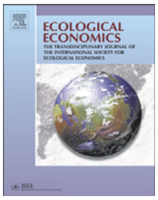
Ecological Economics 120 (2015) 93–99

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon



Analysis

The economic impacts of positive feedbacks resulting from deforestation

Christiane W. Runyan [a,*], Paolo D'Odorico [a], William Shobe [b]

[a] Department of Environmental Sciences, University of Virginia, 291 McCormick Road, Box 400123, Charlottesville, VA 22904-4123, United States
[b] Center for Economic and Policy Studies, University of Virginia, 2400 Old Ivy Rd., Charlottesville, VA 22903, United States

ARTICLE INFO

Article history:
Received 17 May 2014
Received in revised form 2 September 2015
Accepted 15 October 2015
Available online 27 October 2015

Keywords:
Positive feedbacks
Deforestation
Bistability
Strategic behavior

ABSTRACT

Forests can affect environmental conditions in ways that enhance their survival. This effect may contribute to a positive feedback whereby deforestation could degrade environmental conditions and inhibit forest re-establishment. Sudden changes in forest functioning can be attributed to the existence of multiple stable states with one high and one low vegetation state. Multiple factors govern whether a transition between states will occur following deforestation. One such factor is strategic behavior and whether communities or stakeholders with an interest in the forest cooperate to maintain the forest in the fully vegetated state by reducing extraction levels or choose their own extraction rates without considering the collective effect of this behavior. We examine how the effect of a positive feedback and strategic behavior affect the optimal quantity of vegetation, V^*. A clear hysteresis exists for logged forests exhibiting a positive feedback whereby an increase in extraction rates leads to a shift to the low vegetation state. An increase in the ecological value of the forest increases V^* whereas the opposite is true for an increase in the value of timber. V^* is also higher under cooperative conditions than non-cooperative conditions. Notably, accounting for the effect of a positive feedback substantially increases V^*.

1. Introduction

Forest vegetation can interact with its surrounding environment in ways that enhance conditions favorable for its own existence (e.g., Wilson and Agnew, 1992; Bonan, 2002; Lawrence et al., 2007; Runyan and D'Odorico, 2010). These environmental conditions vary depending on the forest ecosystem under consideration. Forests have been found to affect near surface air temperature, precipitation, groundwater depth and salinity, soil nutrient availability (see Runyan et al., 2012a and references therein), and the magnitude and frequency of disturbances such as fire (Beckage et al., 2009) and landsliding (Runyan and D'Odorico, 2014). The effect of forest vegetation on an environmental variable that limits plant's growth may contribute to a positive feedback whereby the removal of forest vegetation would modify the physical environment and degrade the environmental conditions necessary for forest regeneration, thereby inhibiting the re-establishment of the forest (e.g., Runyan et al., 2012a).

Sudden changes in the structure and functioning of ecosystems can be attributed to the existence of multiple stable ecosystem states, which are commonly associated with positive feedbacks (e.g., May, 1977; Holling, 1973). Forest ecosystems exhibiting multiple stable states are characterized by one stable state with no forest vegetation (hereafter termed "low vegetation"; e.g., a grassland, savanna, or bare soil) and another stable state with a full forest cover. A state shift may result as an effect of changes in environmental conditions or disturbance regime that causes some critical bifurcation point to be passed (e.g., Scheffer and Carpenter, 2003; Wilson and Agnew, 1992; Kuznetsov, 1995). As the resilience (i.e., minimum magnitude of event capable of causing a phase transition to another stable state) of a forest ecosystem declines, it becomes increasingly vulnerable to state shifts such that progressively smaller disturbances can cause a transition to the alternative stable state (Holling, 1973).

