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Herbicides and Forest Biodiversity: An Alternative Perspective

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Abstract

Effects of herbicide use on forest biodiversity was the topic of a special section in the winter 2004 issue of The Wildlife Society Bulletin. *In acknowledging public concerns regarding the toxic effects of herbicides, several of the contributing authors argued that these effects are negligible and that intensifying wood production would be beneficial for forest biodiversity and conservation by reducing habitat conversions. We contend there are other important environmental consequences; hence, responding to increased opportunities for selling wood products by augmenting supply through intensifying production should not be the only option. We argue that it is also important to develop mechanisms to reduce the demand for forest products. We believe the focus of the special section was too narrow, particularly with respect to benefiting biodiversity, because herbicide use also intensifies the export of wood products and, thus, nutrients. Other factors that must be considered include soil acidification caused by biomass export and fertilizer application, as well as additional acidification resulting from aerial emissions. In addition, because of mineral cycle dynamics constraints, intensively managed forests may not be sustainable for wood production, and less so for forest-dependent animals. Extensively exploited forests may deplete mineral reserves, and any intensification likely would speed up the declines. We believe the indirect impact from herbicides through accelerating mineral export and loss needs to be addressed, in particular how it may affect mammals' ability to accumulate essential trace elements. We contend using fertilizer applications as a corrective measure at the landscape level would be cost-prohibitive. Thus, heralding that herbicides, a tool to intensify wood production, benefit forest biodiversity appears premature, given the time scale of forest growth and soil development.* (WILDLIFE SOCIETY BULLETIN 34(5):1472–1478; 2006)

Key words

biogeochemical cycles, biomass export, ecological economy, forestry, herbicides, mammalian herbivores, selenium, sustainability.

Modern forestry practices in North America have increased public concerns regarding the environmental consequences of increased herbicide use (Guynn et al. 2004). To synthesize papers published regarding the effects of forest herbicides on wildlife, the Biological Diversity Working Group of The Wildlife Society sponsored a symposium at the 10th Annual Conference, which resulted in a special section in the winter 2004 issue of *The Wildlife Society Bulletin* (Miller and Wigley 2004). The basic tenets common to all papers were 1) increasing demands for wood products, 2) decreasing land bases for production, and 3) public resistance regarding forestry methods. The authors argued that intensive forestry will be required to satisfy the increasing demand (Miller and Wigley 2004, Wagner et al. 2004) and that forest herbicides will be required to maintain high levels of productivity. They also suggest that a side benefit of this production model will be increased forest biodiversity because it will result in conservation of natural habitats. We believe that additional considerations from the point of view of forest sustainability, particularly nutrient flow, and its consequences for wildlife conservation merit further discussion.

Forestry and Sustainability

Basic objectives of forestry include controlling species composition by choosing trees best suited to a site from ecological and economical perspectives, using genetically improved trees, fertilizing, thinning, and effectively controlling competing vegetation (Wagner et al. 2004). A wide variety of deciduous trees, shrubs, and herbaceous plants are considered obstacles to forestry efforts in United States commercial forests. Herbicides are used to minimize competition from such non–crop species (Shepard et al. 2004, Wagner et al. 2004). Whereas the economic perspective is clear, we believe the consequences for ecosystems have not been fully considered.

Herbicide application in forestry has resulted in public resistance (Guynn et al. 2004). As an effective means for increasing wood production, the symposium papers (Guynn et al. 2004, Lautenschlager and Sullivan 2004, Shepard et al. 2004, Wagner et al. 2004) make the case that herbicides produce negligible effects on animals and biodiversity in general. Although there are no data on overall herbicide quantities, types, and application methods used, the trend of employing herbicides is increasing (Miller and Miller 2004).

Applying herbicides has assisted the increase of wood production in the United States considerably. Wagner et al. (2004) reported that application of optimal herbicide treatment would increase "sustainable harvest levels" in Maine by 31% over actual levels. Miller and Miller (2004) and Wagner et al. (2004) reported wood volume gains from using herbicides of 30–450% in Pacific Northwest forests, 10–150% in Southeast forests, 50–450% in northern forests, and up to 5,800% in southern loblolly pine (*Pinus taeda*) forests.

