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A Common-Pool Resource Approach to Forest Health: The Case of the Southern Pine Beetle*

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1. Introduction

The southern pine beetle, *Dendroctonus frontalis*, is a major threat to pine forest health in the South, and is expected to play an increasingly important role in the future of the South's pine forests (Ward and Mistretta 2002). Once a forest stand is infected with southern pine beetle (SPB), elimination and isolation of the infested and immediately surrounding trees is required to control the outbreak. If insect-infested trees are not swiftly removed, infestations can spread to healthy forests. The most effective approach to managing SPB is through preventive measures that maintain forests in vigorous, healthy conditions, including thinning and prescribed burning. At a landscape level, preventive measures reduce the overall incidence of SPB and thereby the spillover of SPB to adjacent landholdings. Yet many forest landowners do not undertake the management actions that can limit SPB outbreaks. The tragedy of the commons in forest health takes place when individual private owners do not acknowledge their communal responsibilities thus risking catastrophic losses due to poor management and/or absentee tenure.

The South's forests are largely in private ownership (89% of the South's timberland, with nonindustrial private forest (NIPF) land ownerships representing about 95% of the private forest landowners and 63% of the private forest land region (Birch 1996, Wicker 2002). Population growth and suburban and exurban expansion in the South have divided many forest landholdings into increasingly smaller-sized parcels. Surveys of forest landowners in the South find that 90% of the NIPF owners hold less than 100 acres, and that owners are diverse in occupation, income, residence, forest land ownership objectives, use of professional forest management assistance, and forest management strategies (Birch 1996, 1997; Bliss and Martin 1989).

The diversity of ownership objectives and management styles on NIPF lands results in widely different awareness and responses to forest pest problems (Ward and Mistretta 2002). Pine beetle outbreaks are cyclic, sporadic, and potentially highly devastating (Meeker

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et al. 1995). Extensive outbreaks not only inflict setbacks on individual owners who suffer losses from forced sale of high-value saw timber for low-value pulp, but also collective damages on all forest owners.

The maintenance of healthy pine forests and the various benefits associated with them in the South depends on effective management and control of the Southern Pine Beetle. To a significant extent, SPB management is a social problem because the most practical way to control SPB requires collective action by individual landowners across the pine forest landscapes in the South. Most social research on programs for forest landowners in the U.S. has tended to view them as individuals, and be oriented toward transferring new knowledge, technical assistance, financial assistance and even cultural content to autonomous forest landowners (Best and Wayburn 2001; Schelhas et al. 2004). Accordingly, we have oriented much of our analysis on forest landowners and SPB to understanding why individual landowners do or do not engage in practices known to be effective in the prevention of SPB (Molnar et al. 2003).

However, we also recognize that, from a social science viewpoint, the characteristics of the SPB issue--the need for action at the landscape level, when landscapes are in multiple ownerships--is a problem of the commons (Ostrom 1990). Natural resource management in the commons has been subject to a great deal of study over the past few decades, although little or none of this research has addressed questions of forest health. However we believe that the general principles of the management of common-pool resources can provide some important insights for SPB management. In this paper we explore the usefulness of examining the management of SPB from the perspective of common-pool resource management. As Hardin (1968) notes, an implicit and almost universal assumption of discussions of resource management problems is that a technical solution must exist and the task is to find it. A technical solution may be defined as one that requires a change only in the techniques of the material sciences, demanding little or nothing in the way of change in human values or ideas of morality.

2. A brief review of theory of common-pool resources and forests

Three types of resources can be identified based on different combinations of two characteristics: (1) *subtractability or rivalness*, or the degree to which use by one person diminishes the potential for use by another, and (2) *excludability*, the cost of excluding potential beneficiaries from the resource (McKean 2003). **Private** resources are subtractable in consumption and others can be excluded relatively easily. **Public** resources are available to all (exclusion is not possible or is extremely costly) but not subtractable. Examples include public radio stations, scientific knowledge, and world peace. Individuals may enjoy the benefits of these without contributing to their production (free ride), but if everyone does this a less than ideal amount of the good will be provided (Dietz 2001, Ostrom and Walker 1997). **Common-pool** resources are subtractable but exclusion is difficult (Dolsak and Ostrom 2003).

