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Intermountain Journal of Sciences

The Intermountain Journal of Sciences is a regional peer-reviewed journal that encourages scientists, educators and students to submit their research, management applications, or view-points concerning the sciences applicable to the intermountain region. Original manuscripts dealing with biological, environmental engineering, mathematical, molecular-cellular, pharmaceutical, physical and social sciences are welcome.

Co-sponsors/publishers include the Montana Academy of Sciences, the Montana Chapter of The Wildlife Society, and the Montana Chapter of The American Fisheries Society. This journal offers peer review and an opportunity to publish papers presented at annual meetings of the co-sponsor organizations. It is the intent of the governing bodies of the co-sponsor organizations that this journal replace printed proceedings of the respective annual meetings. Therefore, it is the policy of the editorial board that presenters at annual meetings of the co-sponsors be given priority in allocation of space and time of publication, although submission of other manuscripts for review and publication without regard to membership is encouraged.

Initial funding was provided by the co-sponsor organizations. Long-term funding will be derived from page charges assessed authors, sponsoring organizations or agencies at $60 per printed page upon acceptance of each manuscript and from annual subscriptions: student $6; regular member $15; patron member $25; overseas member $25; library $25; life member $150; and, sustaining subscriber $2,500.

The intent of the co-sponsors and editorial board is that ***The Intermountain Journal of Sciences*** be expanded to a quarterly journal. Achieving that objective depends upon numbers of acceptable manuscripts received and available funding. It also is the intent of the editorial board that contributing authors be assured of publication within 12 months of acceptance of their manuscript by the managing editor.

The organizational staff is voluntary and consists of an editorial board, an editor-in-chief, a managing editor, associate editors, a business manager and a panel of referees. The editorial board is responsible for establishing policy and the chair of the editorial board serves as liaison to the sponsoring organizations. The editor-in-chief is responsible for determining acceptability and level of revision of manuscripts based on referees' comments and recommendation of an associate editor. The managing editor serves as liaison for layout and printing. Associate editors include but are not limited to the section vice presidents of The Montana Academy of Sciences. Referees are selected on the basis of their field and specific area of knowledge and expertise.

Referees and associate editors judge submitted manuscripts on originality, technical accuracy, interpretation and contribution to the scientific literature. Format and style generally follow the *Guidelines for Manuscripts Submitted to the Intermountain Journal of Sciences, Dusek 1995, revised 2007*.* Organization may vary to accommodate the content of the article, although the text is expected to elucidate application of results.

*For detailed information about IJS, please go to our web site at: www.intermountainjournal.org

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Editorial Review Policy

The *Intermountain Journal of Sciences* (IJS) is a fully refereed journal.

Manuscripts are submitted to the Editor-in-Chief (EIC) for initial consideration for publication in the IJS. This review shall include, but not be limited to, appropriateness for publication in this journal, correct formatting, and inclusion of a letter of submittal by the author with information about the manuscript as stated in the "Guidelines for manuscripts submitted to the *Intermountain Journal of Sciences*" (Dusek 1995, 2007). This cover letter must also include a statement by the author that this paper has not been submitted for publication or published elsewhere. The EIC notes the date of receipt of the manuscript and assigns it a reference number, IJS-xxxx. The EIC forwards a letter of manuscript receipt and the reference number to the corresponding author. The corresponding author is the author who signed the submittal letter.

Three hard copies of the submitted manuscript, with copies of the "Guidelines and checklist for IJS referees" attached are forwarded to the appropriate Associate Editor. The Associate Editor retains one coy of the manuscript and guidelines for his/her review, and submits a similar package to each of two other reviewers. A minimum of two reviewers, including the Associate Editor, is required for each manuscript. The two other reviewers are instructed to return the manuscript and their comments to the Associate Editor, who completes and returns to the EIC a blue "Cover Form" and all manuscripts and reviewer comments plus a recommendation for publication, with or without revisions, or rejection of the manuscript. This initial review process is limited to 30 days.

The EIC reviews the recommendation and all comments. The EIC then notifies the corresponding author of the results of the review and the publication decision.

Acceptance

For accepted manuscripts, each copy of the manuscript containing comments thereon and other comments are returned to the corresponding author. Revised manuscripts are to be returned to the EIC in hard copy, four copies if further review is required, or one hard copy plus the computer disk if only minor revision or formatting is necessary. The revised manuscript shall be returned to the EIC within 14 days of the notification. Review of the revised manuscript by the Associate Editor and reviewers shall be completed and returned to the EIC within 14 days. An accepted manuscript will then be forwarded to the Managing Editor (ME) for final processing.

Rejection

Each manuscript that is rejected for publication is returned by the EIC to the corresponding author along with the reasons for rejection. The author is also advised that the manuscript may be resubmitted, provided all major criticisms and comments have been addressed in the new manuscript. The new manuscript may be returned to the initial review process if deemed appropriate by the EIC. If the manuscript is rejected a second time by either the EIC or the Associate Editor and reviewers, no further consideration will be given for publication of the manuscript in IJS. The corresponding author will be notified of this decision.

Reviewer Anonymity

The identity of all reviewers shall remain anonymous to the authors, called a blind review process. All criticisms or comments by authors shall be directed to the EIC; they may be referred to the ME or the Editorial Board by the EIC for resolution.

Manuscripts Submitted by Editors

Each manuscript submitted by an Associate Editor shall be reviewed by the EIC and a minimum of two other reviewers with expertise in the subject being addressed. Each manuscript submitted by the EIC shall be forwarded with the necessary review materials to the Chairman of the Editorial Board of IJS, who will serve as the EIC for that manuscript.

Abstracts

Only abstracts from the annual meetings of the sponsoring organizations will be published in IJS. Other submissions of abstracts shall be considered on a case-by-case basis by the Editorial Board. Sponsoring organizations shall collect abstracts, review them for subject accuracy, format them in Microsoft Word and email them to Rick Douglass, the EIC (RDouglass@mtech.edu), on or before November 1. Each abstract shall be reviewed by the EIC to assure proper grammar, compliance with IJS "Guidelines for Abstracts Only" and for assignment to the appropriate discipline section. All abstracts will be published in the December issue only.

Commentary

Submissions concerning management applications or viewpoints concerning current scientific or social issues of interest to the Intermountain region will be considered for publication in the "Commentary" Section. This section will feature concise, well-written manuscripts limited to 1,500 words. Commentaries will be limited to one per issue.

Submissions will be peer reviewed and page charges will be calculated at the same rate as for regular articles.

Literature Cited

Dusek, Gary L. 1995, revised 2007. Guidelines for manuscripts submitted to the *Intermountain Journal of Sciences*. Int. J. Sci. 1(1):61-70. Revised guidelines are available on the Intermountain Journal of Sciences web site: (www.intermountainjournal.org)

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Ecological Model for Classifying and Monitoring of Green Needlegrass/Western Wheatgrass/Blue Gramma/Buffalograss Ecological Type

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Abstract

A multivariate statistical model was developed to classify plant seral stages and to monitor succession of the green needlegrass (*Nassella viridula* (Trin.) Barkworth), western wheatgrass (*Pascopyrum smithii* (Rydb.) Á Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus) ecological type on grasslands of North and South Dakota, eastern Montana and Wyoming. Seral stages are objectively derived groupings of vegetation composition based on the range of natural variability within the current grassland ecological type. The model developed in this paper can be used by range and wildlife managers to evaluate management objectives by monitoring changes in plant species cover and composition within and among seral stages and community phases. Four ecological seral stages representing early to late succession were quantitatively identified with an estimated 98 percent accuracy. Three common perennial grasses provide the information to assign seral stages and monitor trends based on index values (canopy cover (%) x frequency of occurrence (%)) for western wheatgrass, buffalo grass and green needlegrass. Estimates of canopy cover and frequency of occurrence of these three plant species are all that is required for the model. The four defined seral stages provide resource managers with options to quantitatively evaluate management alternatives and objectives associated with state and transition community phases. The developed model for this ecological type is simple to use, reliable, repeatable, accurate and cost effective to meet management objectives and monitoring plans.

Keywords: Succession, seral stages, diversity, monitoring, mixed-grass, grassland, management, state and transition.

Introduction

The ecological status of grasslands undergoes changes, over time following natural and human induced disturbances. Knowledge of the various patterns of grassland dynamics provide an ecological framework to evaluate influences associated with natural events and resource management. State and transition models have received much attention in recent years (Briske et al. 2005) and provide a framework to understand natural and human induced disturbances. These models are conceptual based on expert opinion, personal judgments that are essentially qualitative (Twidwell et al. 2013). However, subjective data and interpretations are highly variable among observers (Kershaw 1973, Block et al. 1987) and often make it difficult to obtain consistent interpretations to determine vegetation trends and steady states of succession.

State and transition models can be quantified using multivariate statistical modeling that depicts vegetation change related to weather, fire, grazing, management and plant succession. These multivariate models can provide an approach for predicting ecological processes of vegetation change (Uresk 1990, Mclendon and Dahl 1983, Huschle and Hironaka 1980, Friedel 1991, Benkobi et al. 2007, Uresk et al. 2012). Multivariate models with cluster analyses provide discrete categories based on ecological processes that are related to key plants distributed among seral stages associated with ecological types (Uresk 1990, Benkobi et al. 2007, Uresk et al. 2012). Multivariate models of plant succession allow resource managers to easily obtain quantitative measurements and evaluate current range conditions. The approach outlined in this paper could be equally applied to quantitatively differentiating community phases within state and transition models incorporated into updated interagency ecological site descriptions (Bestelmeyer et al. 2010).

Ecological types and sites are similar and both are used to describe differences in ecological capability and response on rangelands. Ecological type is the classification system used by the USDA-Forest Service. More recently, ecological site is a classification used by Natural Resource Conservation Service (NRCS). Both systems of plant classification are based on conceptual or distinctive landscape elements. These elements include climate, geology, landform, soils and distinctive vegetation or potential vegetation that differs from other kinds of vegetation. The vegetation within a type or site responds similarly to management and natural disturbances (Winthers et al. 2005, USDI and USDA 2013a).

An overall purpose of this research study was to develop a quantitative model based on the interrelationships of plant species, past management practices that best characterize the ecological type throughout the progression of plants between and among seral stages. The objectives were: (1) provide managers a tool for assessment and monitoring ecological change (2) provide a classification of seral stages and (3) to produce a sampling protocol for monitoring.

Study Area

The study was conducted on Fort Pierre National Grassland in central South Dakota. This grassland is comprised of approximately 46,400 ha (116,000 ac) of federal lands with private lands intermixed. The Fort Pierre National Grassland is located west of the Missouri River, within the Pierre Hills physiographic region (Johnson et al. 1995). Topography was characterized as upland flats dissected by intermittent drainages and swales with gently undulating plains. Elevation ranged from 427 m to 701 m. Soils were primarily clays derived from the Cretaceous Pierre formation and the ecological site description is clayey rangeland (Gries 1998, USDA-NRCS 2008). The dominant grasses were green needlegrass (*Nassella viridula* (Trin.) Barkworth), western wheatgrass (*Pascopyrum smithii* (Rydb.) Á Löve), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths) and buffalograss (*Bouteloua dactyloides* (Nutt.) J.T. Columbus). Common forbs included scarlet globemallow (*Sphaeralcea coccinea* (Nutt.) Rydb.), western yarrow (*Achillea millefolium* L.) and prairie coneflower (*Ratibida columnifera* (Nutt.) Woot. & Standl.). The ecological type, wheatgrass-needlegrass, for this study occurs in western North and South Dakota, eastern Montana and Wyoming and is in Kuchler's (1964) potential vegetation type 66. Plant nomenclature followed USDA-NRCS (2013b).

The mean annual precipitation (1964-2012) was 42.4 cm and ranged from 16.3 cm to 60.5 cm (HPRCC 2013). Seventy-three percent of the precipitation falls during the spring and summer as short duration intense thunderstorms. The average monthly temperature ranged from 31°C in the summer to 2° C in the winter.

Methods

Experimental design, data collection and analyses follow procedures developed by Uresk (1990). A field reconnaissance was conducted to assess the ecological type variability of the study area based on Soil Conservation Service range site description, currently described as ecological site description for clayey soils (USDA-NRCS 2008). Site selection encompassed the entire grasslands to include the full range of natural variability. Sites were stratified into three pre-defined (USDA-NRCS 2008) visual seral stages, early, mid and late based on key plant species and their changes through succession by professional range ecologists (Cochran 1977, Thompson et al. 1998, Levy and Lemeshow 1999).

Data were collected on 57 sites (macroplots) during the summer of 1991. Each site was randomly selected within one of three perceived seral stages based on major plant species abundance defined for each seral stage by experienced range professionals (USDA-NRCS 2008). First, an area was located within a perceived seral stage for site selection. Once the area was located, a random direction and a random number of paces were established prior to actual site location for establishment of transects. This procedure was repeated for all sites. However, some late seral stage sites were located in long-term exclosures. At each site, two, 30 m parallel transects were established 20 m apart. Canopy cover (six cover classes) and frequency of occurrence of plant species were estimated within 0.1 m^2 (20 x 50 cm) quadrats (Daubenmire 1959). These quadrats were located at 1 m intervals along each of the two transects for a total of 60 quadrats. Total plant cover, litter cover and bare ground were estimated within each quadrat. Once all data were collected for the site, it was assigned a seral stage. All data were averaged by transect. The two transect means were then averaged for each site to generate a grand mean for data analyses. An index for plant species was created based on canopy cover means time the frequency means: Index = ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2) (Uresk 1990). Conversely, averaging canopy cover and frequency of occurrence over several sites and then multiplying the two variables will not provide the exact overall indices.

Uresk (1990) defined the Index as follows: "The cover-frequency index combines estimates of two important vegetation characteristics. Frequency relates to the number of times a species occurs in a given number of small sample plots and is a measure related to density (Mueller-Dombois and Ellenberg 1974). Canopy cover, the vertical projection of the shoot area of plants, is of greater ecological significance than density in the measurement of plant distribution (Mueller-Dombois and Ellenberg 1974) and gives a better indirect measure of plant biomass than the number of individuals. Cover values may change due to year differences, but multiplied with frequency to form an index, changes in an ecological stage are less likely when a change may not exist; frequency values are less likely to change abruptly on a yearly basis. However, if high frequency paired with low cover is equivalent to low frequency paired with high cover for a species, then the index is flawed. The likelihood of both situations occurring in the vegetation type is highly unlikely". Data were analyzed with SPSS (1992) and SPSS (2003) software.

Preliminary data examinations of the overall index mean for the ecological type removed minor plant species (variables) from analyses with mean index values of <1. The remaining plant species were used as variables for analyses in the following sequence (Uresk 1990): 1) Variable reduction with discriminant analyses for 57 sites with each site assigned to one of the perceived three seral stages as grouping variables. 2) The variables remaining after reduction by discriminant analyses were analyzed by principal component analyses for further variable reduction. Principal component analyses were useful after initial data reduction by discriminant analyses only with fewer plant variables. We used the extraction method and examined the component matrix, component scores coefficient matrix and the mean index value for each variable. There were no further analyses with principal component procedures. 3) A non-hierarchical cluster analysis (ISODATA) defined groupings based on the five variables for seral stages (Ball and Hall 1967, del Morel 1975). Stepwise discriminant analysis was used again to estimate compactness of the cluster and identify key variables that accounted for the differences between and among clusters and to develop Fisher classification coefficients (SPSS 2003, Uresk 1990). Discriminant analyses identified three key variables for model development and for classifying seral stages and monitoring. Misclassification error rates were estimated with SAS (1988) and SPSS (2003), a cross validation using a jackknife or "leave one site out" procedure. In the cross validation procedure, each site was classified by the discriminant functions derived from all other sites other than the site left out. This was repeated for each of the sites and gave a true hold out prediction for each of the sites. The developed model was field tested the following year.

Assignment of a seral stage was achieved by applying Fisher's classification discriminant functions (SPSS 2003) to a new set of data. The Fisher discriminant function coefficients indicated the significance of each key plant species among seral stages. Key plant species with the greatest coefficients by seral stage expressed the indicator value of plants within the ecological type. To determine the seral stage assignment from Fisher's coefficients, we multiplied site index values for green needlegrass, western wheatgrass and buffalograss for each seral stage (row) and then summed the products (+ and -) including the constant for a score. The greatest positive score or the least negative score when all scores were negative assigned the seral stage. Additional information for this ecological type with programs may be downloaded for personal data assistants (PDAs) and personal computers that will directly assign the seral stage at USDA-Forest Service website: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Results

A total of 99 plant species (variables) and total cover for graminoids, forbs, litter and bare ground were sampled on 57 sites. After initial reduction of 99 plant species with index values <1, discriminant analysis reduced the variables to 11 plant species. Principle component analysis further reduced the 11 variables to five plant species: green needlegrass, western wheatgrass, blue grama, buffalograss and threadleaf sedge (*Carex filifolia* Nutt.) and explained 62 percent of the variation. These five variables evaluated by non-hierarchical cluster analysis (ISODATA) resulted in four groupings defined as seral stages. Stepwise discriminant analysis estimated compactness of the groupings that resulted in three variables, green needlegrass, western wheatgrass and buffalograss for the model. These three plant species were defined as key species for classification and monitoring of seral stages.

The clustering procedure grouped the 57 sites (3,420 quadrats (micro-plots), 114 transects) into four distinct seral stages ($P < 0.001$). Index values for the three plant species illustrated the dynamics throughout the four seral stages in this ecological type (Fig. 1, Table 1). Green needlegrass dominated the late seral stage followed by western wheatgrass for late intermediate and early intermediate stages, while buffalograss was dominant in the early seral stage. Each key plant species characterized the vegetation dynamics within this ecological type (Fig. 1).