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Several of the authors argued the intensified wood production ostensibly is beneficial to other lands and its wildlife by reducing habitat conversion necessary to achieve a comparable level of production; therefore, it must be beneficial to the forestry industry as well. Timber production in the southern United States alone is a multibillion dollar industry (Miller and Miller 2004). Also, we are unaware of any popular movement in North America where an anticipated deficiency of wood products was a basis for protest with demands for an increase in production. However, the existing paradigm assumes that the public supports the inherent assumption of increasing wood production to meet anticipated increasing demands. We offer an alternative viewpoint that emphasizes reducing wood consumption through initially informing the public of tradeoffs and implications and then determining the willingness to reduce the use of wood products or work toward government-imposed restrictions (e.g., taxes) on its use. There are many instructive examples of such approaches, often related to demands and use of water or fossil fuel (e.g., Swiss Federal Office of Statistics, <www.bfs.admin.ch>). Moreover, recent reductions in United States demands for wood products resulted simply from decreased purchasing power of citizens during recessions of the United States economy (Power 2006).

Sustainability

Currently Forest Vegetation Management is defined as "the practice of efficiently channeling limited site resources into usable forest products rather than into noncommercial plant species" (Wagner et al. 2004:1031). Hence, the value for biodiversity of managed forests likely depends on the time scale considered. That is, rather than simply examining short-term responses, the real test of this paradigm is examining the issue of sustainability.

Historically, forest sustainability only referred to harvesting of annual regrowth but more recently was broadened to include maintenance of forest health (Hennig 1988). Comerford et al. (1994) suggested that for forestry "long-term" should mean 3 harvest rotations which, depending on species and methods, would be 15–150 years (e.g., Wagner et al. 2004). In contrast, Morris and Miller (1994) estimated that soil reserves of macro-elements generally would be depleted after only several rotations. However, sustainability ought to encompass more than just harvesting the present maximal level of primary or secondary productivity; it has to incorporate systems ecology (also see Myers 1993). Giampietro (1994) uses hierarchal theory to conclude that long-term sustainability has to prioritize the highest system level, which is the life-supporting ecosystems. Lower-level phenomena, such as economic criteria or human living standards, necessarily become secondary in importance.

We define sustainability as comprising those activities that can be repeated indefinitely within the constraints of the natural fluxes of energy and nutrients that produced a specific ecosystem. We propose a time frame of 1,000 years to determine criteria needed for defining sustainability, based on the time needed for development of soils permitting forest communities (DeAngelis 1992, Hildebrand 1994).

The current extent and trend of intensifying forestry is paralleled by increasing rates of exporting biomass from those ecosystems because these are used elsewhere. Natural ecosystems, however, are characterized by levels of product removal (i.e., nutrient export) that are close to zero and by achieving climax or steady-state levels of plant biomass and soil organic matter (Berger et al. 1989, Helyar 1991, DeAngelis 1992, Dobrovolsky 1994). It is evident, therefore, that increased opportunities for wood fiber production, patterns of human distribution, and economic incentives are causing an ever-increasing tendency to export wood and nutrients from production sites. Although intensive agriculture has long recognized the need for basic plant fertilizers (nitrogen [N], potassium [K], phosphorus [P]) to maintain high output rates, there has been little concern for the destiny of other elements. In fact, the implicit assumption is that export of all other elements is not significant for the welfare of plants or animals. Thus, to reduce detrimental effects on forest productivity, fertilizing is recommended to replenish nutrients according to amounts exported by harvesting (Merino et al. 2005), implicitly referring to nutrients important for trees.

Natural systems typically exhibit biologically important element cycles that are practically closed at local levels (DeAngelis 1992, Dobrovolsky 1994). Evidence from deciduous and coniferous forests that are relatively undisturbed by humans indicate that small net nutrient losses are counterbalanced by weathering or atmospheric depositions (Spurr and Barnes 1980, Kennedy et al. 2002). In contrast, systems disturbed by humans are characteristically open, with large quantities of material being translocated to other areas. Some of the consequences are well accepted in intensive agriculture and forestry, and remedies to counter the effects of nutrient export also are well established, namely the input of NPK fertilizers (Brady 1990). Hence, intensifying biomass export from woodlands raises concerns about the fate of mineral cycles. Aside from the direct removal of elements, additional consequences on mineral cycles stem from changes in soil qualities.