Although it has been common in the past to discuss common property resources, recent work has emphasized the importance of distinguishing types of resources (based on their inherent attributes, from types of ownership (Dietz et al. 2001). Property may be held in four ways: (1) *private*, in which individuals or corporations have the rights to exclude others from using a resource and to regulate a resource; (2) *public or state*, in which the government has rights to a resource, and makes decisions about access as well as the nature and level of

exploitation; (3) *common property*, in which the resource is held by an identifiable group of interdependent users with the rights to exclude others, and (4) *open access*, in which there are no well-defined property rights, the resource is unregulated, and it is free and open to everyone (Feeny et al. 1990). Research on the commons suggests that the fit between property type and resource type has an important bearing on effective resource management (Dietz et al. 2001, Stern et al. 2002).

Geores (2003) points out that forests are complex, large scale resources that can be defined and assigned property rights in various ways: (1) Forest are appreciated as renewable natural resources, valued for the use of their products and for their roles in maintaining watersheds, soil fertility, and air quality, as well as for their importance as cultural resources, both religious and aesthetic. (2) Forests are resources that contain resources, being made up of biosystems of varying complexity and used for many different social and economic functions as a part of complex social systems. (3) Forests resources are dynamic and defined on multiple scales. Forest and forest resource definitions differ in scale, but are not necessarily mutually exclusive.

Southern forests illustrate this in the way that the wider public values them for wildlife, watershed, biodiversity, and climatic benefits (each requiring management at different scales). In contrast, trees and forests are used and valued by individual landowners for timber. Even when considering only a single resource, such as timber production or wildlife by individual owners, owners of individual parcels may want to encourage or guarantee that owners of adjacent parcels have compatible and complementary interests in their parcels. Neighbors want their neighbors to maintain wildlife habitat and keep vegetative cover intact. They also want adjacent land owners to allow wildlife transit and to refrain from introducing or encouraging certain problem species (McKean 2000).

Gibson and Becker (2000), recognizing that forests generally constitute multiple resources, note that strong individual property rights alone do not guarantee a forest's health since individuals can have short term incentives to convert or degrade forests that conflict with long term forest sustainability. Because they are common-pool and public resources, many forest resources cannot be effectively managed on the scale at which they are owned or in the decision-making time frames of some private owners. As a result, individual forest owners have an interest in what happens on lands adjacent to theirs. Southern pine beetle is a classic example of the stake neighbors have in the way their neighbors attend to forest health.

One of the problems facing common-pool resources is the appropriation problem. If resource units have high value and institutional constraints do not restrict use, individuals face a strong temptation to overexploit and thereby degrade the resource. For example if a forest is open to access by all with no social institutions to limit use, is it likely that timber would be removed at such a rate that the forest would degrade and future timber harvests would be reduced (Hardin 1968). Extensive study of the appropriation problem by social scientists has found that the tragedy of the commons is not inevitable; resource users can organize to implement social mechanisms to restrict use to sustainable levels (Richard and Stein 2003). Other problems of common-pool resources, such as provision and maintenance problems, have received less study but are still important (Ostrom 1999).

Forest health is essentially a provision and maintenance problem. In many ways, it is a public good, in that people can free ride on other people's efforts to enhance forest health at a landscape or regional level. But McKean (2003) notes that public goods that are subject to crowding, wear, and depletion are not pure public goods, and have many characteristics of

common-pool resources. Furthermore, Ostrom (1999) notes that in the case of negative public goods (e.g. forest pests), individual owners or appropriators tend not to be motivated to pay for or take the collective actions that are required to reduce the negative public good, resulting in a negative provision of that good (e.g. poor forest health). Provision problems in common-pool resources are very similar to pure public good problems (Ostrom et al. 1994). Having shown that forests and forest health have important attributes of common-pool resources, the next question is what common-pool resource theory and scholarship can contribute to the health and management of Southern pine forests. Ostrom and Walker (1997) examined many cases of successful common-pool resource management. They identified design principles for development of institutions that increase the efficiency of management of common-pool resources, institutions that are often developed in combination by the resource users and the state.

3. Key understandings from research on individual NIPF owners

A legacy of medieval times, Carlsson (1996) explains why Swedish common forests have survived as vital and competitive actors in the timber market. These lands are held in common under shareholder arrangements managed by the government. He offers three main explanations: the commoners' conscious attempts to reduce transaction costs, their general inventiveness in adjusting to changed circumstances, and their acclimatization to present economic conditions. Although he does not specifically address forest health issues, the notion that a commons institutions offers multiple advantages to a dispersed, nonresidential, and nontechnical population of forest owners suggests a need for new institutions and mechanisms to bind and benefit nonindustrial private forest land owners (NIPF).