Fisher's classification discriminant functions showed the significance of each key plant species among seral stages and provided coefficients for classifying seral stages and monitoring within this ecological type (Table 2). Key plant species with the greatest coefficients by seral stage expressed the indicator value of plants within the ecological type. Blue grama was common within the ecological type but was not a significant variable for classifying seral stages. An example of calculating seral stage assignment with Fisher's classification coefficients for key plant species indices collected from a site is presented in Table 3. When the index data are multiplied by the Fisher coefficients and summed accounting for the constants, the site is assigned to early intermediate

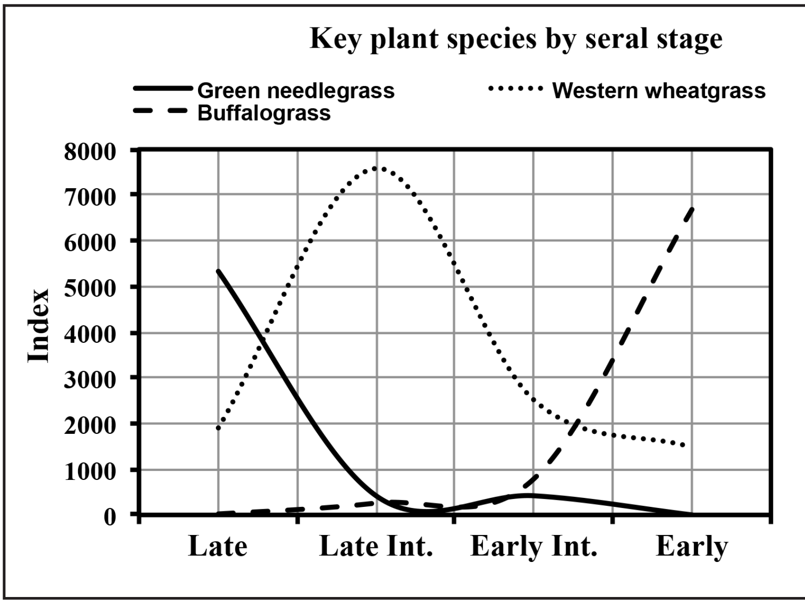

Figure 1. Key plant species with mean index values displayed throughout the four seral stages in a green needlegrass, western wheatgrass, blue grama and buffalograss ecological type. Graph provides an approximate mixture of plant species at each seral stage.

Table 1. Mean indices of key plant species for four seral stages in the ecological type. Indices were calculated as a product of ((transect 1 cover + transect 2 cover)/2)* ((transect 1 frequency + transect 2 frequency)/2).

		MEAN INDEX		
Seral	**n**	**Green needlegrass**	**Western wheatgrass**	**Buffalograss**
Late	10	5318	1927	1
Late intermediate	22	221	7580	259
Early intermediate	18	219	2514	790
Early	7	0	1480	6682

n = number of sites

Table 2. Fisher's discriminant function coefficients and constants for ecological classification model for key variables within the ecological type by seral stage (SPSS 2003).

Species	Late	Late intermediate	Early intermediate	Early
Green needlegrass	0.01128	0.00063	0.00062	0.00103
Western wheatgrass	0.00113	0.00412	0.00138	0.00089
Buffalograss	0.00083	0.00040	0.00087	0.00679
Constant	-32.458	-17.122	-3.529	-24.742

Table 3. An example of assigning seral stages by using Fisher's discriminant coefficients and constants (SPSS 2003) with new index data collected from the field for a site. Indices were calculated as a product of ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2).

	Green needlegrass	Western wheatgrass	Buffalograss		
Seral	**(Coeff[1] X Index +**	**Coeff X Index +**	**Coeff X Index)**	**Constant =**	**Score**
Late	(0.01128 X 84 +	0.00113 X 3290 +	0.00083 X 430)	- 32.458 =	-27.436
Late Int[1]	(0.00063 X 84 +	0.00412 X 3290 +	0.00040 X 430)	- 17.122 =	- 3.342
Early Int	(0.00062 X 84 +	0.00138 X 3290 +	0.00087 X 430)	- 3.529 =	**1.437**[2]
Early	(0.00103 X 84 +	0.00089 X 3290 +	0.00679 X 430)	- 24.742 =	-18.808

[1] Coeff = coefficient, Int = Intermediate
[2] Assigned seral stage

seral stage with a score of 1.44. Cross validation (jackknife procedure) results by seral stage showed a misclassification rate of 1 percent for late and early seral stages, 2 percent for late intermediate and 4 percent for early intermediate seral stage (SAS 1988). Overall accuracy of the model based on cross validation was 98 percent. Additional information on seral stage classification, monitoring, trend monitoring, data collection, plot establishment and programs for PDA's and other computers may be obtained from USDA-Forest Service web site at http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Late seral stage

Late seral stage was dominated by green needlegrass with a mean of 60 percent canopy cover (SE = 4) and 89 percent frequency of occurrence (SE = 3) for 10 sites (Table 4, Table 5). Western wheatgrass, field brome (*Bromus arvensis* L., an annual also known as Japanese brome) and blue grama were the next three most common grasses present. The forb component was dominated by four species with canopy cover between 2-3 percent and frequency of occurrence 8-12 percent. Scarlet globemallow, sweet clover (*Melilotus officinalis* (L.) Lam.), prickly lettuce (*Lactuca serriola* L.) and field bindweed (*Convolvulus arvensis* L.) represented the dominant forbs. Canopy cover of graminoids was 90 percent (SE = 3), forbs 13 percent (SE = 4), litter 23 percent (SE = 9) and bare ground 6 percent (SE = 3). Plant species richness of the late seral stage consisted of 23 forbs and 19 graminoids and no shrubs (Fig. 2). Approximately 80 percent of the plants were perennial species and 20 percent annual-biennial species (Fig. 3).

Late Intermediate seral stage

Western wheatgrass dominated the late intermediate seral stage with a mean of 76 percent canopy cover (SE = 3) and 99 percent frequency of occurrence (SE = < 1) for 22 sites (Table 4, Table 5). Blue grama and field brome were the next most common grasses each with canopy cover of 20 percent (SE = 4, 6) and frequency of 41 (SE = 7) and 43 percent (SE = 9), respectively. Green needlegrass, buffalograss, needleleaf sedge (*Carex duriuscula* C.A. Mey.) and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) were the next most common plants with an average of 5-6 percent canopy cover. Canopy cover for the forb component was dominated by sweet clover and curlycup gumweed (*Grindelia squarrosa* (Pursh) Dunal) with 4 percent and 3 percent cover. Canopy cover of graminoids was 92 percent (SE = 1), forbs 15 percent (SE = 3), litter 26 percent (SE = 7) and bare ground 11 percent (SE = 4). Plant species richness consisted of 52 forbs, 23 graminoids and 1 shrub (Fig. 2). Seventy percent of the plants were perennial and 30 percent annual-biennials (Fig.3).

Table 4. Average canopy cover (%) and standard errors (in parentheses) of common plant species and other variables by seral stages.

Species or variable	Late[1]	Late Intermediate	Early Intermediate	Early
Green needlegrass *Nassella viridula*	59.6(3.6)	6.2(1.9)	5.5(2.5)	0.0(0)
Western wheatgrass *Pascopyrum smithii*	26.1(5.1)	76.3(2.5)	29.3(3.3)	19.3(5.8)
Blue grama *Bouteloua gracilis*	13.4(6.2)	20.4(4.1)	8.8(3.8)	5.8(7.2)
Buffalograss *Bouteloua dactyloides*	<1(0.5)	5.2(2.5)	14.7(3.7)	69.6(6.0)
Purple threeawn *Aristida purpurea*	3.4(1.7)	<1(0.7)	5.4(3.5)	1.3(1.7)
Sideoatsgrama *Bouteloua curtipendula*	1.2(0.7)	5.0(2.2)	5.2(3.5)	5.8(2.7)
Needleleaf sedge *Carex duriuscula*	<1(0.8)	5.4(2.3)	3.0(1.4)	5.0(3.8)
Field brome *Bromus arvensis*	14.9(8.2)	19.5(5.8)	21.1(6.3)	15.2(9.6)
Crested wheatgrass *Agropyron cristatum*	3.4(1.6)	0.1(0.1)	7.7(4.2)	0.1(0.1)
Scarlet globemallow *Sphaeralcea coccinea*	2.0(1.3)	1.1(0.3)	1.7(0.4)	2.5(0.4)
Yellow sweet clover *Melilotus officinalis*	2.7(1.6)	4.1(2.4)	4.4(2.6)	<1(2.9)
Curlycup gumweed *Grindelia squarrosa*	0.1(0.1)	2.6(1.5)	3.5(1.6)	0.2(0.1)
Prickly lettuce *Lactuca serriola*	2.1(1.2)	1.7(0.8)	0.7(0.4)	0.1(0.1)
Field bindweed *Convolvulus arvensis*	2.7(1.8)	0.2(0.1)	1.3(1.1)	0.0(0.0)
Graminoid cover[2]	90.0(3.2)	91.8(0.9)	76.4(4.5)	88.4(2.2)
Forb cover[2]	12.5(4.1)	14.9(3.1)	23.4(3.9)	9.8(1.1)
Litter cover	22.5(9.2)	26.3(6.7)	17.6(7.0)	18.0(12.7)
Bare ground	6.2(3.4)	11.2(4.3)	10.2(3.8)	10.2(7.4)

[1] Sample size: Late=10; Late Intermediate=22; Early Intermediate=18; Early=7
[2] Two dimension cover and not the sum of the individual plant species.

Table 5. Frequency of occurrence averages (%) and standard errors (in parentheses) of common plant species and other variables by seral stages.

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Green needlegrass *Nassella viridula*	88.5(3.4)	15.3(3.6)	10.2(4.1)	0(0)
Western wheatgrass *Pascopyrum smithii*	60.3(9.4)	99.3(0.3)	80.5(3.9)	61.7(10.8)
Bluegrama *Bouteloua gracilis*	24.5(10.1)	41.2(6.8)	19.6(6.8)	2.7(19.3)
Buffalograss *Bouteloua dactyloides*	<1(0.5)	9.9(4.0)	29.3(6.3)	95.5(1.8)
Purple threeawn *Aristida purpurea*	7.0(3.3)	<1(0.5)	10.7(5.5)	4.5(4.0)
Sideoatsgrama *Bouteloua curtipendula*	2.7(1.7)	12.0(5.0)	8.2(4.9)	19.3(8.5)
Needleleaf sedge *Carex duriuscula*	<1(0.8)	18.0(6.9)	7.8(3.2)	20.7(12.3)
Field brome *Bromus arvensis*	27.3(10.5)	42.5(8.5)	41.6(10.7)	34.1(15.6)
Crested wheatgrass *Agropyron cristatum*	9.3(4.2)	0.2(0.1)	15.9(6.2)	1.0(1.0)
Scarlet globemallow *Sphaeralcea coccinea*	8.2(4.0)	8.7(2.1)	14.0(3.1)	27.6(4.7)
Yellow sweet clover *Melilotus officinalis*	15.6(9.5)	11.4(5.7)	11.0(5.7)	<1(2.9)
Curlycup gumweed *Grindelia squarrosa*	0.7(0.5)	7.8(3.5)	13.4(5.0)	4.3(3.3)
Prickly lettuce *Lactuca serriola*	9.8(5.8)	8.9(3.1)	5.2(2.5)	0.5(0.5)
Field bindweed *Convolvulus arvensis*	11.5(7.7)	0.8(0.5)	3.8(3.0)	0.0(0.0)

Early Intermediate seral stage

Early intermediate seral stage was dominated by western wheatgrass with a canopy cover 29 percent (SE = 3) and frequency of occurrence 81 percent (SE = 4) for 18 sites (Table 4, Table 5). Field brome, buffalograss, blue grama and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) were the next most common grasses with canopy cover 21 percent (SE = 6), 15 percent (SE = 4), 9 percent (SE = 4) and 8 percent (SE = 4) and frequency 42 percent (SE = 11), 29 percent (SE = 6), 20 percent (SE = 7) and 16 percent (SE = 6). The forb component based on canopy cover was dominated by scarlet globemallow (2%), sweet clover (4%) and curlycup gumweed (4%). The intermediate seral stage included seven additional forb species with 1 percent or greater canopy

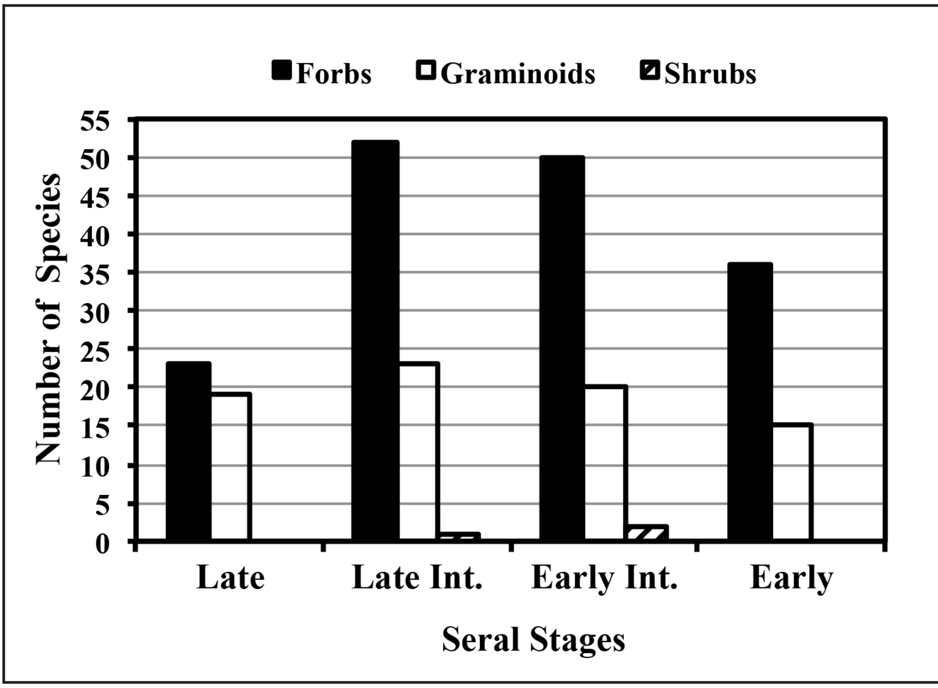

Figure 2. Number of plant species by life form category and seral stages in a green needlegrass, western wheatgrass, blue grama and buffalograss ecological type.

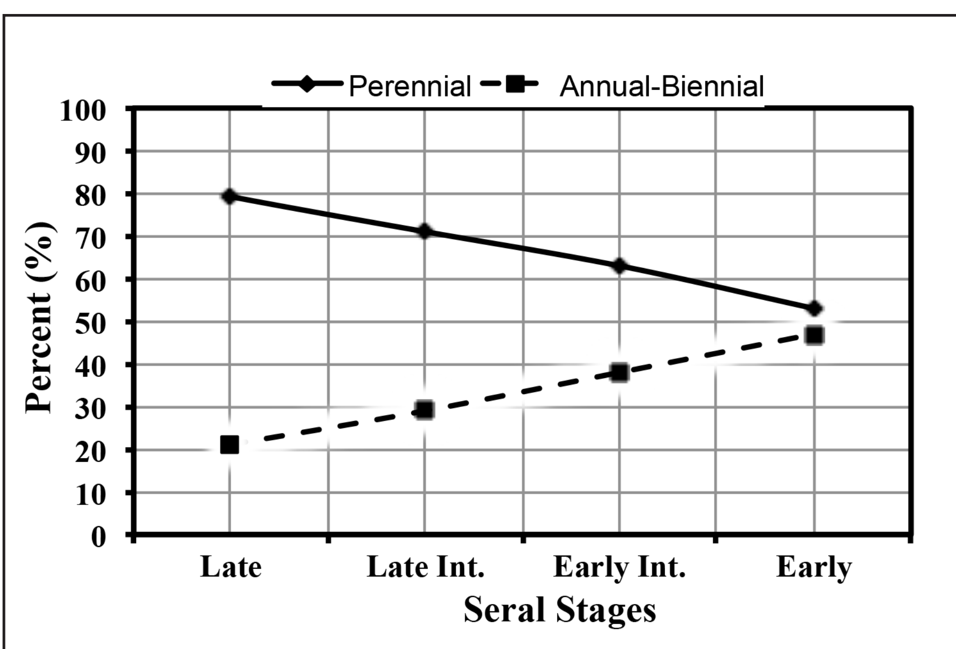

Figure 3. Percent perennial and annual-biennial categories expressed from total plant species throughout the four seral stages.

cover. These forbs included field bindweed, American vetch (*Vicia americana* Muhl. ex Willd.), common dandelion (*Taraxacum officinale* F.H. Wigg.), woolly plantain (*Plantago patagonica* Jacq.), prairie spiderwort (*Tradescantia occidentalis* (Britton) Smyth.), common yarrow (*Achillea millefolium* L.) and snow on the mountain (*Euphorbia marginata* Pursh). Graminoid cover was 76 percent (SE = 5), forbs 23 percent (SE = 4), litter 18 percent (SE = 7) and bare ground 10 percent (SE = 4). Plant species richness included 50 forbs, 20 graminoids and 2 shrubs (Fig. 2). Approximately 63 percent of the plants were perennial and 37 percent were annuals-biennials (Fig. 3).

Early seral stage

Buffalograss was widely distributed and dominant in the early seral stage with 70 percent canopy cover (SE = 6) and 96 percent frequency of occurrence (SE = 2) for 7 sites (Table 4, Table 5). Canopy cover and frequency of occurrence for western wheatgrass was 19 (SE = 6) and 62 percent (SE = 11). Blue grama was a minor component in the early seral stage. Annual field brome had 15 percent canopy cover (SE = 10) and a 34 percent frequency of occurrence (SE = 16). Field brome is an invasive non-native species. Scarlet globemallow was the only forb with greater than 2 percent canopy cover. Canopy cover of graminoids was 88 percent (SE = 2), forbs 10 percent (SE = 1), litter 18 percent (SE = 13) and bare ground 10 percent (SE = 7). Thirty-six forbs, 15 graminoids and no shrubs were represented in the early seral stage (Fig. 2). Perennial plant species represented 53 percent with 47 percent annual-biennials (Fig. 3).

Discussion

The multivariate model developed for this study can be used to describe plant dynamics and species changes between and among seral stages within this ecological type. Disturbances such as grazing, fire and climatic changes can move plant species association or abundance from an early seral stage to a late seral stage or other discrete pathways within the wheatgrass-needlegrass ecological type. State and transition models for plant succession have been a conceptual approach for describing ecological succession and dynamics (Bestelmyer et al. 2003, Briske et al. 2005). The developed model with key plant species and coefficients can be easily incorporated into state and transition models for the ecological type and ecological sites. This model can be used to quantify the differences between and among seral stages and to identify key plants that are indicators of potential shifts. Currently, state and transition models are qualitative and result from personal judgments and observations (Twidwell et al. 2013). The developed model provides resource managers a powerful tool for monitoring resource status resulting from grazing, fire and climatic changes as managers attempt to meet or maintain a desired seral stage at a site (Uresk 1990, Benkobi and Uresk 1996, Zweig and Kitchens 2009, Uresk et al. 2012). Our model was based on data collected from a full range of vegetation values over the landscape (canopy cover and frequency of occurrence) representing natural variation and can be used to determine seral stages regardless of hypothetical past and future climax vegetation.