Soil Acidification

Soil acidification has large impacts on mineral cycles (e.g., Flueck 1990) and as a process it impacts sustainability because soil capacity to hold exchangeable nutrient cations decreases sharply with increasing acidity (Hildebrand 1994). In natural closed systems, most available nutrients are trapped in biomass, subsequent nutrient loss and associated soil acidification are minimal, changing soil quality typically in time periods several times larger than what is required for soil formation, which in central Europe is about 10,000 years (Helyar 1991, DeAngelis 1992, Hildebrand 1994, Moreno and Gallardo 2002).

In contrast, anthropogenic activities have accelerated soil acidification, resulting in soil quality changes within a few decades, even in extensively used areas. Intense acidification of soils through emissions and fertilizer application is well established and a widespread phenomenon (Berger et al. 1989, Ridley et al. 1990). But soil acidification also results from increased primary productivity through various management schemes and by export of biomass that has absorbed base cations while depositing hydrogen ions (H^+) in soils (Helyar 1991, Gustafsson et al. 1993, Moreno and Gallardo 2002). For instance, 30–70% of exchangeable cation pools to a depth of 1 m were lost through acidification in 4 decades, and over half the study sites lost >50% in southern Sweden (Berggren et al. 1990). Large regions in various parts of the world also have experienced soil acidification within a few decades, affecting plant growth (Helyar 1987, Buberl et al. 1994). In contrast, cation uptake in pristine forests is responsible for 77% of soil H^+ deposition, but, when these forests reach the degenerative phase, the lost capacity to neutralize acids could be completely restored by cation release during biomass mineralization (Moreno and Gallardo 2002). Essentially, increased biomass export, use of fertilizers, and acid precipitation are all contributing to a trend of large-scale soil acidification with its consequences for mineral cycle dynamics, including releases of toxic elements (e.g., aluminum, cadmium).

Macro-Element Cycles

Watmough and Dillon (2003) showed that forests in central Ontario, Canada, lost calcium (Ca) and magnesium (Mg) from acidification: Ca lost in 17 years represented up to 60% of the available pool. They suggested that forest health and productivity may be impaired within a few decades if these rates of Ca loss from acid emissions and harvest would continue. Similarly, Ca depletion from export in southeastern United States forests probably will reduce soil reserves to less than the requirement for a merchantable forest stand in about 80 years (Huntington et al. 2000). Since 1950 pools of exchangeable base cation have decreased by 50% in the upper 1 m of forest soils in southern Sweden due to acidification (Falkengren-Grerup et al. 1987). The German Black Forest often now contains <50 kg/ha exchangeable Mg reserves in soils down to 60 cm (rhizosphere), which is about the amount in the biomass of growing spruce forests (Hildebrand 1994). Consequently, over 80% of Mg reserves now are contained in biomass, and these forests continue principally on the "small" cycle, i.e., mineralization of humus rather than from soil reserves (Buberl et al. 1994, Hildebrand 1994). Under such conditions, forests are susceptible to short-term impacts like weather or diseases, but clear-cutting, for instance, would remove the greater proportion of remaining bioavailable Mg.

Nitrogen was the classical limiting element in European forests but now has been replaced by Mg and K. In some areas 44% of forests would need immediate liming to halt this deterioration, although it is not a long-term solution (Helyar 1991, Buberl et al. 1994). Similarly, harvesting results in Ca depletion in most forest systems (Federer et al. 1989, Huntington et al. 2000). Exports of K, Ca, Mg, and especially P by conventional harvesting among several tree species were similar to or higher than the soil-available reserves (Yanai 1998, Merino et al. 2005). In the very fertile rolling Argentine grasslands, soil fertility remained at relatively high levels by planting corn for 10–12 years followed by 3–4 years of ley used to fatten cattle. When corn was grown continuously for over 20 years, nutrient exploitation resulted in 50% decreased productivity. However, when the prior system was replaced with continuous cropping of soybean, soil fertility was lost in only one decade (Ghersa et al. 1994). Even when plant-available soil nutrient reserves become very low, there can still be high growth rates for short periods, such as decades for forests, for biomass growth rates are not an indicator of soil nutrient-reserve conditions (Hildebrand 1994). Thus, while macro-element deficiency has, for a considerable time, been known to have occurred in intensive agricultural production systems, it now also is recognized in more extensive production systems like forestry.