Most NIPF landowners are aware of SPB, many are interested in preventing the pest, and some express a desire to accomplish control measures (Molnar et al. 2003). Those actually taking action to prevent and manage infestations are few, however.

Molnar et al. (2003) found important differences by size of forest landholding. Larger landholders are more likely to have taken steps to control infestations, but there were markedly lower levels of awareness, surveillance, and prevention activities among small holders. Larger landowners had high surveillance efforts and took more action to respond to SPB damage when it happened on their land. Larger landowners were also strongly influenced by timber prices in their efforts to control SPB.

Smallholders lacked knowledge about what to do about SPB, lacking familiarity with public agency programs and utilization of financial assistance. They used fewer information sources, and expressed less desire for information about forest management (Molnar et al. 2003).

Some values that landowners—large and small—have for their forest land may provide less than compelling motivations for SPB management. Those interested in recreation and outdoor enjoyment and indicating preservation as a primary reason for forest ownership were less aware and interested in SPB management (Molnar et al. 2003). The control of SPB and the protection of forest health, involves more than the vigilance of the individual forest owner, however.

Carlsson (1996: 12) concludes that the Swedish forest commons have survived as prosperous timber producers and providers of public goods, not only because of their conscious reduction of transaction costs but also because this reduction has been made possible by a

general fragmentation of the centralized State, playing its multiple roles. This fragmentation has provided a local 'opportunity structure' that the commons have utilized. This has been possible because the commons, their forest managers, boards and assemblies of shareholders still possess sufficient local, current knowledge to be able to adjust the commons to industrialized society. The main lesson to be learned from the Swedish common forests might be their successful integration, rather than their separation, from the logic of the negotiated economy and industrialized society. Designers of institutional mechanisms to articulate and organize the collective aspects of forest health might learn much from the Swedish experience.

4. Calculating the benefit from change in rules of forest management

Ostrom (1999:4) emphasizes that the "social behavior of adopting new practices in natural resources management as a rational decision process. Each user has to compare the net benefits continuing to use the old rules of harvesting from a resource to the benefits he or she expects to achieve with a new set of rules. Each user must ask whether his or her incentive to change is positive or negative.

If the incentive to change is positive for some users, they then need to estimate three types of costs: the up-front cost of time and effort devising and agreeing upon new rules; the short-term costs of adopting new strategies, and the long-term cost of monitoring and maintaining a self governed system over time (given the norms of community where they live). If the sum of these expected costs for each user exceeds the incentive to change, no user will invest the time and resources needed to create new institutions. And if this applies to all the users, no change will occur (Ostrom 1999:4).

In field settings, not everyone expects the same cost and benefits from a proposed change. Consequently, the collective choice rules used to change the day-to-day operational rules related to management activities affect whether an institutional change favored by some and opposed by others will occur (Ostrom 1999:4).

These comparisons can be difficult to make in practice since considerable uncertainty always exists concerning the strategies that participants will follow once rules are changed (Ostrom 1999:4). But even though this is a difficult task, it is one undertaken frequently by users after discussing the effects of a change in rules. Rules about monitoring forest lands for SPB infestation may be one example of an institutional change.

Prevention efforts require vigilant surveillance for infestations and adherence to planting and management recommendations that discourage SPB outbreaks. Once outbreaks occur, control requires prompt treatment, and a comprehensive response by all forest owners to stop the spread of SPB to neighboring lands (Egan and Jones 1993, Ervin et al. 2001). Yet many NIPF owners have weak and uneven ties to their properties, and many do not share the sense of urgency that professional foresters often have about SPB prevention and control (Williston et al. 1998).

5. Forest health as a common property resource

Land (and forest) tenure is now widely understood as bundle of rights, all or some of which may be privately owned. Under communal systems, no individual resource rights are privately owned. Under private property systems, the deed holder seemingly owns all rights.

It is increasingly clear that some rights in the bundle can never be exclusively held by individuals, and are in fact dependent on communal cooperation and respect. Forest health may be one such communally owned and managed resource that is held by all forest owners but no one singly. This common pool, open access resource, abused by one, can cause all to suffer. An ephemeral and situational commodity, forest health is often taken for granted when insects, fire, or other threats are not imminent.

The owners of the forest health right or resource are connected in concentric levels of proximity. That is, near neighbors are more frequently and intensively affected by mutual actions and responsibilities. Distant parties are less frequently benefited or harmed by an individual landowner's vigilance and response to forest health problems. Institutions such as forest fire districts sometimes connect land owners in defense of fire threats, but fire threats are not commonly limited to pest prevention.