The seral stages identified in this study limit the number of management objectives to four. These four stages represent a continuum over the landscape, but allow land managers discrete categories for management at different spatial scales. For example, land managers can easily determine seral condition for each pasture within each grazing allotment. Depending upon the land management objectives, livestock grazing can be used for regulating seral stages (Severson and Urness 1994). Livestock grazing can be adjusted (increased or decreased) to modify plant succession or transition from a non-preferred stage toward a planned objective, a desired seral stage.

By using characteristics of grasses, seral stages can be adjusted. For example, western wheatgrass and green needlegrass are cool season, palatable perennial grasses that often decrease when subjected to overgrazing (Lewis et al. 1956). Buffalograss and blue grama are palatable warm season grasses that are more tolerant of grazing and increase under more intense grazing. Western wheatgrass increased and buffalograss decreased with light grazing on the Cottonwood Range Field Station located west of Fort Pierre National Grassland in South Dakota (Lewis et al. 1956).

Managing for all four seral stages may be a management alternative. Inclusion of multiple seral stages increases plant and animal diversity over the landscape. Because one individual seral stage is not practical for multiple-use management across the landscape, the entire seral range (from early to late) is needed to accommodate greatest plant species diversity, wildlife diversity, livestock production and recreation (Uresk 1990, Vodehnal et al. 2009, Fritcher et al. 2004, Benkobi and Uresk 1996, Uresk et al. 2012). The developed model provides resource managers with a cost effective, accurate and repeatable tool that can be applied across allotments and the landscape. A recommendation of 10-15% of the landscape should be in each early and late seral stages with the remainder in the two intermediate stages (Kershaw 1973, Mueller-Dombois and Ellenberg 1974). This would provide a mixture of seral stages across the landscape to provide for both plant and animal diversity and livestock production.

The developed classification and monitoring system used multivariate statistical methods to define key plant species that would classfy seral stages within a green needlegrass, western wheatgrass, blue grama, buffalograss ecological type. Although blue grama is common in this ecological type, it was not selected through statistical procedures as a key plant for classifying seral stages. As a result, four seral stages with three key plant species were quantitatively identified with an accuracy of 98 percent. Canopy cover and frequency of occurrence for the key plants for the index are the only required field data to determine seral stage classification and monitoring. Indices must be calculated for each individual site (See methods). To obtain an overall mean of several sites, each site index is averaged. Data collection may be conducted yearly or once every few years with a minimum of two macroplots per section (640 acres) within the ecological type. See USDA-Forest Service website for additional information: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

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Ecological Model for Seral Stage Classification and Monitoring with Key Plants on Sandy Ecological Sites in Nebraska and South Dakota

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Abstract

The objectives were to develop a multivariate model (state and transition) to define and classify seral stages with capabilities that enable us to monitor vegetation changes with three key plant species within a sandy ecological site located in the Sand Hills of Nebraska and South Dakota. Three key plant species, prairie sandreed (*Calamovilfa longifolia*) /little bluestem (*Schizachyrium scoparium*)/sun sedge (*Carex inops*) provided inputs for the model to classify seral stages and to monitor vegetation transitions based on index values (canopy cover (%) x frequency of occurrence (%)) from field measurements within the full range of natural variability. The model does not require a straight progression through all seral stages or plant phases but may go through multiple stages or remain at a steady state. Four seral stages that represent early to late succession provided an assignment accuracy of 90 percent. Seral stages were significantly different ($P<0.05$) from each other. Application of the model to predict seral stages and vegetation monitoring is accurate, quantitative and free of subjective judgments.

Keywords: Succession, range, sand hills, state and transition

Introduction

The public has placed greater demands on our rangelands for multiple uses in recent years. Livestock grazing has been a common use of the rangeland resources while the importance of wildlife, recreation and water use has increased. Over the past few decades, to maintain a sustainable rangeland for multiple uses, vegetation classification and monitoring based on plant succession and communities have been important inputs for resource management (Dyksterhuis 1949, Dyksterhuis 1985). The succession and community framework has provided resource managers methods to evaluate vegetation changes occurring from natural events as well as from management activities.

Recently, state and transition conceptual models based on subjective judgments and observations have received much attention (Bestelmyer et al. 2003, Briske et al. 2005). These models are qualitative (Twidwell et al. 2013). Subjective observations and interpretations of vegetation status and trends are highly variable among observers (Kershaw 1973, Block et al. 1987). Various multivariate non linear models have been developed based on plant succession and communities for evaluating the magnitude of vegetation change and to maintain a sustainable resource system. (Huschle and Hironaka 1980, Mclendon and Dahl 1983, Uresk 1990, Benkobi et al. 1996, Uresk et al. 2010, Uresk et al. 2012). Multivariate models provide discrete categories based on ecological processes (plant succession) based on key plant variables to determine changes or transitions in steady states within an ecological site. The objectives in this study were: (1) develop a multivariate ecological model based on the range of vegetation variability that best describes the ecological site with discrete seral stages or community phases and states providing the ability to implement quantitative monitoring, (2) describe and discuss the defined discrete classification of seral stages (community phases) and (3) present application guidelines for sampling protocol and monitoring.

Study Area

The study was conducted on the Nebraska National Forest in the Sand Hills of central Nebraska. This region encompases approximately 5 million hectares (19,300 miles^2) in southern South Dakota and Central Nebraska (Bleed and Flowerday 1990). Study areas included the Samuel R. McKelvie District that encompasses 46,280 hectares (115,700 acres) and the Bessey District with 36,183 hectares (90,456 acres). The two areas are separated by 80 kilometers (50 miles).

Climate is semi-arid (Burzlaf 1962), with a mean annual precipitation (HPRCC 2013a) of 53 cm (21 in) at Halsey, NE (1903 to 1990) and 48 cm (19 in) at Valentine NE (1948 to 2013) (HPRCC 2013b). Eight to 78 percent of the precipitation falls during the growing season (April-September) as short duration intense thunderstorms. Average monthly temperature ranged from a low of -13° C (8° F) in the winter to a high of 32° C (89° F) in the summer.

Sand Hills flora has been described numerous times since the late 1800's. An overall review of the Sand Hills for the ecology of flora and fauna, soils, livestock grazing, climate, geology, hydrology, streams lakes and history of the area is presented by Bleed and Flowerday (1990). Burzlaff (1962) defined the vegetation of the Nebraska sandhills into three range sites, dry valleys, rolling sands and choppy sands. Each of the range sites were characterized by plant species cover as a measure of forage production and soils. Topography is important in the distribution of plants within these range sites (Barns and Harrison 1982). This study focused on flat valleys, between choppy and rolling sand hills, also known as dry valleys or sandy range sites (Bleed and Flowerday 1990, USDA-NRCS 2014). Dominant plant species include prairie sandreed (*Calamovilfa longifolia*), sand bluestem (*Andropogon hallii*), little bluestem (*Schizychyrium scoparium*), big bluestem (*Andropogon gerardii*), blue and hairy grama (*Bouteloua gracilis* and *B. hirsuta*), needle and thread grasses (*Hesperostipa comata* and *H. spartea*), sedges (*Carex inops*) and switchgrass (*Panicum virgatum*). The forb, common ragweed (*Ambrosia psilostachya*) and shrub, prairie rose (*Rosa arkansana*) were common on the ecological site (Burzlaff 1962, Barnes and Harrison 1982, USDA-NRCS 2014). Plant nomenclature followed USDA_NRCS (2013).

Methods

Data collection for canopy cover and frequency of occurrence followed Daubenmire (1959) and experimental designs and statistical analyses followed Uresk's (1990) procedures. Data were collected on 29 macroplots (sites) during the summer of 1989 and 1990. Each macroplot was randomly selected within one of three perceived seral stages of early, mid and late plant succession (Cochran 1977, Thompson et al. 1998, Levy and Lemeshow 1999). At each macroplot, 2, 30 m (99 ft) parallel transects were set 20 m (66 ft) apart. Canopy cover and frequency of occurrence in 0.1 m^2 (20 x 50cm) plots of individual plant species, total gramoinds, forbs, shrubs, percentage of plant litter and bare ground (Daubenmire 1959) were recorded . Daubenmire cover classes were transformed to mid-point values. However, the mid points for interpretation are based on the assumption that the actual values tend to be symmetrically dispersed around the mid points (Bonham 1989). Analyses were based on transect means (percentages); not individual microplots with mid point classes or ordinal data. These microplots were placed at 1 m (3.3 ft) intervals along each transect. All macroplot data (60 microplots) for each site were averaged for canopy cover and frequency of occurrence for individual plant species and litter, bare ground and life forms (grasses, forbs, shrubs) by site for analyses. An index for plant species, per site, was created based on canopy cover means multiplied by frequency means: Index = ((transect 1 cover + transect 2 cover)/2) X ((transect 1 frequency + transect 2 frequency)/2) (Uresk 1990). To determine the overall mean index, individual site indices were averaged for the area. Note, averaging canopy cover and frequency of occurrence over several sites and then multiplying the two variables will not provide the exact overall mean index. Data were analyzed with SPSS (1992) and SPSS (2003). Sample size estimates (macroplots) were estimated to be within 20 percent of the mean at 80 percent confidence (Cochran 1977).

Stepwise discriminant analyses were used for the initial reduction of variables on the three perceived seral stages (early, mid, late) (Uresk 1990). This initial procedure for data reduction produced a data set that was employed for all subsequent analyses. Principal component analyses on data from the initial data reduction were useful for further data reduction with fewer variables. We used the extraction method and examined the component score coefficient matrix for each of the variables after initial data reduction (Uresk 1990, SPSS 2003).

The reduced data were analyzed with ISODATA, a non-hierarchical cluster analyses (Ball and Hall 1967, del Moral 1975). Discriminant analyses on cluster groups identified key variables for seral stage classification and provided a quantitative model for classification and monitoring ($P < 0.05$). Misclassification error rates were estimated with cross validation procedures of leaving one site out (SPSS 2003, SAS 1988). Assumptions for multivariate modeling were examined by Q-Q plots for normality, multicollinearity between predictor variables and independence of variables (SPSS 2003). Homogeneity of variances was analyzed by Levene's test. Means of means approach a normal distribution (Steel and Torrie 1980). All assumptions were acceptable for multivariate modeling.

The model was field tested in 1991. Field testing of the model for a new macroplot was first evaluated biologically based on plant species composition, followed by evaluating the classification of the site to a seral stage.

Results

Cluster analyses (ISODATA) grouped the 29 sites into 4 distinct seral stages ($P<0.05$). Stepwise discriminant analysis for model development defined 3 key plant species (prairie sandreed, little bluestem, sun sedge), as the best predictive variables for seral stage classification and monitoring transitions within this ecological site. The distributions of indices for each key plant species showed the biological dynamics throughout the seral stages or plant phases (Fig. 1, Table 1). Prairie sandreed and sun sedge dominated the late seral stage. Little bluestem and sun sedge were most abundant in late intermediate and early intermediate stages.. Lesser amounts of all three key plant species described the early seral stage. Each key plant species individually and collectively characterized the vegetation dynamics of the model within this ecological site.

Fisher's discriminant functions (SPSS 2003) provided model coefficients and biotic potential of key plant species for predicting and classifying plant and seral stage dynamics (multistates) within this ecological site (Table 2). An example of using Fisher's discriminant functions and applying the coefficients to a new index data collected in the field (pasture or allotment) for key plant species is presented in Table 3. These coefficients when computed with the new index values provide the seral stage assignment. Mathematical calculations are as follows: Multiply the site index values for each of the key plant species by seral stage (row) and then sum the products for the score. The greatest value of the four scores is the seral stage assignment. If all products are negative; the least negative score is the seral stage assignment. Site index values for prairie sandreed = 317, little bluestem = 2067 and sun sedge = 1529 assigned the site

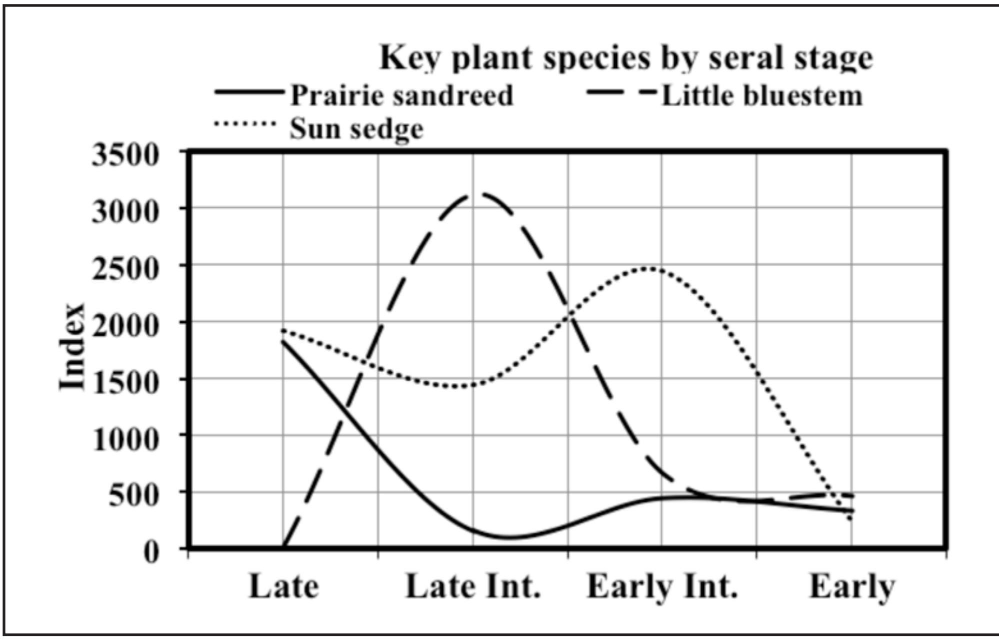

Figure 1. Key plant species with mean index values (canopy cover (%) x frequency of occurrence (%)) throughout the four seral stages in sandy sites in Nebraska and South Dakota.

Table 1. Mean indices of key plant species through four seral stages within the sandy ecological site in Nebraska and South Dakota.

Seral	n	Prairie sandreed	Little bluestem	Sun sedge
Late	5	1810	4	1921
Late intermediate	7	157	3122	1448
Early intermediate	9	449	665	2445
Early	8	387	468	237

n= number of sites

Table 2. Fisher's classification discriminant function coefficients for classification of seral stages with key species in a sandy ecological site in Nebraska and South Dakota.

Species	Late	Late intermediate	Early intermediate	Early
Prairie sandreed	0.01642	-0.00093	0.00367	0.00314
Little bluestem	-0.00172	0.00465	0.00032	0.00041
Sun sedge	0.00168	0.00068	0.00191	0.00014
Constant	-17.864	-9.061	-4.658	-2.107

to late intermediate seral stage with a score of 1.30 (Table 3). Cross validation results showed the overall accuracy of the model was 90 percent.

Additional information on seral stage classification, monitoring, trend monitoring, data collection, plot establishment and programs for personal digital assistant (PDA) and other computer programs can be obtained from USDA-Forest Service web site at: http://www.fs.fed.us/rangelands/ecology/ecologicalclassification/index.shtml.

Table 3. An example of assigning seral stages by using Fisher's discriminant coefficients with new index data collected from the field using sites in Nebraska and South Dakota.

	Prairie sandreed		Little bluestem		Sun sedge				
Seral	(Coeff[1] X Index)		+ (Coeff X Index)	+	(Coeff X Index)		Constant	=	Score
Late	(0.01642 X 317	-	0.00172 X 2067	+	0.00168 X 1529)	-	17.864	=	-13.65
Late Int[2]	(-0.00093 X 317	+	0.00465 X 2067	+	0.00068 X 1529)	-	9.061	=	**1.30**[3]
Early Int	(0.00367 X 317	+	0.00032 X 2067	+	0.00191 X 1529)	-	4.658	=	0.09
Early	(0.00314 X 317	+	0.00041 X 2067	+	0.00014 X 1529)	-	2.107	=	-0.05

[1] Coeff = function coefficients used for classification
[2] Int = Intermediate
[3] Assigned seral stage

Late Seral Stage

Prairie sandreed and sun sedge (Table 4, Table 5 and Fig. 1) equally dominated the late seral stage with an average canopy cover of 21 percent and 22 percent and frequency of occurrence 87 percent and 78 percent. Blue grama was the most common perennial grass in the late seral stage with 45 percent canopy cover and 82 percent frequency of occurrence (Table 4, Table 5). Other common grasses included sand bluestem, sand dropseed (*Sporobolus cryptandrus*) and switchgrass. Total graminoids made up 76 percent canopy cover. Forb and shrub canopy cover was 5 percent and 4 percent. Litter and bare ground cover was 76 percent and 25 percent.. Plant species richness in the late seral stage consisted of 29 forbs, 18 graminoids and 3 shrubs (Fig. 2) with 17 plant families.

Late Intermediate Seral Stage

Little bluestem and sun sedge dominated the late intermediate seral stage (Fig. 1, Table 1). Little bluestem had an average canopy cover of 36 percent and 85 percent frequency of occurrence (Table 4, Table 5). Average canopy cover for sun sedge was 19 percent with 96 percent frequency of occurrence. Other common grasses were blue grama, sand bluestem, switchgrass, hairy grama, needle and thread and prairie junegrass. Graminoid cover was 84 percent. Forb and shrub canopy cover was 9 percent and 5 percent. Litter cover was 83 percent and and bare ground 16 percent. Plant species richness consisted of 44 forbs, 18 graminoids and 3 shrubs (Fig. 2). A total of 18 plant families were identified in the late intermediate seral stage.

Early Intermediate Seral Stage

Sun sedge dominated the early intermediate seral stage (Fig. 1) with a mean canopy cover of 26 percent and frequency of occurrence 96 percent (Table 4, Table 5). Prairie sandreed and little bluestem exhibited canopy cover 6 percent, 12 percent and frequency of occurrence 52 percent, 29 percent, respectively. Common grasses included blue grama, sand bluestem, switchgrass, hairy grama, needle and thread and Kentucky bluegrass (*Poa pratensis*). Total forb and shrub canopy were 7 percent and 6 percent, respectively. Litter cover was 79 percent and bare ground 22 percent. Plant species richness included 46 forbs, 27 graminoids and 5 shrubs that included 22 plant families in this seral stage (Fig. 2).