Micro-Element Cycles

Forest landscapes, especially in mountain ranges, often are naturally low in macro- and micro-nutrients (Kubota et al. 1967, Kubota and Allaway 1972). All of the essential elements can be limiting to biological production, important especially in the more heterogeneous terrestrial systems (DeAngelis 1992, Dobrovolsky 1994).

Micro-Elements Essential for Plants and Animals

Many trace elements are essential to both plants and animals. However, although plants may be partially affected by a deficiency, they may still grow and, hence, provide inadequate forage to herbivores. Many regions, characterized by low concentrations of soil and plant trace elements, thus induce subclinical or clinical deficiencies in mammalian herbivores. When such areas are exploited, even extensively, these micro-elements may become important as animal deficiencies. For instance, copper (Cu) and molybdenum (Mo) contents in plants generally are associated with soil availability, and the Cu requirement of plants is much lower than that of animals (Van Soest 1982, Jones and Wilson 1987). As forest landscapes are modified by liming, fertilizing, and reseeding, secondary Cu deficiency can appear in wild herbivores (Alloway and Tills 1984, Bonniwell 1986). The apparently new Alvsborgs disease was discovered in Swedish moose (*Alces alces*) in 1985, resulting in >1,000 deaths over a 9-year period (Steen et al. 1989, Broman et al. 2002). Many animals showed severe Cu deficiency, and some were diagnosed as suffering from primary Cu deficiency (Rehbinder and Petersson 1994). Furthermore, between 1982 and 1988, a decrease of about 30% in hepatic Cu concentration was observed, and by 1992 it had dropped by 50% (Frank et al. 1994). In the same time period, Mo levels in moose increased more than 20%. Because this area is heavily acidified, these authors considered reduced Cu release as a possible scenario, while efforts since the 1980s to improve forest condition by intensive liming increased Mo release. In general, weathering does not keep pace with documented losses of several macro- and micro-elements due to increased soil acidification in southern Sweden (Bergkvist et al. 1989). For instance, the present-day extractable soil pool of zinc in deciduous and coniferous forests of southern Sweden is only 50% of the level 40–50 years ago.

Micro-Elements Affecting Only Mammals

Elements not essential to autotrophs but essential to heterotrophs represent an additional complexity of nutrient cycling dynamics. In these cases, disturbance to mineral cycling will only affect the heterotrophs, although the consequences will have cascading effects throughout the ecosystem. Even though livestock can be treated for nutrient imbalances, practical protocols are not yet available for wildlife species.

Significant areas worldwide have marginal soils relative to these micro-elements (Kubota et al. 1967, Kubota and Allaway 1972), resulting in subclinical deficiencies that are mostly unrecognized in wildlife (Flueck 1994) or in extensive animal production systems (Johnson et al. 1979, Jones et al. 1987). However, the incidence of overt and subclinical deficiencies is likely to increase where biomass export is accelerated.

For instance, selenium (Se), a micro-element usually occurring in low soil concentrations, is insufficient for mammals in many areas such as northern Europe, the western United States, New Zealand, Chile, and China (Kubota et al. 1967, Robinson 1988, Singh 1991, Tan and Huang 1991). Selenium, nonessential to plants, occurs in plants proportional to soil concentrations. However, it is an essential micro-element for mammals, important at very basic biochemical levels, and deficiency primarily affects juveniles, resulting in increased mortality during the neonatal period (Keen and Graham 1989). Due to these basic functions, suboptimal Se levels result in a myriad of symptoms, and pronounced deficiency is lethal. With regard to wildlife, sustainability of forestry implies maintaining functional geochemical and biogeochemical cycling of Se. Several factors make the Se cycle susceptible to depletion with its associated consequences for the fauna (Flueck 1990, Flueck and Smith-Flueck 1990). For instance, increased inputs of sulfur (S), P, and N through fertilizers or emissions decrease Se bioavailability to plants and, thus, animals. The global continental deposition rate of anthropogenic S is 6–9 times greater than the natural preindustrial deposition rate (Dobrovolsky 1994). Similarly, N input already is several times greater than natural fixation through use of N fertilizer and legume crops and through emission of oxidized N, much of which becomes deposited even in remote areas (Aber et al. 1989, Dobrovolsky 1994). Therefore, input of S and N cannot be ignored, as they impact Se bioavailability. Furthermore, acidification of soils transforms Se into unusable forms, i.e., unavailable for plant uptake (Geering et al. 1968, Mikkelsen et al. 1989). For example, soils in southern Swedish forests showed a 10-fold increase of proton concentration throughout the soil profile over a 25- to 40-year period (Gustafsson et al. 1993), whereas a 20-fold increase occurred in Germany over a 65-year period (Hildebrand 1994), both of which impacted Se absorption.