These indirect and fleeting communal connections among NIPF owners are at the core of the problems facing public agencies charged with promoting forest health. For the most part, locally resident forest land owners often have little basis for interpersonal association. Even among landowners who reside in the same county as their forest land, the increasing separation of residence from ownership diminishes the prospect for face-to-face interaction with neighboring forest land owners.

McKean and Ostrom (1995) find it noteworthy that the definition of private property rights has to do with the rights, not the nature of the entity that holds them. The privateness of private property rights does not require that individual persons hold them; they may also be vested in groups of individuals. Unfortunately, the rights to forest health are not alienable or separable; such rights are evanescent or intangible. Yet when unevenly exercised, forest fires or large-scale timber losses from insect damage are the result.

Scholars who have designed taxonomies to point out the difference between open access arrangements and common property have sometimes distinguished four very general "types" of property: public, private, common, and open access. McKean and Ostrom (1995) object to this classification because it creates the erroneous impression that common property is not private property and thus does not share in the desirable attributes of private property, although forest health property rights are indeed commonly held. They feel that common property is in fact shared private property and should be considered alongside business partnerships, joint-stock corporations and cooperatives. Yet, the shared resource of forest health is often not widely recognized as a common property resource

Oakerson (1986) has suggested a model to analyze and explain the main factors involved in the management of common property resources. In its simplest form, the Oakerson model is based on understanding the relationships between the physical characteristics of the resource, the decision making rules of the group or users involved, the patterns of interactions resulting from the appropriation and use of the resource, and the outcomes of this process. Blaikie and Brookfield (1987) have modified the Oakerson model to explain the dynamic interactions and adaptive changes when a resource is managed under a communal (or collective) regime.

Mutual regulation through the institutional equivalent of a common property regime is more desirable as resource use intensifies and approaches the productive limits of a resource system (McKean and Ostrom 1995). Further, since it is people who use resources, forest health common property becomes more desirable - not necessarily more workable but more valuable and thus more worth trying - as population density increases on a given resource

base. Thus the challenge to resource agencies endeavoring to create a common property resource in forest health must find a way to communicate with NIPF owners in such a way so they become aware of the common property resource they share and have a sense of ownership in the commons.

Natural resources stakeholders have different interests, and investigation of these through discussion can help to identify how people view their current and potential roles in forest management (Higman et al.1999: 170). The challenge to resource managers is to communicate the common property resource aspects of forest health. Higman et al. (1999:170) claim that finding out how people see their own roles in forest management is an essential step toward agreeing about the objectives of forest management. One way of doing this is to focus discussion on stakeholders' rights, responsibilities and results with respect to surveillance and timely response to SPB outbreaks.

As a result from their different rights, responsibilities and returns, stakeholders also have different sorts of relationships with each other. Some may not be aware of each other, or may ignore each other; others may be in varying states of disagreement or cooperation in different issues related to forest management. Yet all share some level of common interest in forest health.

6. Characterizing a robust common property system for forest health

A robust system of social organization for NIPF owners that would promote and protect the common property aspects of forest health has yet to be devised. McKean (1992, 1996, 2000) has written on the nature of common property systems that would lead to ecological benefits for the natural world. She identifies a number of design criteria that may make common property systems robust (McKean 2000a), focusing on internal and external features of the resource management system.

Internal Features pertain to relationships among co-owners, that is, among NIPF owners. Each of McKean's design features is discussed in terms of a common property management system for forest health.

1. Co-owners of resource rights must be a self-conscious and self-governing group.

This feature is hard to envision occurring beyond a watershed or county scale. As previously discussed, nonresident, nontechnical, and dispersed landowners have no mechanism for communication or collaboration. Thus efforts to promote the common pool resource aspects of forest health must develop new mechanisms for linking heretofore-unconnected NIPF owners.

2. The group needs a mechanism for resolving internal conflict.

Current mechanisms generate little direct conflict because NIPF owners have little occasion to interact with one another. Animosity toward noncompliant landowners may be manifested under specific circumstances, but the forest health consequences of NIPF owner indifference or neglect are typically absorbed or ignored by neighboring landowners.

3. The rules need to provide for monitoring of behavior and enforcement of sanctions.

Some states have laws and regulations that sanction noncompliant NIPF for neglecting SPB infestations, yet it is not clear how often these measures are put into play nor how effective they are in influencing behavior.