Early Seral Stage

In the early seral stage, key plant species (prairie sandreed, little bluestem, sun sedge) showed similar indices (Fig. 1, Table 1). Mean canopy cover ranged between 6-9 percent and frequency ranged between 23-57 percent (Table 4, Table 5). Sand bluestem and switchgrass showed greater mean cover in the early seral stage with 12 percent

Table 4. Canopy cover (%) and standard error (in parentheses) of common plant species by seral stage in sandy sites in Nebraska and South Dakota.

Species or variable	Late	Late Intermediate	Early Intermediate	Early
Prairie sandreed *Calamovilfa longifolia*	20.8(2.0)	3.2(0.8)	6.3(1.6)	6.1(2.2)
Little bluestem *Schizachyrium scoparium*	0.4(0.3)	35.6(3.6)	11.6(4.2)	9.0(4.3)
Sun sedge *Carex inops*	21.7(6.8)	18.8(2.6)	25.5(4.7)	8.8(4.3)
Blue grama *Bouteloua gracilis*	44.6(9.0)	8.2(4.1)	13.6(5.4)	3.7(1.9)
Sand bluestem *Andropogon halli)*	9.6(3.6)	4.6(1.7)	4.2(1.3)	12.1(4.9
Sand dropseed *Sporobolus cryptandrus*	7.7(2.4)	1.5(0.9)	1.2(0.4)	1.7(0.6)
Switchgrass *Panicum virgatum*	6.8(3.1)	11.6(1.9)	6.9(2.6)	17.6(7.0)
Western wheatgrass *Pascopyrum smithii*	1.9(1.9)	0.2(0.1)	0.9(0.5)	3.8(3.7)
Hairy grama *Bouteloua hirsuta*	1.0(0.6)	4.8(2.0)	4.0(1.9)	0.9(0.5)
Needle and thread grass *Hesperostipa comata*	2.4(0.5)	3.9(0.9)	2.6(0.9)	4.6(2.6)
Prairie junegrass *Koeleria macrantha*	0.6(0.3)	3.7(1.1)	1.1(0.4)	0.7(0.3)
Heller's rosette grass *Dichanthelium oligosanthes*	0.1(0.1)	1.8(1.4)	1.6(0.7)	2.4(0.9)
Kentucky bluegrass *Poa pratensis*	0(0)	<0.1)(<0.1)	2.1(1.6)	2.7(2.6)
Cuman ragweed *Ambrosia psilostachya*	0.8(0.6)	1.9(0.8)	0.4(0.2)	1.8(0.6)
Prairie rose *Rosa arkansana*	3.0(1.2)	2.0(0.9)	2.9(1.2)	2.8(1.0)
Graminoid cover	**76.5(9.2)**	**83.5(1.4)**	**75.0(3.5)**	**79.1(4.6)**
Forb cover	**5.0(1.5)**	**9.2(1.1)**	**7.4(1.1)**	**10.4(2.3)**
Shrub cover	**4.3(1.0)**	**4.5(0.8)**	**6.4(1.0)**	**5.9(1.2)**
Litter cover	**75.6(5.2)**	**82.8(2.2)**	**79.1(7.6)**	**73.5(10.0)**
Bare ground	**24.8(5.5)**	**15.7(2.3)**	**21.5(7.3)**	**22.8(9.6)**

Table 5. Percent frequency (%) and standard error (in parentheses) of common plant species by seral stage in sandy sites in Nebraska and South Dakota .

Species	Late	Late Intermediate	Early Intermediate	Early
Prairie sandreed *Calamovilfa longifolia*	87.2(2.4)	39.3(6.0)	52.2(10.6)	41.5(11.7)
Little bluestem *Schizachyrium scoparium*	2.3(1.5)	84.8(3.6)	28.9(9.6)	22.5(8.5)
Sun sedge *Carex inops*	78.3(10.7)	95.7(1.3)	95.7(2.6)	57.1(13.6)
Blue grama *Bouteloua gracilis*	81.7(11.4)	26.2(12.3)	40.6(13.1)	11.9(6.1)
Sand bluestem *Andropogon halli*	34.0(11.7)	42.6(7.8)	34.6(11.0)	37.7(11.2)
Sand dropseed *Sporobolus cryptandrus*	35.7(9.9)	12.6(6.1)	14.1(5.4)	16.0(6.7)
Switchgrass *Panicum virgatum*	20.3(7.5)	66.9(5.5)	35.0(8.3)	46.0(10.9)
Western wheatgrass *Pascopyrun smithii*	12.3(11.9)	4.1(2.3)	15.6(8.6)	12.3(9.3)
Hairy grama *Bouteloua hirsuta*	4.3(2.2)	32.1(10.1)	24.4(11.5)	5.6(1.5)
Needle and thread grass *Hesperostipa comata*	18.0(3.8)	32.6(6.3)	24.8(7.2)	20.2(10.7)
Prairie junegrass *Koeleria macrantha*	5.3(3.1)	39.8(8.2)	16.7(4.9)	10.0(4.5)
Heller's rosette grass *Dichanthelium oligosanthes*	0.1(1.3)	17.9(12.0)	20.7(8.0)	21.5(6.0)
Kentucky bluegrass Poa pratensis	0(0)	0.5(0.3)	8.9(5.7)	12.9(12.5)
Cuman ragweed *Ambrosia psilostachya*	7.3(5.0)	28.8(10.6)	10.4(4.2)	24.6(8.3)
Prairie rose *Rosa arkansana*	23.0(8.5)	13.3(4.5)	22.6(9.0)	22.3(7.9)

and 18 percent than the key plant species. Western wheatgrass, needle and thread grass and blue grama were each approximately 4 percent cover. Other common grass species were Heller's rosette grass (*Dichanthelium oligosanthes*) and Kentucky bluegrass. Average forb cover was 10 percent and shrub cover 6 percent. Shrub cover was dominated by prairie rose (*Rosa arkansana*). Litter cover was 74 percent and bare ground 23 percent. Forty six forbs, 25 graminoids and 3 shrubs (Fig. 2) represented plant richness. Nineteen plant families were identified in this seral stage.

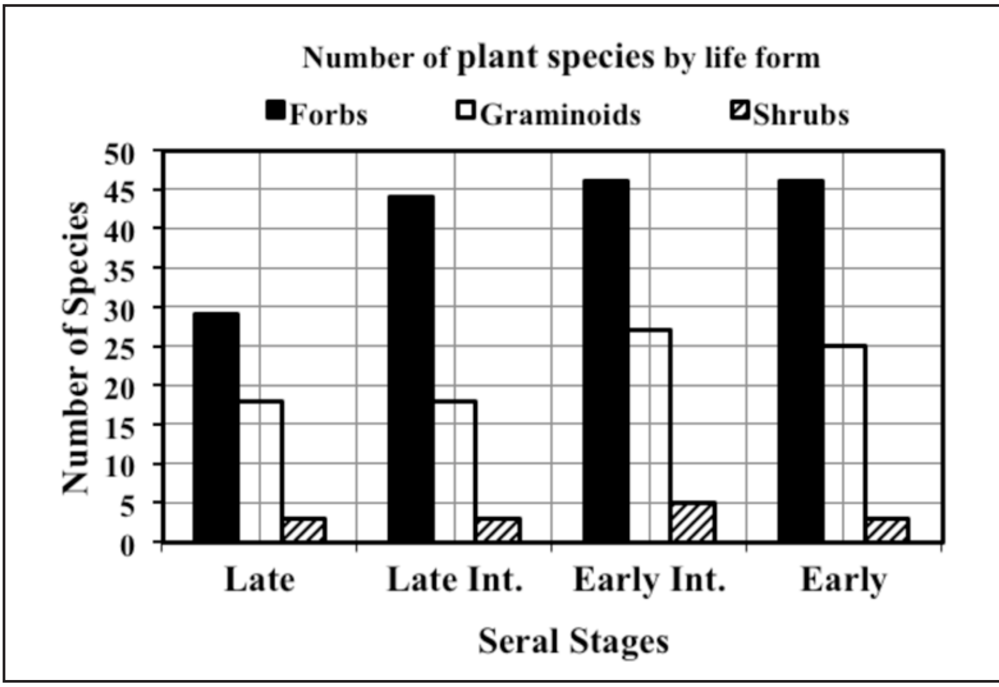

Figure 2. Number of plant species by life form throughout the four seral stages within the sandy ecological site in Nebraska and South Dakota.

Discussion

State and transition models are conceptual models for rangeland assessments and classification of multiple states within an ecological site. The conceptual state and transition model defined for this ecological site (Fig. 2 State-and-Transition Diagram) is reported in USDA-NRCS (2014), sands ecological site description. These models are based on expert qualitative opinion without scientific evaluation to determine their quantitative usefulness (Twidwell et al. 2013). Our developed model is quantitative and can be used to describe the plant dynamics and transitions between and among seral stages (plant community phases) using three key plant species. This model can be used for identifying transitions by sampling permanent macroplots within pastures or allotments yearly or once every few years to determine plant trends for transitions between and among seral stages. When permanent macroplots are established within the ecological type to assess the vegetational trend of a site, re-sampling and comparing the previously assigned seral stage to the current stage provides information about succession or retrogression. Model coefficients developed for this ecological site may be incorporated into the conceptual state and transition model for the ecological site description. Our model is linear but the key plant species are not linear when they progress through all four plant phases of plant succession.. Plant succession may go from early to late successional phase bypassing the intermediate phases or a site may be static for many years (Samuel and Hart 1994). This multivariate model provides resource managers a tool to define discrete stages or plant phases with only three key plant indicators to identify state and transition shifts within the ecological site. Evaluation and monitoring trends of the vegetation resource can be validated and documented for recovery or deterioration affected by herbivore grazing, fire, soil erosion, yearly and climatic changes for resource management areas (Uresk 1990, Benkobi et al. 1996, Uresk et al. 2010, Uresk et al. 2012). Canopy cover of perennial graminoids and litter cover offer the greatest potential for soil protection against wind or water erosion of soils within this ecological site (Malakouti et al. 1978, Mergen et al. 2001).

Management for all seral stages optimizes plant and animal species richness in this ecological site. A mosaic of seral stages (plant phases) with sufficient land area across the landscape is considered optimal for increased plant and animal species diversity (Rumble and Gobeille 1995, Fritcher et al. 2004, Vodehnal et al. 2009, Uresk et al. 2012). One individual seral stage might not be practical for multiple-use management, however; the entire range from early to late seral would accommodate greatest plant species diversity, wildlife diversity, livestock production and recreation. The late and intermediate seral stages may be more important for specific wildlife species. An example is sharptailed grouse and their association with late and intermediate seral stages for nesting cover (Prose et al. 2002, Vodehnal et al. 2009). Bird species diversity varied among seral stages on the mixed grass prairie in central South Dakota (Fritcher et al. 2004). To meet species diversity for both plant and animals, wildlife habitat, a recommendation of 10 - 15 percent of the landscape would be in early and late seral stages with the remainder within early intermediate and later intermediate stages or plant phases as a mosaic (Kershaw 1973, Mueller-Dombois and Ellenberg 1974).

Livestock grazing can be used as a management tool to provide a mosaic of seral stages across the landscape and to produce changes in seral condition. An adjustment of timing of livestock grazing, number of animals and time of grazing can be a management tool to achieve the desired landscape of mosaic seral stages and maintain livestock production (Severson and Urness 1994). The developed quantitative model can quantify changes in plant species composition and spatial distribution of seral stages over the landscape. Prairie sandreed and green needlegrass are considered highly palatable perennial grasses and these grasses often decrease when subjected to overgrazing (Lang 1973, Lewis et al. 1956, Uresk and Voorhees 2013). Little bluestem is considered more tolerant of grazing than prairie sandreed. Sun sedge decreases with intense grazing.

The developed model can be used to monitor and classify seral stages or plant phases based on prairie sandreed, little bluestem and sun sedge with an accuracy of 90 percent. Data collection for canopy cover and frequency of occurrence for each of the key species are the only field requirements. These data provide inputs to the model that predicts seral classification and for monitoring plant changes over time. The recommendation is to establish 1 macroplot per section (640 acres or 259 ha) within the same ecological site because other ecological sites may be present within the section. See aforementioned web site for additional information and methodology. Depending on yearly climatic conditions, data collections may be from mid-June through mid-September. In dry years, the sampling period may be shorter. Data may be collected yearly or every few years, depending upon management objectives.

The model developed for this ecological site can be used to quantify relationships between grazing intensities, wildlife, plant succession and to maintain a desired management objective. Additional information on rare plant and animal species, soil erosion as related to seral stages or plant phases may be included in resource management plans. Application of the model to predict seral stages and monitoring transitions is accurate, quantitative and free of subjective judgments.

Summary

A multivariate statistical model was developed based on prairie sandreed, little bluestem and sun sedge to classify seral stages (plant phases) and to monitor transitions on sandy ecological sites in Nebraska and South Dakota. Four resource categories (seral stages) were derived from discrete groupings with vegetation index values based on canopy cover and frequency of occurrence. Range and wildlife resource managers will be able to use this model to monitor the vegetation and evaluate management actions. Monitoring and evaluating vegetation is a process to improve existing management objectives. It will allow resource managers the ability to develop management plans and refine their assessment for multiple uses. Overall, it is equally important to understand the ecological system to maintain sustainable resources for both plants and animals over the landscape.

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Effects of Swim Strokes in Labor-wear With and Without a Personal Flotation Device

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Abstract

We determined how three different swim strokes were affected by standard labor-wear with and without use of a personal flotation device (PFD). The two main research questions included (1) what effects would standard labor-wear have on the American crawl, elementary back stroke and breast stroke with and without a PFD for 11.4 m (12.5 yds). The sub questions included: (2) Will the addition of the PFD improve swim times? We addressed these questions with six hypotheses. Statistical analysis showed statistically significant *P*-values for the American crawl (no PFD 23.29 sec, PFD 18.29 sec, $P = 0.0010$) and back stroke (no PFD 36.96 sec, PFD 31.00 sec, $P = 0.0223$); the strokes showed improved swim times with the PFD. We detected no statistical evidence ($P = 0.2086$) for the mean swim time (22.61 sec) for the breast stroke with PFD and the mean swim time (23.00 sec) for breast stroke without a PFD. Swim time between swimmers with and without a PFD differed. The mean swim time for all swimmers with a PFD (24.17sec) was faster than the mean swim time for all swimmers without a PFD (27.75 sec, $P = 0.0153$). The mean swim time for swimmers using the elementary back stroke (33.98 sec) was slower than the mean swim time for swimmers using the crawl stroke (21.10 sec, $P < 0.0001$) and the mean swim time for swimmers using the breast stroke (22.81 sec). We detected no difference between the mean swim time for swimmers using the crawl stroke and the mean swim time for swimmers using the breast stroke. We also detected no evidence ($P = 0.164$) of a stroke X flotation interaction effect.

Keywords: swim stokes, labor-wear, swim times, personal flotation device, life vest

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Introduction

We examined the effects of different swim strokes while wearing standard work clothing, with and without a personal flotation device, on subjects' abilities to swim 11.4 m (12.5 yds) relevant to work performed on or near water. For example, on 2 May 2003, a laborer was working near a pond in Oregon. The pond was surrounded by an angled embankment where the laborer was placing rocks at strategic locations on the inclined bank to prevent erosion. The laborer fell down the embankment and into the pond. By the time he was rescued from the water, first responders were unable to resuscitate him. It took them 47 min to locate and remove the body before resuscitation efforts began (NIOSH 2003).

In March 2011, a train derailment along the Kootenai River in Northwest Montana required railway workers to be transported to the derailment site via jet boat and to work on an inclined embankment along the river. The ensuing clean-up effort lasted 4 mos and involved > 1000 people. Many of the laborers were transported on jet-boats to islands and worked in close proximity to the flooding river. During this time, the air temperature fluctuated between -1-12 ˚C (30-54 ˚F), the Kootenai River was flowing at about 566.34 m^3/ sec (20,000 ft^3/ sec) and the temperature of the water was about 3.8 ˚C (39 ˚F) (U.S. Geological Survey 2011).

A common question of the laborers during transport was, "If we fall into the drink [while working], how long would we be able to stay up before you guys are able to rescue us?" The average worker transported to the worksite was wearing standard workwear: a hard hat with a liner, a heavy Carharrt® canvas jacket with insulation under the jacket, Carharrt® canvas bib coveralls and heavy leather work-boots with steel-toe protection. Amtmann et al. (2012) tested the hypothesis that occupational clothing would impair performance during swimming and treading water.

Further, Amtmann et al. (2012) provided evidence that standard laborwear had adverse effects on 11.4-m swim time, water treading time and rate of perceived exertion (RPE) on the Borg (1998) scale during water treading. The mean swim time more than doubled when the subjects wore standard labor-wear and their average rate of perceived exertion increased from 11.6 in standard swimwear to 17.1 in standard labor-wear. Because the trials excluded the use of a personal flotation device (PFD), the authors' recommendations for future research included comparing the effectiveness of different strokes with and without a PFD (Amtmann et al. 2012).

The Occupational Safety and Health Administration requires use of personal protective equipment and PFDs when individuals are working on, over or near water when a drowning hazard exists (U.S. Department of Labor 1926.106(a)). The purpose of the current research was to determine how three different strokes were affected by standard labor-wear with and without use of PFDs.

The two main research questions included (1) what effects would standard labor-wear have on the American crawl, elementary back stroke and breast stroke with and without a PFD for 11.4 m (12.5 yds)? The sub questions included, (2) Will the addition of the PFD improve swim times?

Hypotheses:

Null Hypothesis 1

The average 11.4 meter American Crawl swim time in standard labor-wear with a PFD will be > than the average swim time without a PFD.

Research Hypothesis 1

The average 11.4 meter American Crawl swim time in standard labor-wear with a PFD will be < than the average swim time without a PFD.

Null Hypothesis 2

The average 11.4 meter elementary back stroke swim time in standard labor-wear with a PFD will be > than the average swim time without a PFD.

Research Hypothesis 2

The average 11.4 meter elementary back stroke swim time in standard labor-wear with a PFD will be < than the average swim time without a PFD.

Null Hypothesis 3

The average 11.4 meter yard breast stroke swim time in standard labor-wear with a PFD will be > than the average swim time without a PFD.

Research Hypothesis 3

The average 11.4 meter yard breast stroke swim time in standard labor-wear with a PFD will be < than the average swim time without a PFD.