Thus, there are several aspects of biomass removal that need special consideration. First, the characteristics of the Se biogeochemical cycle result in the majority of the Se available to organisms to be accumulated in biomass (Gissel-Nielsen and Hamdy 1977, Swaine 1978). Consequently, export of plant biomass, directly or indirectly as through herbivores, removes important proportions of bioavailable Se. Second, plant export results in soil acidification, which decreases Se absorption rates by plants (Helyar 1991, Gustafsson et al. 1993). Third, biomass export in the form of ruminant herbivores not only removes Se, but Se deposited in feces and urine is principally in forms unavailable to plants (Butler and Peterson 1963, Peterson and Spedding 1963, Olson et al. 1976). Therefore, artificially high densities of ruminants (through forest management, fertilizers, emissions, lack of large predators) impact immobilization rates of Se. Fourth, intensified plant production is accompanied by fertilizer application with associated consequences (direct interference with absorption, soil acidification, dilution effect) on the Se cycle. Fifth, Se removal by volatilization during fires may be substantial in systems with marginal or low Se concentrations because much of the Se available to plants occurs in standing biomass (Swaine 1978, Frost 1987). In addition, other anthropogenic activities strongly decrease bioavailability of Se, notably increased concentrations of heavy metals (through emission, mobilization in acidified soils), which render Se unavailable to plants. Furthermore, exposure to heavy metals in animals increases the physiological need for Se as do other oxidative stresses through exposure to pollutants or toxicants; thus, these factors have to be accounted for in a discussion of Se requirements. For instance, studies of glaciers showed that concentrations of mercury and cadmium have doubled since the industrial revolution (Berger et al. 1989), and many studies reported increased tissue levels in wild herbivores (Backhaus and Backhaus 1983, Lindevall 1984). These factors help explain the worldwide increase in incidence of Se-responsive diseases (Jenkins and Hidiroglou 1972, Gissel-Nielsen 1975, Fischer 1982, Millar 1983). Programs of fertilizing soils with Se to overcome deficiencies demonstrated that applications last only 1–2 years (Gupta et al. 1982, Watkinson 1987); thus, fertilizing programs at the landscape level would be prohibitively expensive.

Conclusion

Information presented on herbicide use in forestry (*Wildlife Society Bulletin* 32) showed that direct impacts on wildlife and biodiversity through toxicity are negligible. We also agree that intensified production on some land alleviates pressures for other sites. However, there are other important associated issues that are well known but have not been addressed in the special coverage. More importantly, responding to increased market opportunities by augmenting supply through intensifying production is not the only option. We believe that potential long-term negative consequences for sustainability provide compelling reasons to consider opportunities and incentives to reduce needs, although this is not an expected approach from the traditional economic perspective.

The special publication on herbicides and forest biodiversity was considered the state-of-the-knowledge on current forest herbicide issues, based on reviewing pertinent literature (Miller and Miller 2004, Miller and Wigley 2004). Nevertheless, continuously exporting wood products based mainly on forest regrowth rates as a surrogate for sustainability ignores other important relationships for healthy functioning of ecosystems. Similar simplistic models include the *sustainable* harvest rates in wildlife management based only on birth and death rates to maintain a specific population size, or *sustainable* soil productivity defined as capacity to supply nutrients to plants (Brady 1990, Morris and Miller 1994).