Once a state shift occurs, the system remains largely locked in a state of low vegetation until there is a change in the environmental conditions controlling the vegetation dynamics. When the system is in the basin of attraction for the low vegetation state, restoring the environmental conditions present before the collapse is not sufficient to switch back to the fully vegetated state. This concept, which is known as hysteresis, indicates that in order for the system to return to the other stable state (i.e., the fully vegetated state), the environmental conditions must be restored beyond another bifurcation point (provided that it exists) (e.g., Walker and Salt, 2006).

For forest ecosystems where deforestation is driven primarily by anthropogenic causes, the likelihood that a transition between states will occur is a function of the current system state, environmental conditions, and economic factors that govern the decision-makers' actions (Brock et al., 2002; Perrings and Brock, 2008). Decision-makers allocate resources through actions that describe the consumption and production activities of economic agents. The activities of economic agents are determined by a set of behavioral rules that depend on the institutional and cultural conditions in their society. These activities depend on institutional conditions such as property rights and governmental

---

[*] Corresponding author.
E-mail address: cwr6zf@virginia.edu (C.W. Runyan).

http://dx.doi.org/10.1016/j.ecolecon.2015.10.007
0921-8009/© 2015 Elsevier B.V. All rights reserved.

capacity, decision-maker objectives, as well as the strategic behavior of economic agents (Brock et al., 2002). Strategic behavior refers to whether those with a stake in the resource cooperate in their extraction of the common pool resource or are non-cooperative with other members having a stake in the common pool resource and determine their own extraction rate.

One well-studied problem, often referred to as the ‘tragedy of the commons’ (Hardin, 1968), is the tendency to over-harvest common pool resources (CPR) such as forests. Overharvesting occurs because excluding harvesters is costly. Harvesters will likely not face the full marginal social opportunity cost of their actions. They will harvest up to the point where their private marginal harvest cost equals their private marginal profit, but the full social cost of the marginal unit of harvest includes the “congestion cost” imposed on other harvesters. In the case studied here, it also includes the added social risk of reduced forest resilience, that is, the likelihood that the forest will move to the low vegetative state. Since harvesters do not pay the cost to others of congestion or resilience risk, they will tend to overharvest relative to the social optimum. Extraction from a CPR has often been formalized in game theory as a one-shot prisoner's dilemma game where over extraction is the dominant strategy for harvesters. The socially optimal outcome would not be expected to occur unless agents can cooperate to avoid the unattractive Nash equilibrium outcome (e.g., Ostrom, 1990). While overharvesting, and hence lower resilience, is more likely to result in the non-cooperative than cooperative case, a transition to the low vegetation stable state can also result in the cooperative case due to incomplete information about the location of the systems critical bifurcation point and random fluctuations in environmental conditions.

The evolution of social institutions for managing CPRs should not be viewed as an exogenous event (Ruttan and Hayami, 1984; Hurwicz, 1973). Factors that help to facilitate a cooperative outcome have been extensively studied and include, among other things: clearly defined boundaries for the CPR and for the set of harvesters who can “appropriate” resources from the CPR, whether harvesting rules are designed by local appropriators and are consistent with local physical conditions, whether monitoring is done by the harvesters themselves or by individuals who are accountable to the harvesters, and whether sanctions are graduated (Ostrom, 1990, p. 90). As Ostrom et al. (1994) clearly demonstrate, single-shot prisoner's dilemma games will not, as a general matter, be the best model for evaluating CPR management regimes. The fate of a forest, is not the result of management decisions made only once by all who have a stake in its output. Cooperative outcomes may result from a repeated prisoner's dilemma game (Axelrod, 2006) or from single plays of games that allow for local choices about long-run institutional arrangements (Ostrom et al., 1994). Just as forests may be subject to bifurcated equilibria that depend on dynamic factors, so may institutional outcomes be subject to tipping points. Iwasa et al. (2010) raise the possibility that people may loose their willingness to cooperate for improved CPR management following successful efforts to improve CPR conditions.