Null Hypothesis 4

No flotation main effect

Research Hypothesis 4

Have a flotation main effect

Null Hypothesis 5

No stroke main effect

Research Hypothesis 5

Have a stroke main effect

Null Hypothesis 6

No stroke* flotation interaction effect (* = by).

Research Hypothesis 6

Have a stroke* flotation interaction effect.

Methods

We tested the hypotheses in a controlled indoor pool environment. Each subject swam two trials each of the three strokes, one trial was performed wearing standard labor-wear, including coveralls and boots and no PFD. The other trial was performed wearing standard labor-wear and a PFD. Thus, each subject swam six trials total. The PFD used was a United States Coast Guard Approved Type V PFD that provides about 20 lb of buoyancy (United States Coast Guard 2013). The labor-wear consisted of canvas coveralls worn over the subjects' swim-suit and steel-toed work-boots.

Nineteen volunteer subjects were chosen based on current or previous experience and credentials. The exclusion criteria were guided by the American College of Sports Medicine risk stratification process. American College of Sports Medicine (ACSM) guidelines suggest a pre-participation screening that identifies current medical conditions that would exclude those who are at risk for adverse cardiovascular, pulmonary, metabolic, as well as other conditions that would cause adverse responses to exercise (ACSM 2009). The list of conditions that excluded a subject included:

- Pregnancy
- Diabetes
- Hypertension or are taking blood pressure medication
- Asthma
- Concerns about safety of exercise or swimming ability
- Heart surgery
- Chest discomfort with exercise
- Unreasonable breathlessness with exercise
- Unexplained dizziness or fainting
- Musculoskeletal problems that limit functional capacity
- Current smoker

All subjects completed the pre-participation screening intended to identify anyone who should be eliminated. Additionally, all subjects chosen were under the age of 50 years.

Safety of the subjects for the swim was ensured in two ways. First, the swim was conducted in water that was 4 ft deep, in which all of the subjects were able to stand. The subjects were instructed to simply stand up if they were in distress. The subjects were surrounded by a lifeguard in the water and a lifeguard on the deck with appropriate rescue equipment as back-up measures.

The subjects read an informed consent form that emphasized the voluntary nature of this study and that if they were uncomfortable doing anything related to this study they had the option to not participate. The decision to take part in this research study was entirely voluntary and the subject could withdraw from the study at any time. Additionally, all procedures were presented to and authorized by, an institutional review board.

After the subjects read the informed consent form, they were informed of the order of the randomly selected trials. Each subject would swim each stroke with and without a PFD; we randomly assigned the order in which testing was carried out. Resting heart rate and blood pressure on each subject was measured prior to the start of testing and each subject was allowed to rest following each trial until heart rate and blood pressures reached their resting states.

The subject's heart rate was taken immediately following completion of each trial using an ADC Diagnostix 2100 pulse oximeter, as well as by palpation of the radial artery. Additionally, each subject's rating of perceived exertion was recorded. The subjects performed the next time trial when their heart rate and blood pressure returned to their resting norms.

Results

The mean 11.4-m American crawl swim time for subjects with PFD was 18.91 sec and mean swim time for the American Crawl without PFD was 23.29 sec. The Wilcoxon Signed Rank test generated a *P*-value of 0.0010. Thus, we rejected null hypothesis 1 in favor of research hypothesis 1 at a significance level of 0.05.

The mean 11.4 m back stroke swim time for subjects with labor-wear and PFD was 31.00 seconds and the mean swim time with labor-wear without PFD was 36.96 seconds. The Wilcoxon Signed Rank test for paired data generated a *P*-value of 0.0223 and, based on this result we rejected null hypothesis 2 in favor of research hypothesis 2 at a significance level of 0.05.

The mean 11.4 m breast stroke swim time for subjects with PFD was 22.61 seconds and the mean swim time without PFD was 23.006 seconds. The Wilcoxon Signed Rank for paired data produced a *P*-value of 0.2086. Based on this result we failed to reject null hypothesis 3 in favor of research hypothesis 3 at a significance level 0.05. That is, we have no evidence that the mean swim time for the breast stroke with PFD differs significantly from the mean swim time for breast stroke without a PFD (Fig 1), Swim Time Versus Stroke and PFD Use, shows a comparison of the three strokes with and without a PFD.

We also used a two-factor ANOVA with repeated measures on both factors. The repeated measure occurs because each swimmer was tested at every treatment. There are a total of 6 treatments (3 X 2 = 6). The factors used were:

1. Stroke, with 3-levels: crawl, back and breast
2. Flotation; with 2-levels: PFD and without PFD

The mean swim time for all swimmers without a PFD was 27.75 seconds and the mean swim time for all swimmers with a PFD was 24.17 seconds. A *P*-value of 0.0153 was computed. Thus, we rejected null hypothesis 4 in favor of research hypothesis 4 at a significance level of 0.05. Our results indicated that wearing a PFD increases average swim time, over all strokes, compared to not wearing a PFD.

The mean swim time for the crawl, overall, was 21.10 sec, the mean swim time

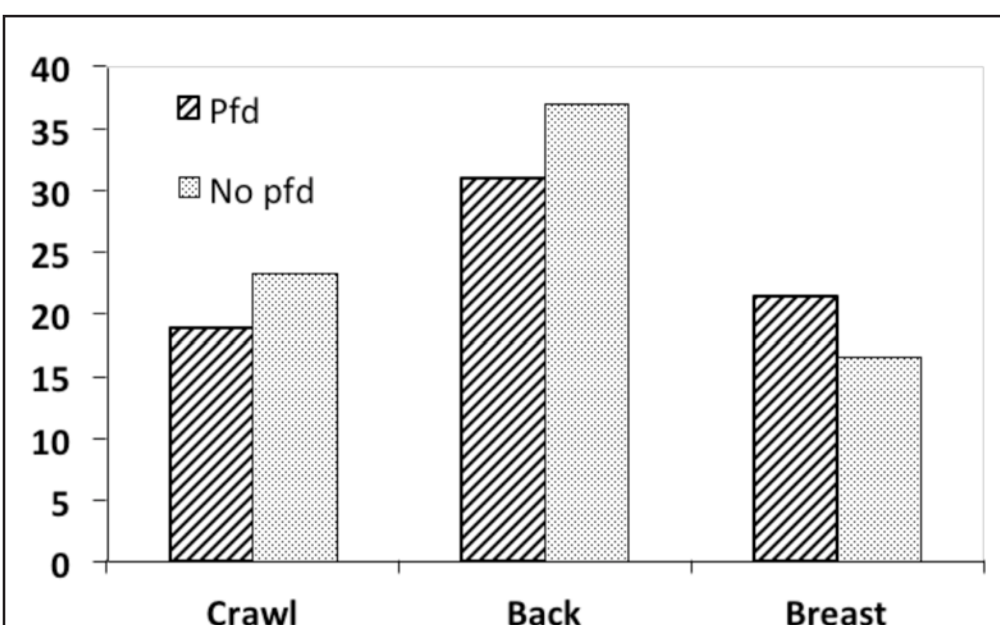

Figure 1. Comparison of swim times in seconds for all strokes with and without PFD.

for the back stroke, overall, was 33.98 sec and the mean swim time for the breast stroke with and without a PFD for all swimmers was 22.81. Based on a *P*-value of < 0.0001, we rejected null hypothesis 5 in favor of research hypothesis 5 at a significance level of 0.05. The stroke does have a main effect on swim times. Evidence indicates the mean swim time for swimmers using the elementary back stroke was slower compared to both crawl and breast stroke. In addition, there was no statistically significant difference between the mean swim time for the crawl stroke and the breast stroke.

Testing hypothesis 6 for a stroke X flotation interaction effect, we fail to reject the null hypothesis based on a *P*-value of 0.1640. We have no significant evidence of a stroke*flotation interaction effect. That is, we have no significant evidence that wearing a PFD will affect the three strokes in significantly different ways; the change to swim times was relatively consistent.

Discussion

Our results suggest that it is more efficient to swim 11.4 m in coveralls and work boots while wearing a personal flotation device as compared to making the swim when not wearing a personal flotation device. An individual who ends up in the water with standard labor-wear without a PFD should expect the physical requirements to swim for self-rescue to be more difficult than if they were wearing a PFD. Of the three strokes tested, the American crawl and the back stroke were significantly faster with the PFD.

When a person swims, it takes energy to stay on top of the water and to propel themselves forward (McArdle 2010). Labor-wear adds drag making swimming more difficult, so wearing a PFD will add more surface area creating extra drag (Parsons and Day 1986, Benjanuvatra et al. 2002, Vennell et al. 2006). The PFD keeps the person on top of the water so there is no need to expend energy to stay afloat and the person can use that extra energy to propel themselves forward, making the swim faster. However, wearing a PFD will not always ensure a successful self-rescue. The American Whitewater Affiliation keeps a database of deaths occurring on American rivers and from 2010-2013 13 deaths were reported on Montana creeks and rivers. Of the 13 fatalities, nine victims were wearing PFDs, two were not wearing a PFD and it was not reported whether the remaining two were wearing PFDs (American Whitewater Affiliation 2013).

The Whitewater Rescue Institute recommends using the defensive swim position, which involves floating on the back with feet downstream, to conserve energy and negotiate obstacles and hazards. They encourage aggressive swimming to self-rescue. For example, when swimming in a section of river with swift moving water and obstacles, it may be prudent to lie back in the defensive swim position, keeping the feet on the surface of the water to avoid foot-entrapment while steering with the arms. When an opening is encountered to reach a safe location, aggressively swimming to that spot may be necessary to avoid drowning (Harris and Johnston 2011). This may involve staying on the back and aggressively swimming using a back stroke or turning over from the defensive swim position to be able to use the American crawl or the breast stroke, or any other stroke.

Our research indicated that the fastest stroke was the American crawl, followed by the breast stroke and elementary back stroke, respectively. This was true whether a PFD was worn or not, though we detected no difference between the breast stroke times.

The limitations to this study included a small sample size, age of the subjects and lack of objective fitness data. Most of the subjects were of a young age ranging from 20 to 38 yrs and only one subject was > 40 years old, which may not accurately reflect the average age of the work-force. The subjects were relatively fit with some being collegiate athletes, firefighters and this also may not be a true representation of the work-force. Also, the labor-wear only consisted of boots and the coveralls; no inner layers were worn. Insulation layers may have had a further impact on the measurements. The environment was controlled; the water was warm, clear and non-moving when, in reality, many water incidents occur in cold, dark moving water.

Suggestions for Future Research

To gather more information, conducting fitness assessments on, each subject would be beneficial. Also, adding the insulation layers that are normally worn may more accurately reflect a laborer's physiological response in water. Monitoring heart rates and oxygen consumptions and comparing the different strokes would provide information on energy expenditure. It would also be important to compare the effect of different water temperatures on swim times and strokes.

Practical Application

When recreating or working on or near water where there is a drowning hazard, wearing a PFD will ensure an easier self-rescue. The Occupational Safety and Health Administration requires workers to wear a PFD when working near a drowning hazard and we recommend that employers strictly follow that requirement. Simply wearing a personal flotation device will improve the efficiency of self-rescue, making swimming easier. However this rule is not always followed and wearing a PFD will not always prevent the loss of a life. Based on the results of this study, we believe it is beneficial for those who work on or near water to always wear a PFD. If there is a need for self-rescue we recommend using the stroke with which the person is most comfortable. The American crawl was the fastest, but also appeared to be the most exhausting, so distance to safety may need to be considered during self-rescue.

We also recommend that any company requiring their employees to work on or near water consider implementing water safety plans that may include swift water rescue professionals to conduct training and to be on-site to help prevent water injury and death. Finally, we recommend training that allows in-water experiences so employees develop an understanding of their abilities and limitations and practice the different strokes in the water to find out which stroke they are most comfortable with if water-based self-rescue is required.

Acknowledgements

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Snowmobile Noise Exposure Monitoring of Yellowstone National Park Employees

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Abstract

In Yellowstone National Park (YNP) the use of snow machines has steadily increased since 1949. Paralleling the rise in snow machine travel were concerns over increases in noise emissions. The concerns resulted in the establishment of winter-use plans for YNP. As periodic iterations of winter-use plans began to appear, input was needed concerning noise exposures received by YNP employees regulating snow machine traffic entering the Park. This study provides noise monitoring results of worker exposure from snow machine traffic at the west entrance to YNP. The study objectives were to characterize noise exposures received by YNP employees and to evaluate these exposures relative to Occupational Safety and Health Administration (OSHA) standards. Concerning area and personal monitoring of YNP employees supervising snow machine traffic, study results suggest compliance with OSHA regulations. This is also true when applying a more conservative approach to estimate daily noise exposure. In contrast, monitoring results estimating noise exposures received by YNP employees operating snowmobiles revealed that 1 of 10 (10%) were not compliant with the OSHA noise standard and 5 of 10 (50%) equaled or exceeded its action level. While the findings associated with snowmobile operators serve to provide awareness of the potential for adverse exposures, limitations concerning these exposure estimates are discussed and point to the need for additional monitoring using more precise methods. Given that winter-use plans for YNP will continue to evolve, it is anticipated that the results of this study will provide information that can better manage occupational noise exposure and the protection of employee health.

Key words: snowmobiles, snow coaches, occupational noise, Yellowstone National Park

Introduction

In Yellowstone National Park (YNP), winter tourism by motorized travel first occurred in 1949 (Haines 1996). These one-to-two passenger vehicles, fitted with three skis and powered by small airplane engines mounted on the rear of an enclosed cab, were deemed snow planes. By 1955, the primary mode of motorized winter tourism in the park had advanced to 15-passenger snow coaches, which are still in use today (Yochim 2003). Yochim explains that the first snowmobiles entered the park in 1963 marking the start of a dramatic rise in motorized winter tourism that would continue over the next several decades into the 1990's where annual counts of snow coaches and snowmobiles entering the park approached seventy thousand.

Paralleling the rise in snow machine travel were concerns over increases in engine exhaust and noise emissions, calling into question the biological value that society was placing on the park (Gourley 2005). As a result, in 1990 YNP began instituting a winter-use plan (or rule) that, in part, regulated tourism using snow machines (USDI 1990). The plan was based on findings derived from environmental studies and impact statements and was intended to address concerns over ecological impacts caused by mechanized travel at the same time as preserving public access to the park via the use of snow machines. Since approval of the first winter-use plan, YNP has revised and approved subsequent plans using findings from numerous studies performed by environmental professionals (NPS 2011, Olliff et al. 1999).

Along with concerns over biological impacts, further concerns began to mount related to adverse noise exposures received by YNP employees monitoring snow machine traffic entering the Park (Glacier National Park 1975). This study was conducted to characterize occupational noise exposures to provide YNP administrators with information required to establish winter-use plans that not only protect the biological and recreational aspects of the park, but also the occupational health of its employees.

Monitoring of snowmobile and snow coach noise emissions was performed at the west entrance to YNP during two monitoring campaigns in 2005 and one monitoring campaign in 2006. The objectives of these campaigns were to characterize occupational noise exposures received by YNP employees and to evaluate these exposures relative to established Occupational Safety and Health Administration (OSHA) thresholds. The results of this study will add to the limited body of scientific knowledge that has been published regarding the occupational health risk presented by this type of noise exposure.

Methods and Materials

Historical visitation data compiled by YNP shows that holiday weekends associated with Presidents' Day and Martin Luther King Day are typically busy times in terms of the number of snowmobiles and snow coaches entering the national park for wintertime usage (B. Gauthier, personal communication, November 30, 2004). In an effort to characterize peak occupational noise exposures resulting from snow machine traffic, each monitoring campaign coincided with one of these holiday weekends. The specific dates for the three campaigns performed in this study were 15, 16 and 17 January 2005; 19, 20 and 21 February 2005 and; 18, 19 and 20 February 2006. Due to its popularity as a portal and the likelihood of encountering high numbers of snow machines entering the park, noise emission monitoring was performed at YNP's West Entrance, an entry portal adjacent to the city of West Yellowstone, Montana.

Instrumentation

The assessment of exposures received by YNP employees from snow machine noise emissions was based on acquisition and evaluation of personal and area monitoring data using Quest Q-400™ and Quest NoisePro™ dosimeters. These instruments are classified as ANSI Type 2 dosimeters and house omnidirectional, ceramic microphones having an accuracy of ± 2dB, which is the minimum accuracy requirement established by OSHA for the assessment of compliant noise measurements. To ensure that acquired noise measurements were suitable to evaluate compliance with the OSHA noise standard, each dosimeter was configured to record sound using the instrument settings summarized in Table 1. In an effort to maximize the precision and accuracy of acquired sound measurements during a given monitoring period, each dosimeter was pre- and post-calibrated using a Quest Model CA-12B acoustical calibrator emitting a 1000 Hz pure tone at a sound pressure level (SPL) of 114 dB.

Personal Monitoring of Kiosk Attendants

Monitoring of personal noise exposure was performed on YNP employees supervising snow machine traffic passing two 3 m x 3.75 m x 3.75 m buildings (kiosks). Each kiosk, denoted in this study

Table 1. Instrument settings for the Quest Q-400™ and Quest NoisePro™ Dosimeters used during personal and area noise monitoring at YNP during January 2005 and February 2006.

Instrument Setting	Instrument Setting Definition
A-Weighting	The internal weighting filter that reduces sound energy in the lower frequencies (less than 1000 Hz), is based on how humans perceive sound and is designated dBA.
90 dBA Criterion Level	The constant sound level that, if applied for eight hours, would result in a 100 percent sound exposure dose.
5 dB Exchange Rate	The number of decibels required to either halve or double the rate of accumulated sound exposure dose.
Slow Response	A one second averaging time for sound intensities received by the dosimeter.
80 dB and 90 dB Threshold Levels[1]	The decibel level above which sound is accumulated into a dosimeter measurement.

[1] *Both threshold levels are simultaneously applied using separate instrument channels*

as "Kiosk 1" and "Kiosk 2", were identical and adjacent to a snow machine traffic lane. Figure 1 provides a visual depiction of one of these Kiosks. As shown in Figure 2, during the morning hours when traffic flow was at its peak (0700 to 0900), both traffic lanes were simultaneously occupied by snow machines entering YNP. Each traffic lane was configured such that a snow machine would approach and pass the west facing

Figure 1. Kiosk used by employees to supervise snow machine traffic entering YNP through its West Entrance.