4. The rules need to include arrangements to prevent abuse by guards.

It is not clear who the "guards" might be for forest health. At present, public forest managers monitor aerial photos and accumulate reports of infestations to provide

assessments of SPB problems. Under a common property regime, NIPF owners themselves might play a greater role in surveillance, requiring access to private lands and other measures that might otherwise compromise individual property rights. If such access were used for private gain – e.g., off-roading, hunting, fishing, or trapping -- cooperation and the common property institution would be undermined.

5. The rules need to be easily enforceable and ecologically conservative.

Rules for managing forest health as common property would require a great deal of public education and would have to be nested in the current web of property law and public agency regulation. Monitoring and infestation response requirements would have to achieve a level of technical and sociopolitical consensus about the techniques of SPB control. Motivating NIPF owners to participate in such discussions would a challenge to resource management agencies not only in terms of the sheer number of actors that would have to be contacted, but also in terms of the communication and participation efforts that would be needed to enlist and sustain NIPF owner involvement and commitment.

6. The allocation of benefits from the commons needs to be roughly proportional to the effort (time, money) invested in the commons.

Under the Swedish system discussed earlier, common members are shareholders in corporate institutions that protect and manage production from forest lands (Carlsson 1996). A U.S. system that endeavored to enlist NIPF in monitoring and managing forest health on a per acre basis might not produce sufficient incentives for small holders. Devising institutional incentives that motivate participation and commitment from large and small holders would have to balance the costs of participation with the infrequently tangible, usually delayed, and often diffuse benefits of forest health.

External Features encompass relationships between the body of co-owners and the outside world. Four considerations relate to the issue of forest health.

7. The co-owning community of resource users is much better off if it has independent jurisdiction or autonomy

Soil and water conservation districts are examples of communities of resource users that have some independent jurisdiction. Such entities are, however, creatures of state and federal laws that enable them. It is clear that not all landowners participate, nor do all that participate benefit equally from these programs – particularly in terms of size of holding and ethnicity of the land owner (Schelhas 2003).

8. The boundaries of common property regimes need to be set at an appropriate ecological scale and need to match ecosystem boundaries.

It is not clear what the appropriate ecological scale is for forest health. Other efforts are underway to organize land owners on the scale of the watershed, thus it seem prudent to seek coincident boundaries between soil, water, and forest resource units of social organization. McKean (2000:10) points out that it is silly to introduce common property institutions where parceled individual property would make more sense, and it is vital to use common property where parcelization to individuals is not a good idea. Forest health is not a resource that is easily parcellized.

9. It is important to select the right group to vest common property rights in order to get capacity to affect the problem.

The unit of organization must be close enough to the problem to aggregate individual decisions and realize consequences for the resource to be managed. A common property institution should combine NIPF forest landowners in a way that connects their efforts to

the cause of forest health and achieves demonstrable consequences for the resource as well as the NIPF owners.

10. On large resource systems, it is important to nest new layers of governance (federalism)

Social organization designed to coalesce NIPF owners to achieve forest health must be aligned with the other emerging forms of association that endeavor to promote and protect resources. Forest resource management must complement water and soil management efforts; there must be some level of mutual reinforcement and synergy to achieve effective environmental management. The environment is interconnected; so must the efforts to make it sustainable.

7. Social capital, social organization, and common property

Each U.S. county has some level of social capital – fire districts, irrigation districts, soil conservation districts, forest associations, extension councils, etc.--that can be drawn on to construct the common property institution in forest health. Institutional changes that expand fire protection vigilance to forest health surveillance including SPB monitoring can build on existing social arrangements to protect forest health. Flora (2000: 87) notes the importance of building human and social capital for communities that are engaged in natural resources management. Social capital involves mutual trust where people know they can count on someone, which fosters reciprocity. Mutual trust is established when different institutions and individuals can both give and receive. Mutual trust and reciprocity tend to occur when people work together.

Flora (2000: 87) mentions that one way of building trust is to start with small projects that have immediate visible results that everyone can measure and contribute to. Face-to-face groups are the building blocks of social capital. The measurement of increased social capital is done by looking at the strengthened relationships and communication among unlikely segments within or outside the community and the increased availability of information and knowledge. McDonald and McLain (2003) describe the successful integration of community well-being and forest health in the Pacific Northwest. They found that a central vehicle for change was the creation of a quasi-public organization (Conservation and Development Council) that had as its first objective to improve economic and social well-being. Specifically, the Council promoted forest health and community well-being through habitat restoration programs that employed people in the area. The Council used special forest products programs to encourage businesses to pool resources for equipment and marketing, and give employees training in forest products harvest and marketing. The Council also sponsored a wood products production and marketing activities programs to help public and private owners produce and market wood products.