Common property forests are prevalent throughout the world with Papua New Guinea and then Mexico containing the highest percentages of forests (possibly as high as 80%) that are owned by local communities (White and Martin, 2002; Bray et al., 2003). Because communities in these areas are forming enterprises based on a common property natural resource, it is important to understand how the strategic behavior of community members with a stake in the forest will affect profits from timber production (Antinori and Rausser, 2010). Strategic behavior may also be important in affecting the location of the stable states for privately owned forests because the spatial scale of physical processes that control positive feedbacks associated with deforestation oftentimes does not coincide with the size of the area being deforested and the number of entities harvesting the forest (e.g., Runyan et al., 2012a). In turn, the strategic behavior of these parties with a stake in the forest will determine to which stable state the forest converges to and the location of those states.

Many natural systems such as coral reefs, shallow lakes, fisheries and invasive species populations (Coutts et al., 2013) have been shown to be bistable (e.g., Scheffer et al., 2001). Shallow lakes that receive large amounts of runoff containing high nutrient levels from agricultural areas and that have a high inflow of wastewater from human settlements and industries can transition from a clear state to a turbid state caused by a dominance of phytoplankton (Carpenter and Cottingham, 1997; Scheffer, 1997). Mäler et al. (2003) showed that, in a model without uncertainty and where it is socially optimal to maintain the oligotrophic state, whenever there is more than one community using the lake, some initial conditions will lead to a Nash equilibrium in the eutrophic state and others to the oligotrophic state. Furthermore, if the communities end up in the eutrophic state and then decide to coordinate their policies to regain the oligotrophic state, the policy may be quite expensive due to hysteresis. Iwasa et al. (2007) examined how the willingness of each player to cooperate depends on the cooperation of other players and on the level of environmental concern of the society in general. They found that more cooperators leads to stronger social pressure and in turn, higher levels of cooperation and clean water, whereas low cooperation leads to weak social pressure and polluted water. They also found a negative feedback whereby lake water pollution strengthens the environmental concern and enhances the level of cooperation in the subsequent year.

Crepin and Lindahl (2009) accounted for the dynamic interaction between grassland management and grazing pressure and examined how the strategic behavior of farmers and herders affects common property grasslands. When grazing pressures increase, grasslands can become degraded and in turn, only support a relatively low quantity of livestock. Crepin and Lindahl (2009) show that when no feedback is considered, a low grass state (with high grazing pressure) is optimal for non-cooperative farmers whereas a high grass state is optimal for cooperative farmers when the system is initialized in the low grass state. In contrast, a high grass state with reduced grazing pressure is optimal for both cooperative and non-cooperative behavior when the effect of a feedback is considered and when the system is initialized in a low grass state.

Following a shift to the bare stable state, there is a reduction in management options for restoration and significant trade-offs between restoration and the best use of financial resources (Anderies et al., 2006). The feasibility of restoration options will depend not only on the net value of the restoration itself, but also on institutional capacity, including the ability to raise funds for investing in socially profitable endeavors. Thus, understanding not only environmental factors, but also socioeconomic factors that affect a forests' convergence to a given state and the location of these states are important as an incremental change in these conditions has the potential to trigger a large systematic shift (Scheffer et al., 2001).

The choice of the path of future land-use states depends on the discounted sum of expected utility in future periods associated with land conversion (Satake et al., 2007). The discounted expected utility depends on i) the recovery rate of vegetation whereby a high rate of forest regrowth leads to greater densities of forested land, and ii) factors that affect the land-owner's discount rate, with a lower discount rate giving higher weight to the future relative to the present, leading to a larger proportion of forested versus agricultural and abandoned land (Satake et al., 2007).

In this study, we examine how the effect of a positive feedback and the strategic behavior of economic agents dependent on harvesting or using the forest affect the optimal quantity of vegetation present under steady state conditions. We also consider the effect that ecological and economic parameters have on this quantity. We focus here on a static, full information analysis in order to illuminate the underlying ecologic and economic drivers controlling a state change. Analysis of dynamic, stochastic regimes is a promising area for future investigations.