Figure 2. Two lanes of snow machine traffic approaching kiosks at the West Entrance to YNP.

wall of a kiosk. In this study, the YNP employee occupying Kiosk 1 is denoted as "Kiosk Attendant 1" and the YNP employee occupying Kiosk 2 is denoted as "Kiosk Attendant 2".

To allow for the appropriate characterization of personal noise exposures received as snowmobiles and snow coaches approached, stopped, idled and departed a given kiosk, dosimeter measurements were collected in the hearing zone of each Kiosk attendant. OSHA defines the hearing zone as a sphere having a 61 cm diameter surrounding a human head (USDL 1999). As shown in Figure 3 hearing zone measurements were performed by clipping the dosimeter microphone to an employee's jacket collar at a point midway between the base of the neck and the tip of the shoulder, which resulted in an approximate linear distance from the ear canal to the tip of the microphone of 20 cm. Each microphone was fitted with a foam screen to reduce the likelihood of recording anomalous noise measurements through contact with wind, clothing, or other surfaces. Care was taken to attach dosimeters to employees in such a manner as not to interfere with their normal job duties.

Monitoring times for the collection of personal exposure measurements were chosen to coincide with the highest levels of daily traffic entering YNP on holiday weekends. After discussions with YNP employees concerning historical traffic patterns on these weekends, it was decided that personal exposure monitoring would begin as close as possible to 0700 and continue until snowmobile and snow coach traffic subsided, typically around 1230.

Area Monitoring at Kiosks

In an effort to extrapolate localized noise emission measurements to human exposures, area monitoring was performed at the opening of a square, 112 cm x 112 cm, sliding glass window centered on the west facing wall of each kiosk. This window was adjacent to snow machine traffic lanes and was a location where employees spend a majority of time during traffic supervision.

Figure 4 provides visual confirmation of the location where area monitoring was performed. Figure 4 also shows that the dosimeter's microphone was clipped to the

Figure 3. Microphone placement on the collar of a YNP employee during personal noise monitoring.

Figure 4. Microphone placement on the window frame of a kiosk during area monitoring at the West Entrance to YNP.

south side of the window at a point halfway between the window's top and bottom (66 cm). Care was taken to clip the microphone to the outer surface of the window housing such that it would remain parallel to the plane of the window. The microphone cable and dosimeter unit inside the kiosk were carefully placed so they didn't interfere with YNP employee job duties.

Personal Monitoring of YNP Employees While Operating Snowmobiles

Two types of snowmobiles were used to assess personal noise exposures to YNP employees during snowmobile operation. The first type was a 2003 Polaris Frontier snowmobile equipped with 4-cycle, 784 cc, 2-cylinder engine. The second type was a 2004 Arctic Cat T660, housing a 4-cycle, 660 cc, 3-cylinder engine.

During personal monitoring of noise exposures two riders were seated on each snowmobile. The noise dosimeter unit was attached to the belt of the snowmobile passenger and the unit's microphone was held by the passenger as close as possible to the hearing zone of the snowmobile operator. While it is recognized that wind noise is a concern as a potential contributor to hearing loss when operating high speed vehicles, care was taken to shield the microphone from the wind generated by the speed of the snowmobile during operation. Also, each microphone was fitted with a foam screen to provide additional protection against accumulation of measurements resulting from wind and other noise artifacts. These sampling practices were done to enhance the repeatability of each sample given that the microphone was being held and not attached to the lapel of the snowmobile operator.

Quantification of Noise Exposures

The evaluation of compliance with occupational noise exposure limits was based on standards published in the 29 CFR 1910.95 (United States Department of Labor, OSHA, 1970). Under this Federal rule, OSHA has established an eight hour time-weighted-average (TWA) permissible exposure limit (PEL) of 90 dBA with a 90 dBA integration threshold. This PEL, also known as the Engineering Standard, is the sound pressure level (SPL) TWA that, when exceeded, requires employers to implement feasible administrative or engineering controls. If such controls fail, personal protective equipment shall be provided and used to reduce sound levels.

An update to 29 CFR 1910.95 occurred in 1981 known as the Hearing Conservation Amendment (United States Department of Labor, OSHA, 1981). Under the amendment, OSHA established an eight hour TWA with a PEL of 90 dBA with an 80 dBA integration threshold. The amendment requires employers to take specific actions when employee noise exposures meet or exceed an eight hour SPL TWA of 85 dBA (also known as the "action level"). The intent of OSHA's Engineering Standard and Hearing Conservation Amendment is to limit further exposure to noise levels above the established allowable level and, when necessary, require administrative control measures, such as the establishment of a written hearing conservation program and audiometric testing when exposures equal or exceed an 8-hour time-weighted average of 85 dBA.

When evaluating compliance with regulatory threshold limits a common way to document noise exposure is through the conversion of an eight hour SPL TWA to its percent dose equivalent using the following equation:

$$\%\,\text{Dose} = 2^{\left(\frac{SPL-90}{5}\right)} \times 100 \qquad \text{(eq. 1)}$$

Where,
SPL = TWA sound pressure level averaged over an eight hour time duration.

When using the equation above, SPLs can be applied from OSHA's Engineering Standard and Hearing Conservation Amendment criteria to express eight hour doses. For the purpose of assessing compliance with these exposure standards, all personal and area monitoring data were reported as percent dose equivalents of acquired SPLs.

During the performance of area and personal monitoring all but one of the monitoring events performed in this study were less than eight hours. For these events, dose equivalents had to be extrapolated over an eight hour time frame to allow for comparison with OSHA's eight hour standards. For these extrapolations, two separate assumptions were made concerning the level of exposure for the remaining portion of the eight hour period when monitoring did not occur.

Exposure Assumption #1–This assumption is intended to provide an indication of the worst case exposure that could be received over an employee's eight hour work shift. Under this assumption it is presumed that the SPL acquired at the end of a monitoring event remains constant for the remainder of the eight hour exposure period where monitoring did not occur. In other words, the monitoring event SPL is equal to the eight hour SPL. This eight hour SPL is then converted to its percent dose equivalent and is reported as the eight hour percent dose exposure for a given monitoring event.

Exposure Assumption #2--Under this assumption it is presumed that there is no further exposure to noise above the instrument's threshold levels (80 dB and 90 dB) after cessation of the monitoring event and extrapolates the acquired TWA over an eight hour time duration using the following equation:

$$TWA_{8-hr} = \frac{TWA_{me}(t)}{8} \qquad \text{(eq. 2)}$$

Where,
$TWA_{8\text{-}hr}$ = The SPL extrapolated over an 8 hour time duration;
TWA_{me} = The SPL acquired at the end of a monitoring event and;
t = Monitoring event duration in hours.

The extrapolated eight hour SPL is then converted to its eight hour percent dose equivalent.

In this study, these two assumptions were used to quantify and report exposure estimates acquired during the performance of personal and area monitoring. Exposure results under each assumption are reported separately for both the 80 dB and 90 dB threshold levels and are used to assess compliance with the Federal standard for occupational noise exposure.

Results

Snow Coach and Snowmobile Populations

The results provided in Table 2 show that over the duration of the study's three monitoring campaigns a total of 1732 snowmobiles and 178 snow coaches entered YNP through its west entrance, yielding a daily average of 192 snowmobiles and 20 snow coaches. Averages for the eight days sampled represent 32 percent and 18 percent higher snowmobile and snow coach traffic when compared with the daily average for all winter use days encompassing the 2005 and 2006 seasons (Ray 2008).

Time Durations for Personal and Area Monitoring

Table 3 summarizes the time durations and standard deviations for personal and area monitoring events performed in this study. All but one of the monitoring events were less than 480 minutes (8 hours). The time durations for the thirteen personal and area monitoring events performed at Kiosks' ranged from 199 minutes to 360 minutes with an average monitoring duration of 291 minutes for personal monitoring events and 230 minutes for area monitoring events. Also provided in Table 3 are the time durations of personal monitoring events associated with snowmobile operation. Because the intent of this personal monitoring was to assess noise exposures received by YNP employees while riding snow machines, monitoring durations were limited to actual riding time and ranged from

Table 2. The number and type of snow machines entering YNP through its West Entrance on the days when noise monitoring was performed during January 2005 and February 2006.

Date	Snowmobiles	Snow Coaches
1/15/05	163	21
1/16/05	142	12
1/17/05	109	19
2/19/05	279	25
2/20/05	227	23
2/21/05	164	15
2/18/06	243	25
2/19/06	231	23
2/20/06	174	15
Total	**1732**	**178**
Per Day Average	**192**	**20**

Table 3. Descriptive Statistics associated with Time Durations for Personal and Area Monitoring Events at the West Entrance to YNP during January 2005 and February 2006.

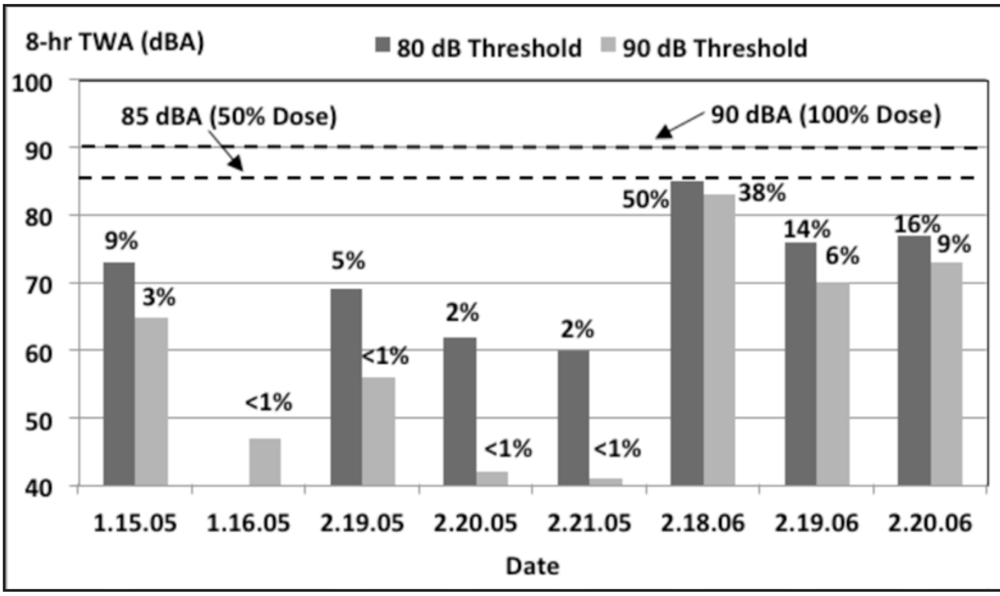
Type of Monitoring	No. of Events	Range) (minutes	Average (minutes)	SD
Personal Monitoring of Kiosk Attendants	8	214 to 360	291	50
Area Monitoring of Kiosks	5	199 to 257	230	32
Personal Monitoring of Snowmobile Operators	7	274 to 480	328	69

274 minutes to 480 minutes, with an average duration of 328 minutes.

Personal Monitoring Results of Kiosk Attendants

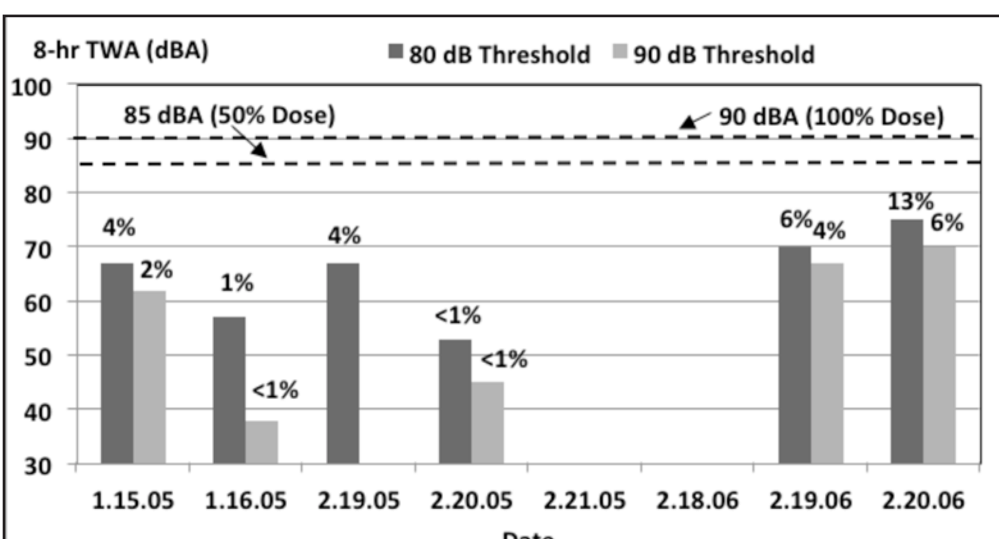
Figures 5 through 8 provide exposure estimates for kiosk attendants supervising snowmobile and snow coach traffic entering YNP. All exposure estimates are expressed as dose equivalents of eight hour SPLs and are differentiated based on the assumption applied to quantify the dose equivalent and on measurements acquired using the instruments' 80 dB or 90 dB threshold level. The dotted lines on each figure identify the 90 dBA (100 percent equivalent dose) and 85 dBA (50 percent equivalent dose) eight hour TWA exposure limits established for OSHA's Engineering Standard and Hearing Conservation Amendment.

Personal Monitoring Results at the 90 dB Threshold Level–As is shown in Figures 5 through 8, consideration of both exposure assumptions at the 90 dB threshold level provide dose equivalents for both kiosk attendants that were less than the non-compliance limit established for OSHA's Engineering Standard (90 dBA



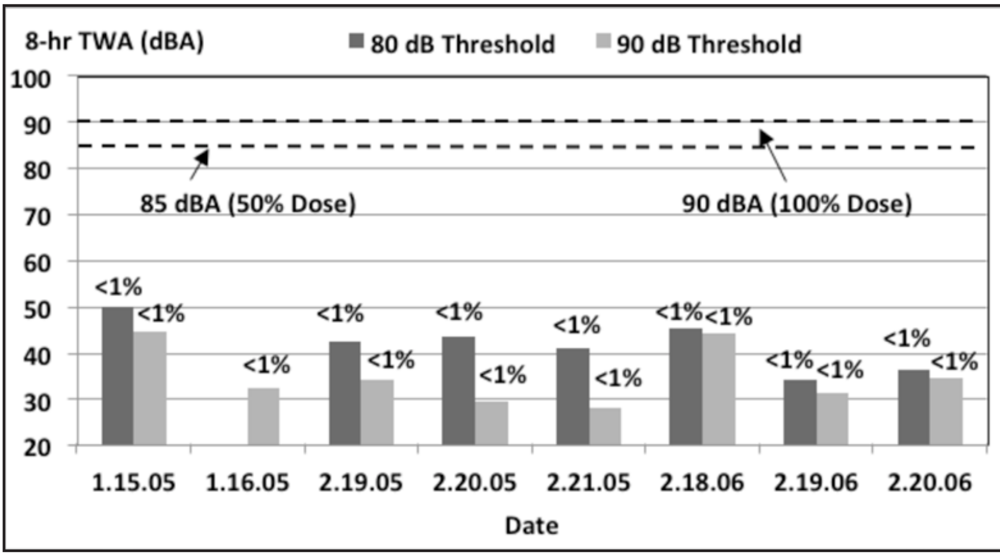
[1] The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume no further accumulation of noise exposure for the remainder of an 8-hr work shift.
[2] No data are available at the 80 dB Threshold for Kiosk attendant 1 on 16 February 2005.

Figure 5. Personal Noise Monitoring of Kiosk Attendant 1 at the West Entrance to YNP during two weekend monitoring campaigns in January 2005 and one in February 2006 **(using Exposure Assumption #1)**.



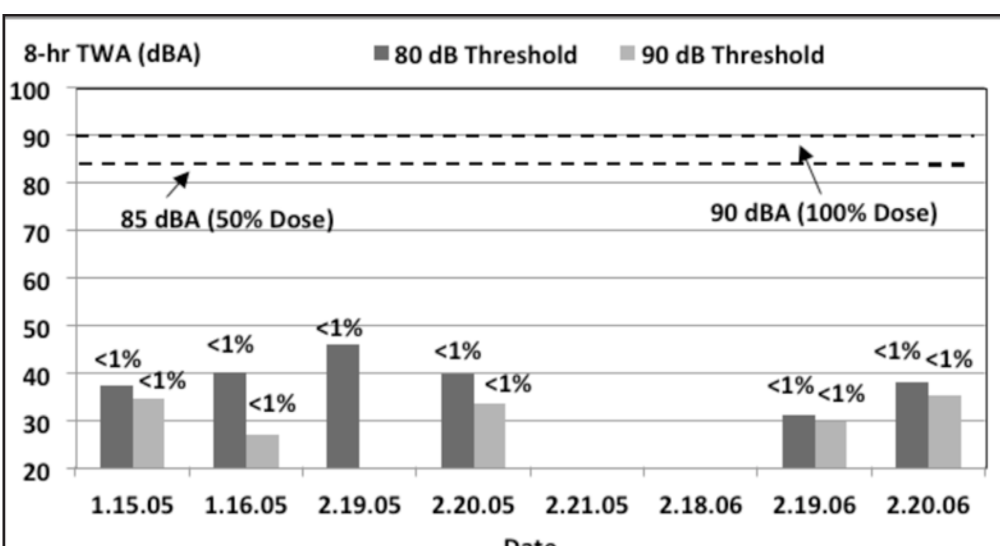
[1] The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume no further accumulation of noise exposure for the remainder of an 8-hr work shift.
[2] No data are available for Kiosk attendant 2 on 21 February 2005, 18 February 2001 and at the 90 dB Threshold on 19 February 2005.

Figure 6. Personal Noise Monitoring of Kiosk Attendant 2 at the West Entrance to YNP during two weekend monitoring campaigns in January 2005 and one in February 2006 **(using Exposure Assumption #1)**.



[1] *The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume that average noise exposures measured at the end of the monitoring period are equivalent to percent dose exposures acquired for an 8-hr work shift.*
[2] *No data are available at the 80 dB Threshold for Kiosk attendant 1 on 16 February 2005.*

Figure 7. Personal Noise Monitoring of Kiosk Attendant 1 at the West Entrance to YNP during two weekend monitoring campaigns in January 2005 and one in February 2006 **(using Exposure Assumption #2)**.