Council activities also played an important role in creating new alliances and changing relationships among local and non-local organizations. It increased the capacity of local groups to obtain funds and gain access to technical expertise from outside organizations. In short, it provided an institutional substrate for managing the forest health commons.

Ostrom (1999:2) defined a self-governed forest resource as one where actors, who are major users of the forest, are involved over time in making and adapting rules within collective-choice arenas regarding the inclusion or exclusion of participants, appropriation strategies, obligation of participants, monitoring or sanctioning, and conflict resolution. In most modern political economies it is rare to find any resource system that are governed entirely

by participants without rules made by local, regional and national authorities also affecting key decisions. Thus in a self-governed system, participants make many, but not all, rules that affect the sustainability of the resource system and its use.

Both the natural physical boundaries of a forest as well as the legal boundaries for a particular community's forest must be clearly identified and defined (McKean and Ostrom 1995). The lack of definition and assignment of forest health property rights quite clearly represents a barrier to forestry management, on the one hand limiting the realization of prevention and control benefits and, on the other, encouraging "free rider" behavior and giving rise to the so-called tragedy of the commons – outbreaks that spread to neighboring properties and create otherwise avoidable catastrophic timber losses.

Inflexible rules are brittle, and thus fragile, and can jeopardize an otherwise well-organized common property regime (McKean and Ostrom 1995). In particular, the science behind SPB had not fully defined the rise and fall of SPB populations. Consequently, in some years natural forces driving surges in SPB infestation may overcome high levels of surveillance and response to outbreaks. The setbacks and frustrations occurring to NIPF owners stress the institutions that normally prevent and control SPB outbreaks.

Institutions for managing very large systems need to be layered, with considerable authority devolved to small components. Many different communities, some of which are in frequent contact with each other and some of which are not, may use a large forest. The need to manage a large forest as a unit would seem to contradict the need to give each of that forest's user communities some degree of independence. Nesting different user groups in a pyramidal organization appears to be one way to resolve this contradiction, allowing simultaneously for independence and coordination (Cernea 1985). The most successful models of nesting come from irrigation systems serving thousands of people at a time (McKean and Ostrom 1995). It is not clear whether such high levels of social organization are necessary or feasible to achieve forest health.

8. Conclusions

If forest health is an emerging commons, every new enclosure of the commons involves the infringement of somebody's personal liberty (Hardin 1968). Infringements made in the distant past are accepted because no contemporary complains of a loss. Newly proposed infringements to articulate monitoring and management responsibilities may be vigorously opposed by NIPF owners as violating property rights. But what do property rights mean? When landowners mutually agree to prevent and limit losses from natural threats, all forest owners become more free and perhaps more wealthy. As Hardin (1968) concludes by citing Hegel, "Freedom is the recognition of necessity"; individuals locked into the logic of the commons are free only to bring on universal ruin. Once they see the necessity of mutual coercion, they become free to pursue other goals.

Like individual parcellation, the recognition of common property gives resource owners the incentive to prevent and control insect damage, to make investments in forest health and to manage them sustainably and thus efficiently over the long term (McKean and Ostrom 1995). Forest health cannot be privately owned; it is an open-access resource. However, unlike individual parcellation, common property offers a way to continue productive use of the private aspects of a resource system while solving the monitoring and enforcement problems posed by the need to survey forest lands for insect problems.

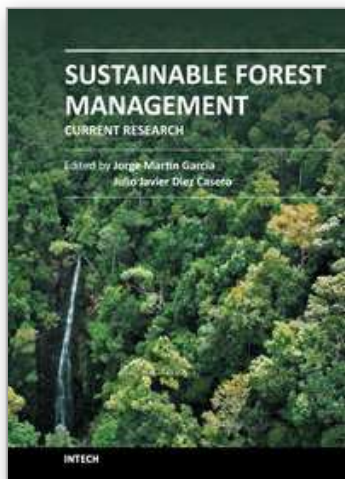
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Sustainable forest management (SFM) is not a new concept. However, its popularity has increased in the last few decades because of public concern about the dramatic decrease in forest resources. The implementation of SFM is generally achieved using criteria and indicators (C&I) and several countries have established their own sets of C&I. This book summarises some of the recent research carried out to test the current indicators, to search for new indicators and to develop new decision-making tools. The book collects original research studies on carbon and forest resources, forest health, biodiversity and productive, protective and socioeconomic functions. These studies should shed light on the current research carried out to provide forest managers with useful tools for choosing between different management strategies or improving indicators of SFM.

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