It follows that "in relation to circumstances, patterns of (LU) change observed among units produce subsequent patterns of (changes in LU systems)" [25]. Put differently, LU systems are effectively evolutionary systems.

As in other evolutionary systems, then, LUs or LU institutions that evolve in and adapt to a certain environment can become maladaptive when the ancestral environmental is changed [15]. These LUMs typically initiate a learning process during which new LU policies are adopted or extant institutions are modified [2,10]. The macro dynamics of this learning process are succinctly illustrated by Platt's [2,10] model of Land Use and Society (LU&S). The LU&S model shows how human-environment interactions in general impose hazards and risks on a society in which human LUs are constrained by a set of extant regulations. Within this model, evidence of hazards and risks is the main input to new LU policy and LUM management (Figure 1). Significantly, however, the evidence that flows to decision-makers is first framed by stakeholders in ways that advocate for their preferred problem definitions, and, by extension, their preferred problem solutions [30,32,37]. As it were, the LU&S model limits its attention to the political frames and political processes that produce LU policy outcomes, in favor of explaining those outcomes in terms of observable evidence. The current paper contributes to this gap by advancing a framework for critically analyzing LUM frames in the context of several elements that are generally required to diagnose a case of evolutionary mismatch (Table 1). Employing the LUM framework can aid researchers and decision-makers in knowing: (i) whether there is critical diagnostic information missing from a frame, which would imply that it does not fully comprehend the evolutionary dynamics of a LUM; or (ii) what mechanism the frame purports to proximately cause a LUM, which would serve as a key leverage point for policy intervention. As we argued above, such knowledge can be made available for each frame in the political discourse by systematically applying the nonpartisan LUM information criteria (Table 1) thereto. Doing so assists in laying the foundations for asking empirical questions that inform comparative analyses. In turn, comparatively analyzing multiple frames can lead to actionable intelligence, when the resultant evidence confirms that a given LUM is proximately caused by one or more mechanisms. These mechanisms, then, may be targeted for policy interventions.

To echo a substantive point made in Section 4.1, there is a nontrivial distinction between deconstructing political frames to expose possible leverage points for policy intervention on the one hand, and using that information in evaluative and prescriptive policymaking processes on the other. Significantly, the LUM framework is limited to the former of these activities. That is, the LUM framework is a meta-approach for critically analyzing frames from LUM political discourses, and it is not put forward as a tool of governance in and of itself. However, to the extent that it exposes path-dependencies and causal histories in LU systems, the LUM framework can plausibly be synched up with evolutionary approaches to governance and spatial planning that are becoming increasingly influential in the social sciences [63,69–71]. While this stream of literature goes beyond the scope of the current paper, future research might usefully synthesize these perspectives into a holistic, evolutionary approach to LUM analysis and governance.

Beyond its potential utility for identifying mechanisms or leverage points for environmental intervention, the LUM framework has value for explaining why evidence of a LUM does not always result in transformational change. Precisely, cases of LUM often occur when societies are "trapped on local maxima" on the fitness landscape [25,26]. This "trapping" effect means that "better" outcomes are not immediately accessible from society's current position, and, as such, certain LUs or LU institutions become locked-in to place. Escaping these traps reiteratively calls on society to bear immediate losses in welfare, to which there is likely to be political aversion [25,26]. In this sense, interested parties might find significant value in the LUM framework. By recognizing that the short term welfare losses from moving off of local maxima are met by selective pressures on existing LUs [25,26], which over time tend to weed out those that are unsuited to the changed environment so as to produce higher-value LU systems [66–68], evolutionary-minded planners, researchers, and other observers can actively reframe LUM political discourses, especially by campaigning to set and manage public expectations about the paths to "fitter" outcomes.

Nonetheless, we offer that a framework such as the one developed here is only *useful* inasmuch as it is *used*. To that end we encourage applied research that examines LUMs through the lens of evolutionary theory. The Cypress Freeway application presented in Section 4 is intended to be instructive in this regard, though that case was greatly simplified for illustrative purposes. Future research must take added care to precisely and methodically trace the causal (evolutionary) history of a given LUM. While this often proves to be a difficult challenge that transcends multiple disciplines, disassembling a LUM into the diagnostic pieces from Table 1 facilitates critical thinking in pursuit of these ends. Areas of inquiry that are particularly well-positioned to exploit the capabilities of the LUM framework in applied research projects include, for example, environmental justice and sustainability. Both of these issue spaces are characterized by competitive environmental politics, and they tend to focus on LUs that evolved under a given set of environmental circumstances but are now imposing hazards and risks on society [24,38,60]. Accordingly, as intimated throughout this paper, these discourses can benefit soundly from adopting an evolutionary perspective.

As a final matter, consider that evolutionary theory is increasingly being taken up as a general framework for studying phenomena in the social sciences because of its integrative nature [40,49,50]. That is, far from competing with existing theoretical contributions in relevant disciplines, evolutionary theory is supplementing or operating in conjunction with them [39–44,49–51]. Along these lines, we stress that the LUM framework is not intended to supplant established perspectives on LU policy change (e.g., the LU&S model). In stark contrast, it serves as a meta-theoretical toolkit that we perceive to be highly compatible with extant scholarship. Future efforts to implement the framework in practice—both in empirical research and in policy discourses—will reveal the parts of the toolkit that are presently understocked. Over time, much like the evolutionary systems studied herein, these engagements and interactions within and between disciplines are expected to increase the "fitness" of the framework in the broader multidisciplinary fields of LU planning and politics.

Acknowledgments

The authors thank the *Land* editors, editorial board, staff, and two anonymous reviewers for their helpful feedback and insights.

Author Contributions

Russell Weaver developed the theoretical framework presented above and drafted the manuscript. Jason Knight reviewed the manuscript and offered guidance to ground it in LU planning scholarship and practice.

Conflicts of Interest

The authors declare no conflict of interest.

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