[1] *The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume that the noise exposures measured at the end of the monitoring period are equivalent to percent dose exposures acquired for an 8-hr work shift.*
[2] *No data are available for Kiosk attendant 2 on 21 February 2005, 18 February 2006 and at the 90 dB Threshold level on 19 February 2005.*

Figure 8. Personal Noise Monitoring of Kiosk Attendant 2 at the West Entrance to YNP during two weekend monitoring campaigns in January 2005 and one in February 2006 **(using Exposure Assumption #2)**.

or 100% dose). Further scrutiny using Exposure Assumption #1 at the 90 dB threshold level reveals that of the 13 dose equivalent exposures estimated for both kiosk attendants, six were less than one percent, 12 were less than 10 percent and one was 38 percent. Similar scrutiny of the results reported using Exposure Assumption #2 at the 90 dB threshold level shows that all dose equivalent exposures for both kiosk attendants at this threshold level were less than one percent.

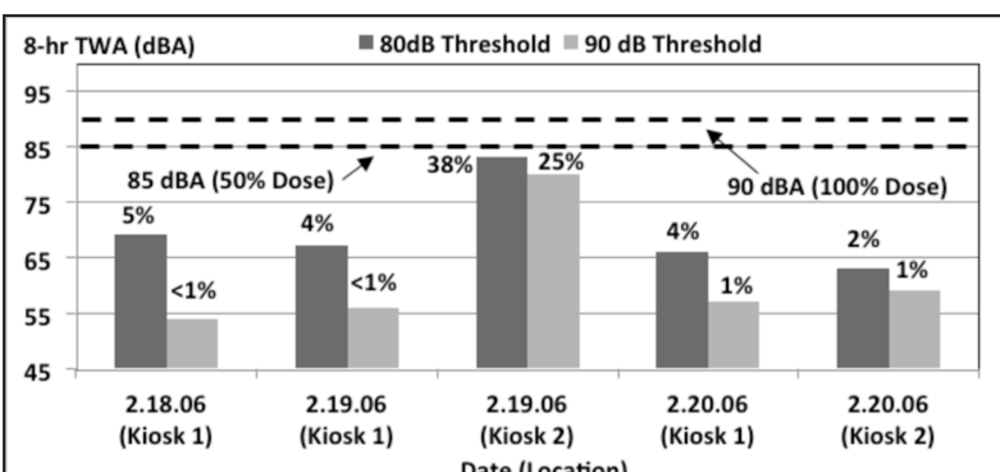
Personal Monitoring Results at the 80 dB Threshold Level–The results provided in Figures 5 through 8 show that for both exposure assumptions at the 80 dB threshold level, all but one of the dose equivalent exposures were less than the 50 percent dose action level that initiates implementation of OSHA's Hearing Conservation Amendment. Consideration of Exposure Assumption #1 in Figures 5 and 6 reveals that of the 13 dose equivalent exposures estimated for both kiosk attendants, nine were less than 10 percent, two were less than 20 percent and one was 50 percent. In Figures 7 and 8, which provide dose equivalent exposures using Exposure Assumption #2, the results show that all 13 dose equivalent exposures estimated for both kiosk attendants were less than one percent.

Area Monitoring at Kiosks

Figures 9 and 10 provide the results of area monitoring at both Kiosk 1 and Kiosk 2. As is shown in these figures, dose equivalent exposure results using both assumptions and at both threshold levels were less than the dose limit imposed by OSHA's Engineering Standard and Hearing Conservation Amendment. Over the five events where area monitoring occurred, all dose equivalent exposure results were less than 10 percent except on 19 February 2006, when area monitoring results showed an equivalent dose exposure of 38 percent at the 80 dB threshold level and 25 percent at the 90 dB threshold level.

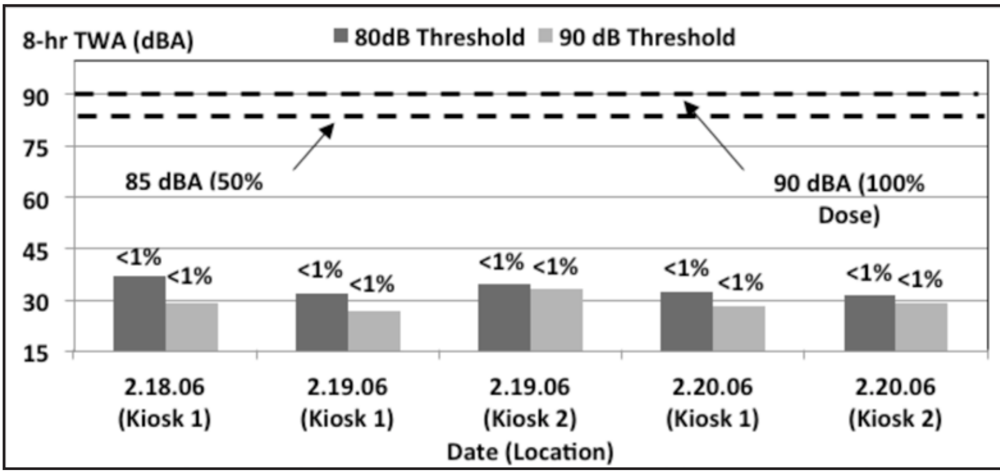
Personal Monitoring of YNP Employees Operating Snowmobiles

Figures 11 and 12 provide results of personal exposure monitoring of YNP employees while operating snowmobiles. In both figures, snowmobile Type 1 refers to the 2003 Polaris Frontier and snowmobile Type 2 refers to the 2004 Arctic Cat T600.



[1] *The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume that the noise exposures measured at the end of the monitoring period are equivalent to percent dose exposures acquired for an 8-hr work shift.*

Figure 9. Area Noise Monitoring at Kiosks Located at the West Entrance to YNP from18 February 2006 through 20 February 2006 **(using Exposure Assumption #1)**.



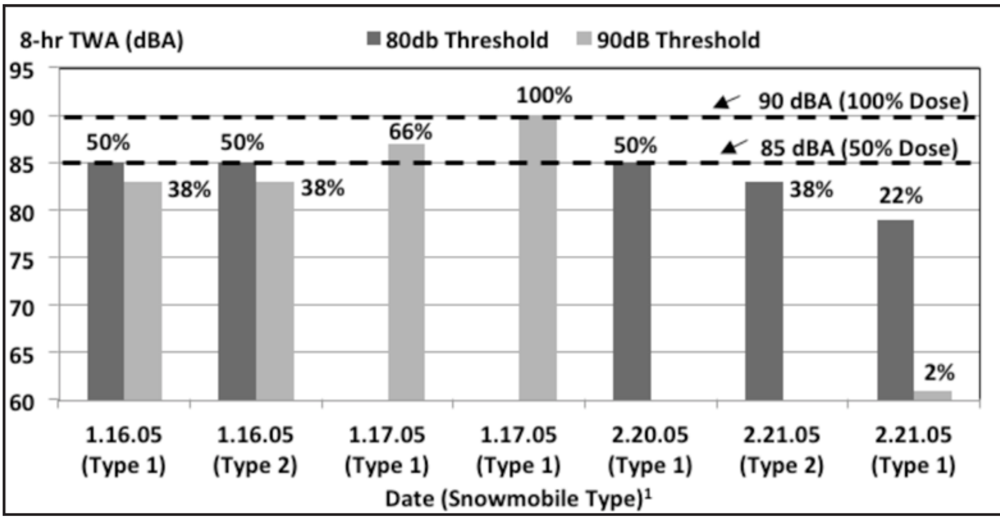
[1] *The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume no further accumulation of noise exposure for the remainder of an 8-hr work shift.*

Figure 10. Area Noise Monitoring at Kiosks Located at the West Entrance to YNP from 18 February 2006 through 20 February 2006 **(using Exposure Assumption #2)**.

In Figure 11 accumulated exposure doses approached or exceeded OSHA's Hearing Conservation Amendment Threshold (50% dose) on all but two of the monitoring events. Most striking is the result on 17 January 2005 where the accumulated dose exposure equaled OSHA's Engineering Standard (100% dose equivalent), assuming that the 90 dBA TWA achieved after 274 minutes of monitoring remains the same when extrapolated over eight hours (Exposure Assumption #1). Another result of note is the 50 percent dose equivalent observed for the 2003 Polaris Frontier snowmobile when applying either exposure assumption on 20 February 2005 (Fig. 11 and Fig. 12). Most noteworthy concerning exposures received during snowmobile operation is the overall lack of significant dose accumulation when applying Exposure Assumption #2 (Fig. 12). Again, the one exception was on 20 February 2005 where the dose accumulation was 50 percent, which initiates OSHA's Hearing Conservation Amendment.

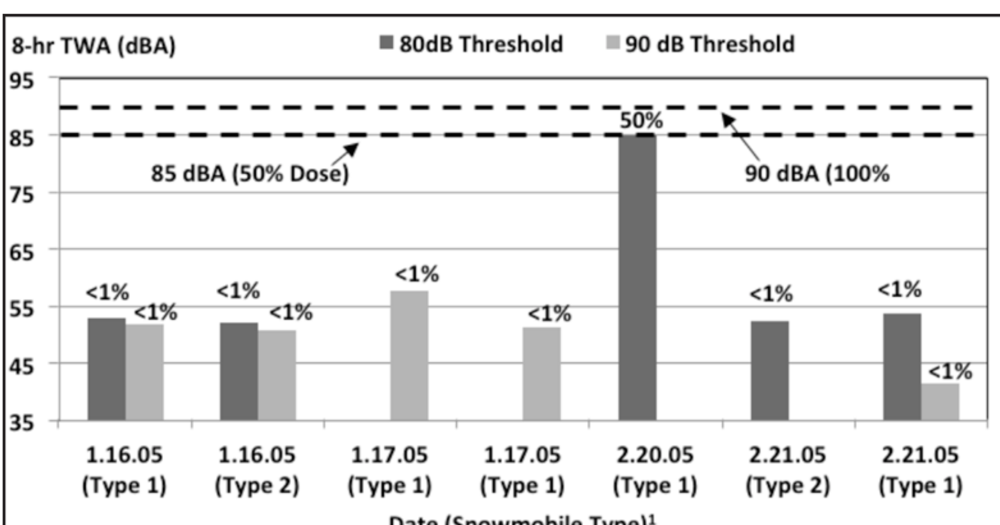
Discussion

In an effort to characterize worst case exposures received by employees supervising snow machine traffic entering YNP, President's Day and Martin Luther King Day holiday weekends were chosen for noise monitoring. The results in Table 2 show increases in snow machine traffic patterns over these chosen time periods, which appear to validate the decision to monitor on these days. Another decision made by the study's researchers was to perform personal and area monitoring for less than 8 hours, which is the typical work duration used by OSHA to establish compliant noise exposures. This decision was based on the daily character of noise exposures received by YNP employees during the performance of their job duties. For YNP employees supervising snow machine traffic, the primary source of exposure during a work shift was from noise generated as snowmobiles and snow coaches approached, stopped and passed a kiosk. Once snowmobile and snow coach traffic subsided, these employees returned to an office environment that contained noise levels below 80 dB. Since 80 dB is the lower threshold at which sound was accumulated into a dosimeter measurement for comparison against the OSHA Hearing Conservation Amendment, the exposures received in the office environment did not contribute additional noise dose to their daily exposure. Thus, for personal and area monitoring, efforts were made to



[1] Snowmobile Type 1: 2003 Polaris Frontier; Snowmobile Type 2: 2004 Arctic Cat T600.
[2] The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume that average noise exposures acquired at the end of the monitoring period are equivalent to percent dose exposures acquired for an 8-hr work shift.
[3] On 17 February 2005 personal monitoring was performed twice using snowmobile type 1 and no data are available on this date for snowmobile type 2.
[4] No data are available at the 80db Threshold for snowmobile type 1 on 17 February 2005 and at the 90 db Threshold for snowmobile type 1 on 20 February 2005 and 21 February 2005.

Figure 11. Personal Noise Monitoring of YNP Employees Operating Snowmobiles in YNP on 16-17 January 2005 and 20-21 February 2005 **(Using Exposure Assumption #1)**.



[1] Snowmobile Type 1: 2003 Polaris Frontier; Snowmobile Type 2: 2004 Arctic Cat T600.
[2] The % values above each bar represent dose equivalents for corresponding dBA-TWA values and assume no further accumulation of noise exposure for the remainder of an 8-hr work shift.
[3] On 17 February 2005 personal monitoring was performed twice using snowmobile type 1 and no data are available on this date for snowmobile type 2.
[4] No data are available at the 80db Threshold for snowmobile type 1 on 17 February 2005 and at the 90 db Threshold for snowmobile type 1 on 20 February 2005 and 21 February 2005.

Figure 12. Personal Noise Monitoring of YNP Employees Operating Snowmobiles in YNP on 16-17 January 2005 and 20-21 February 2005 **(Using Exposure Assumption #2)**.

coincide the sampling duration with the time when snowmobiles and snow coaches were allowed to enter through YNP's west entrance (0700) and continue until snow machine traffic passing entrance kiosks subsided (between 1200 and 1300 each day).

Overall personal monitoring of kiosk attendants provided exposure results that were well below OSHA's Engineering Standard and Hearing Conservation Amendment. The single outlier in these results is associated with the personal monitoring of Kiosk Attendant 1 on 18 February 2006, who received a 50 percent dose equivalent exposure upon completion of the monitoring event (Fig. 5). While this level of exposure is equal to the threshold that initiates OSHA's Hearing Conservation Amendment, it was noted during monitoring that a portion of the exposure dose was likely caused by noise emissions received from human speech due to the kiosk attendant's loud voice and tendency to speak directly in or proximal to the dosimeter's microphone.

The results in Figures 11 and 12 show that on 20 February 2005 the percent dose received by the operator of the Polaris Frontier snowmobile was the same when using both Exposure Assumptions #1 and #2. The reason the percent dose amounts are equal is because the duration for this monitoring event was exactly 480 minutes (8 hours) negating the need to extrapolate the exposure over a time period not sampled (as is done in Exposure Assumption #2). Thus, in this instance, exposure estimates applying both Exposure Assumptions yield the same percent dose.

Conclusions

Given the volume of snow machines entering the Park on the holiday weekends chosen to perform noise monitoring, it is likely that the results in this study provide a conservative (worst case) estimate of exposures received by YNP employees supervising this traffic. Concerning area and personal monitoring of kiosk attendants, the results suggest compliance with the OSHA Engineering Standard and Hearing Conservation Amendment. This was true when applying an even more conservative approach to estimate daily noise exposure (Exposure Assumption #1). Using this approach it was assumed that the average noise exposure received by an employee over the time period when snow machine traffic and resulting sound intensities were at their peak (0700 to 1300) remained the same for the duration of an eight hour work shift. Through observation and discussion with YNP employees it became clear that once snow machine traffic subsided they would return to an office environment where noise intensities were below those that would contribute to additional daily exposure dose. Thus, it is likely that exposures measured using this approach are overestimated and their compliance with OSHA noise standards provides added confidence of compliance throughout the Park's entire winter-use time frame.

Contrary to the exposure estimates for area and personal monitoring, many of the monitoring results intended to estimate 8-hour TWA noise exposures received by YNP employees operating snowmobiles were close or exceeded the 8-hour TWA that initiates OSHA's Hearing Conservation Amendment (85dBA). Further, it is likely that operation of snowmobiles for durations longer than those monitored in this study, would yield 8-hour TWA exposures that approach or exceed OSHA's Engineering Standard, requiring evaluation of the use of administrative and engineering controls, the mandatory use of hearing protection devices and a Hearing Conservation Program, with all it elements. That said, study limitations concerning the monitoring methods used to estimate operator exposure include, (1) the fact that the snowmobile operator wore a helmet that served to attenuate noise intensity, (2) the variability of microphone placement proximal to the human hearing zone, due to being held by the snowmobile passenger, (3) the contribution of anomalous noise from wind blowing across the microphone's surface. Thus, while these results serve to raise awareness of the potential for adverse occupational noise exposures received by snowmobile operators, better monitoring methods are needed to provide more precise estimates.

The latest and most recent winter-use plan for YNP, titled the 2012/2013 Winter Use Plan/Supplemental Environmental Impact Statement (Plan/SEIS), was approved by the NPS on 21 August 2013 (NPS 2013). This latest plan focuses on a daily number of "transportation events" in the park, instead of a total number of snow machines allowed in YNP each day. As defined in the 2012/2013 Plan/SEIS, a transportation event is defined as either one snow coach or on average a group of seven snowmobiles. The 2012/2013 Plan/SEIS will allow up to 110 transportation events in YNP each day with no more than 50 being characterized as snowmobile transportation events. Under the 2012/2013 plan, engine performance of snowmobiles and snow coaches will have to meet enhanced best available technology (E-BAT) requirements, which require lower engine exhaust and noise emissions than previous engine performance requirements.

Given that future winter-use plans will continue to evolve, it is anticipated that the results of this study will provide YNP administrators, charged with the development of future winter-use plans, important science-based information regarding noise exposures received by employees supervising snow machine traffic or riding snowmobiles. Having this information will allow for improved management of these types of occupational exposures and better protect employee health.

Acknowledgements

We would like to commend the Yellowstone National Park employees for their patience during the study's field campaigns. Funding for this project was provided, in part, by the Rocky Mountain Cooperative Ecosystem Studies Unit (RM-CESU) under agreement number: H1200040001.

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Evaluating the Use of Indoor Residential Wipe Samples Following a Wildfire

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Abstract

The Las Conchas wildfire that burned in New Mexico between 26 June and 3 August, 2011 was one of the largest in state history. In addition to burning nearly 160,000 acres, smoke from the fire significantly impacted downwind communities. In an effort to quantify the extent of smoke exposure to indoor environments, wipe samples were collected inside of 64 homes located throughout the north/central region of New Mexico. These wipe samples were analyzed for char and ash (indicators of biomass smoke) using Polarized Light Microscopy, with the results plotted in Google Maps. Out of the 64 residences that were investigated, char was detected from within 78% of the homes. Ash was not measured from any of the wipe samples. Mapping of these results demonstrates the far-reaching impact that smoke from the Las Conchas wildfire had on downwind communities, as indoor wipe samples from homes up to 50 kilometers from the fire tested positive for char. This project also demonstrated the usefulness of collecting wipe samples to retrospectively assess wildfire smoke impacts on indoor environments in lieu of expensive indoor air sampling campaigns.

Key Words: Wildfire smoke, Las Conchas wildfire, indoor air pollution, $PM_{2.5}$, air sampling.

Introduction

The primary goal of this research was to investigate the impact that wildfire smoke from the 2011 Las Conchas wildfire had on 64 residences downwind of the fire. A secondary goal was to evaluate the effectiveness of using wipe samples (in lieu of expensive sampling equipment) to serve as a surrogate for detecting forest fire smoke ($PM_{2.5}$) in indoor environments. In this manuscript, we present the results of a sampling, analytical and mapping program, which includes results of wipe sample evaluations.