Because of constraints of mineral cycle dynamics, intensively managed forests may not be sustainable for wood production and less so for forest-dependent animals. As pristine forest systems are practically closed with respect to nutrient flow, even rather extensively exploited forests have been shown to further diminish certain mineral reserves, and any intensification would accelerate the declines. Application of herbicides clearly leads to several-fold increases in wood production and export. In so doing, intensive wood-fiber production results in soil acidification, which together with emissions need to be considered in terms of their effect on mineral bioavailability; it accelerates direct removal of minerals contained in biomass and thereby reduces soil reserves, and it causes cumulative loss of several minerals through burning slash and water runoff. Such indirect impacts of herbicides need to be addressed, particularly for mammals and their unique needs of several micro-elements. For these reasons, we believe the conclusion that herbicide application as a management tool to intensify wood production also is beneficial to biodiversity appears premature, given the temporal scale of forest growth and soil development.

The objective of herbicide use in forestry was repeatedly stated as a tool to increase wood volume. We posit that this is only an intermediary stage of the *ultimate* goal that has been omitted from the discussion. The ultimate goal is to generate economic profits by taking advantage of new opportunities to sell products; increasing volumes is then a logical step, as well as the harvest and export of these materials. Herbicide use in forestry can thus be described as an expression of economic growth, the value of which to wildlife conservation has been questioned in another special coverage (Czech 2000). We suggest that accelerated removal of biomass and its consequences are issues to be included in a holistic analysis of herbicide impacts in forestry, even if public concerns are only directed at toxic effects.

Intensive forest-production sites might not be able to sustain certain wildlife species, particularly mammals. Although use of fertilizer has become a widely accepted practice in agriculture and intensive forestry, one does not normally think of it as a strategy in landscape management. As Merino et al. (2005) recognized, even in European settings, terrain and logistics may be prohibitive for fertilizer applications. Certainly, mitigating micro-element depletions at the landscape level would be extremely expensive and would not be an option for all countries now and less so in the future.

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Werner T. Flueck (right) is a research scientist at the Argentine National Scientific Research Council (CONICET) and associated research fellow of the Swiss Tropical Institute. He received a B.A. in zoology, followed by a B.S. in wildlife management from Humboldt State University, California, and a Ph.D. (1989) in comparative pathology from the University of California, Davis. He is a Certified Wildlife Biologist with The Wildlife Society (TWS). He initiated his research career in 1982 with employment at the University of Berne's wildlife disease department in Switzerland. Later he was a consultant on several cervid research projects for the California Department of Fish and Game and, as a United States Peace Corps Natural Resource Technician, he supervised red deer (*Cervus elaphus*) management projects, working alongside the Argentine National Park Service. His research interests include the interplay of nutrition, predation, and population dynamics of wild herbivores in modified environments, nutrient cycles, interactions between exotic deer and native herbivores and predators, quality management of red deer, and conservation of the critically endangered Patagonian huemul deer (*Hippocamelus bisulcus*). Research on red deer introduced to Patagonia has touched on the current distribution, densities, diseases, genetics, population dynamics, mortality factors, and spatiotemporal behavior. He is promoting the implementation of science-based management and hunting for conservation of exotic red deer, and science-based conservation to help recover the huemul deer. In addition to his research, as consultant to the Argentine National Park Service, he serves as instructor, teaching red deer management techniques to rangers and park-approved hunting guides. ***Jo Anne M. Smith-Flueck*** (left) is the environmental program director for the Arelauquen Foundation, which is dedicated to preserving environmental resources and ecological processes in the Andean–Patagonian region of Argentina and Chile. She earned her B.S. in wildlife management at Humboldt State University, California, her M.S. in ecology at University of California, Davis, and her Ph.D. (2003) in biology at Universidad Nacional del Comahue, Argentina. She is a Certified Wildlife Biologist. Her research focuses on cervid and camelid ecology, management, and conservation, which includes studying factors potentially limiting the recovery of the endangered huemul, development of a conservation research and breeding center for the huemul, interspecific interactions particularly between exotic and native species, social behavior in regard to reproduction strategies and movement patterns, and conservation genetics. Her field studies on the endangered huemul began while working for the United States Peace Corps (1992–1994), during which time she conducted surveys in various remote areas throughout the southern Andean mountain range to determine the presence of the species. Before moving to Argentina, she worked as consultant to the California Department of Fish and Game on several cervid research projects. Her coauthored monograph on the huemul received the TWS Outstanding Publication in Wildlife Ecology and Management Award in 2003. Currently, she is serving as Chairperson of the Scientific Steering Committee for the 6th International Deer Biology Congress.