On 26 June, 2011, the Las Conchas wildfire started in the Jemez Mountains located in the Santa Fe National Forest of north/central New Mexico (Fig. 1) when a tree fell on a power line. By the time the fire was 100% contained on 1 August, nearly 160,000 forested acres (~244 square miles) had burned, making it one of the largest wildfires in New Mexico state history. Not only were 63 residences and 49 outbuildings destroyed during the Las Conchas wildfire, smoke directly impacted areas downwind of the fire throughout the duration of the event.

Biomass combustion emissions can be transported over hundreds of kilometers, such that air quality is degraded even at great distances from forest fire locations (Gillies et al. 1996, Sapkota et al. 2005). The smoke that is transported during these episodes is primarily composed of $PM_{2.5}$ (airborne particulate matter with aerodynamic diameters of ≤2.5 microns). Larger particles (those >10 µm in aerodynamic diameter) tend to settle closer to their source due to gravitational settling, while ultrafine particles (those < 100 nm) tend to coagulate, leading to loss of particles in that size fraction (Hinds 1982, Zhu et al. 2002).

Forest fire smoke impacting downwind populations can be episodic, with elevated ambient $PM_{2.5}$ concentrations lasting from hours up to weeks at a time. If the downwind impacts are sustained, elevated $PM_{2.5}$ concentrations can result in exceedances of health based standards such

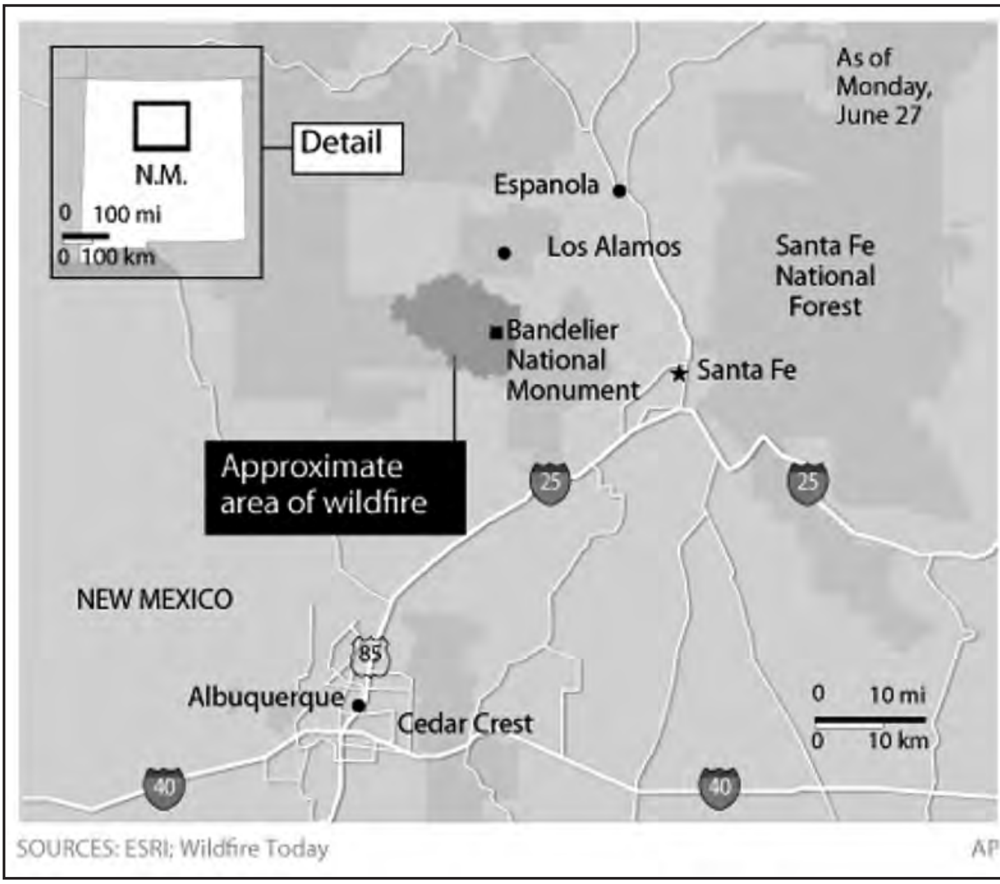


Figure 1. Location of the Las Conchas (New Mexico) wildfire and surrounding communities, summer 2011.

as the Environmental Protection Agency's (EPA) 24-hour National Ambient Air Quality Standard (NAAQS). During such events, source apportionment computer modeling research has shown that over 80 percent of the airborne $PM_{2.5}$ originates from wildfire smoke (Ward and Smith 2005). Less is known about the impact of forest fire smoke on indoor environments during such episodes. This indoor component is critically important, in that most people spend ~95 percent of their time indoors (Fishbein and Henry 1991, Jenkins et al. 1992).

Currently, the primary method of accurately determining the magnitude and duration of forest fire smoke exposures within homes is through indoor air sampling, consisting of expensive sampling equipment operated by trained personnel. However, this can be a challenge if there is a lack of sampling resources – especially if the goal is to simultaneously assess indoor exposures in a large number of homes over an extended period of time. Therefore it is of interest to identify an inexpensive, easy to use and accurate alternative to assessing the impact of forest fire smoke on indoor environments.

Methods and Materials

Sampling Program

Between November 2011 and April 2012, 64 homes were recruited for sampling in north/central New Mexico in areas downwind of the Las Conchas wildfire. Each of these homes had previously filed claims with their insurance companies, requesting that their homes be cleaned to remove forest fire smoke particles that had impacted the interior of their homes. Each home was within 100 km of the Las Conchas fire and was located in the following communities: Cordova, Espanola, Chimayo, Velarde, Los Alamos, Santa Cruz, Cuarteles, Alcalde, San Juan Pueblo, La Mesilla, Ojo Caliente, Rio Rancho, Chamita, Santa Fe, Fairview, Penasco and San Juan Pueblo (El Grique).

As this study aimed to qualitatively determine the presence of forest fire smoke by-products within the homes (weeks to months following the actual forest fire event), active air sampling was not conducted during the home visits. In lieu of air sampling, three individual surface wipe samples of visible dust were collected within each of the homes using pre-moistened 1 x 1" isopropyl alcohol pads. Sampling was conducted by wiping flat, horizontal, undisturbed surfaces (10 cm x 10 cm) such as windowsills, tops of fan blades, tops of shelves and door jambs, etc. For consistency within the homes, we focused our wipe sample collection efforts within the common areas and bedrooms of the residences. Once the samples were collected, the alcohol pads were placed in pre-labeled Ziplock baggies.

Analytical Program

All wipe samples were sent to LA Testing (South Pasadena, CA) where they were analyzed for wildfire combustion by-products (char and ash) using Polarized Light Microscopy (PLM) following the Visual Area Estimation Method (used in asbestos analysis for bulk samples EPA 600 method). Char is a solid decomposition product composed of particles that are larger than 1µm. Char may preserve the original form (including cellular morphology) of the material that was burned and is mostly composed of elemental carbon (with lesser concentrations of other elements). Ash is the mineral content of a product remaining after complete combustion of vegetation. The main difference between ash and char is that ash may not preserve any of the original morphology of the precursor and it may have a higher concentration of inorganic components (including calcium) due to the complete combustion of some of the organic matrix (Moffett, 2010).

Results

Ambient $PM_{2.5}$ Concentrations During the Wildfire

During the time period when the Las Conchas wildfire was burning (26 June-1 August, 2011), ambient $PM_{2.5}$ concentrations were elevated in locations downwind of the wildfire. In Los Alamos (located 20 kilometers northeast of the fire), the EPA's Air Quality Index (AQI) for $PM_{2.5}$ ranged from "Unhealthy" to "Hazardous", with elevated 24-hr concentrations measuring 68.2 $\mu g/m^3$ on 11 June and 258.9 $\mu g/m^3$ on 30 June (Resnick et al. 2013). Both of these samples from these days exceeded the 24-hr $PM_{2.5}$ NAAQS of 35 $\mu g/m^3$. Though we do not have measured ambient $PM_{2.5}$ concentrations from any of the other communities targeted in this study, many homeowners reported being in smoke for extended periods of time throughout the duration of the Las Conchas wildfire (personal communication).

Wipe Samples

Table 1 presents the results of the wipe samples. Importantly, ash was not found on any of the wipe samples collected within the 64 homes, likely due to the larger sizes of these particles (that deposited near the source) compared to the char. However, 50 of the 64 homes that were sampled contained measurable concentrations of char above the Limit of Quantitation (LOQ, ~1%, based on surface area). The majority of the homes that tested positive for char

Table 1. Char concentrations measured from wipe samples collected in 64 homes after the Las Conchas, New Mexico fire in 2011.

Char Concentrations	Number of Homes
<1% in all wipe samples (non detects)	14
1-2%	37
2-5%	10
>5%	3

had an average concentration between 1 and 2 percent (Table 1). Ten of the homes had average concentrations between 2 and 5 percent, while three homes had concentrations above 5 percent (9.7, 6.3 and 5.7%). The variability within the three samples per home ranged from 0 to 13.3 percent, with an overall standard deviation of 1.5 percent across all homes. The highest char concentrations from individual wipes were measured within a home ~42 km from the fire (25%) and a home ~60 km from the fire (15%).

Char Concentration Gradient Mapping

Using Google Maps, sampling points (addresses of the homes) were plotted on a satellite map of the north/central New Mexico region. Once points were plotted, a color was assigned to each respective point based on the concentrations of char measured from the wipe samples collected within the residences. For the purpose of mapping (e.g., to get a wider distribution of sample points), final concentrations (per home) were determined by summing the concentrations of each of the three individual wipe results collected. In presenting the different concentrations in the map (Fig. 2), the following color scheme was utilized: green (<1% char detected); blue (1-4% char detected); yellow (5-9% char detected); and red (10-30% char detected). The results in Figure 2 illustrate that char was consistently measured above the 1 percent LOQ within the majority of homes sampled in areas located to the northeast, east, southeast and south of the Las Conchas fire.

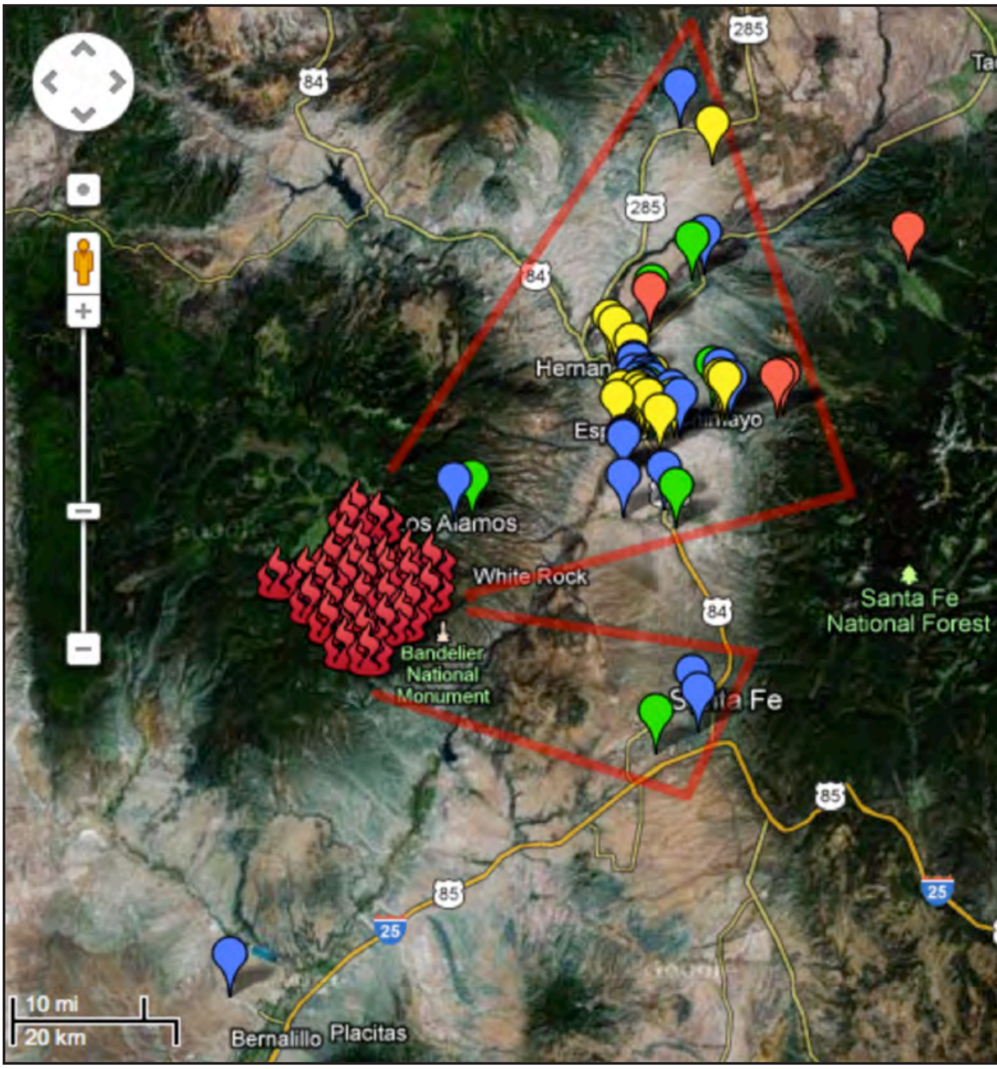
Discussions

The Impact of Smoke on Downwind Communities

Forest fire smoke is composed of a complex mixture of air pollutants in both particulate and gas-phases. Of the thousands of chemicals identified, many have well-documented adverse human health effects. Fine particulate matter ($PM_{2.5}$) is the largest pollutant in wood smoke and can travel hundreds of kilometers once emitted into the air, degrading local air quality even at great distances from forest fire locations (Gillies et al. 1996, Sapkota et al. 2005). During the summer months, the prevailing wind directions (direction with the highest percent of frequency) as measured by the Los Alamos meteorological monitoring site (near the Las Conchas fire) were from the south to the north (Western Regional Climate Center, 2012). The wind direction suggests that areas ranging from the west-northwest to the east-northeast of the fire were likely impacted by smoke at variable concentrations and frequency throughout the duration of the wildfire.

During forest fire events, smoke from the ambient air can penetrate the indoor environment, resulting in elevated, prolonged human exposures. Henderson et al. (2005) found that indoor $PM_{2.5}$ concentrations were 58–100% of the concentrations measured outdoors during one prescribed burn and three wildfires during the 2002 Colorado fire season. During 2002 Canadian forest fires, Sapkota et al. (2005) found that penetration of ambient $PM_{2.5}$ indoors during a smoke event was efficient (median indoor-to-outdoor ratio 0.91), such that the high ambient levels were similarly experienced indoors. Barn et al. (2008) measured infiltration rates in homes in British Columbia affected by summer forest fire smoke, concluding that a person remaining indoors gained little protection from outdoor smoke.

Prior to sample collection we hypothesized that the homes closest to the fire would have the greatest concentrations of char measured from the wipe samples compared to homes further from the fire. However, this was not the case (Fig. 2). Some of the homes closest to the fire (Los Alamos, ~10 km away) had minimal char measured within their homes (although one of these homes had already been cleaned by a restoration professional prior to sample collection), while homes furthest from the fire (>50 km) had elevated char concentrations. Statistically, there was not a



Note: green (<1% char detected); blue (1-4% char detected); yellow (5-9% char detected); and red (10-30% char detected).

Figure 2. Mapping of residential wipe sampling results.

strong correlation between distance from the wildfire and char concentrations measured within the homes. When comparing the two variables across all 64 homes, a correlation coefficient of 0.35 was calculated. Correlations between distance from the wildfire and char concentrations in homes within 30 km of the fire (n=38, communities of Los Alamos, La Mesilla, Espanola, Santa Cruz and Cuarteles) were small (correlation coefficient = 0.20). Statistically insignificant correlations occurred in homes greater than 30 km away from the fire (n=26, communities of San Juan Pueblo, Santa Fe, Fairview, Chimayo, Cordova, Chamita, Velarde, Alcalde, Rio Rancho, Penasco and Ojo Caliente), where a correlation coefficient of 0.25 was calculated.

A greater frequency of sampling was conducted in the Espanola area (~30 km from the fire) compared to the other communities. Results from the Espanola homes showed that the majority of residences tested positive for char. However, there were some homes in the vicinity that did not measure any char from the indoor wipe samples. This variability could be explained by residential behaviors within the homes. For example, some of the homeowners may have thoroughly cleaned or painted the indoor environment following the wildfire (and prior to wipe sample collection). In addition, physical building characteristics of the homes could explain some of the variability. This includes some homes being sealed tighter than others, preventing the penetration of ambient particles to the indoor environment. In addition, some of the homes could have utilized air filtration systems during the wildfire event. Unfortunately, none of these confounding variables were recorded during the wipe sampling program.

Effectiveness of Indoor Wipe Samples to Assess the Presence of Wildfire Smoke

In order to accurately assess indoor exposures, air sampling equipment is typically used by trained personnel to collect samples. To collect samples within a large number of homes, many sets of equipment would be needed, with a corresponding increase in equipment costs as well as the level of effort of sampling personnel. In addition, it is difficult to predict when and where a wildfire will occur and if smoke will be impacting indoor environments during the sampling program. Oftentimes the smoke plume passes directly over communities, while other times the communities and homes are directly impacted for extended periods of time. All of these factors underscore the difficulty in conducting wildfire smoke sampling in downwind communities and the need for a cheap, easy to use, reliable and efficient method of evaluating indoor smoke exposures.

In contrast to comprehensive air sampling programs, utilizing wipe samples (and analyzing for char and ash) is a simple and inexpensive way of determining if an indoor environment has been exposed to forest fire smoke. Wipe samples have been used in a variety of applications to measure contaminants from surfaces including those in buildings, homes, outdoor areas and hands (dermal wipes). Specifically, wipe samples have been used to test household surfaces for lead, airport luggage screening for explosives and post-remediation sampling of methamphetamine houses (USEPA 2007). However, there are some limitations to using this technique. Although wipe samples give a qualitative result indicating whether the indoor residence was infiltrated with forest fire smoke, it provides little information on actual human exposures that may have occurred within the homes. It also provides little information on actual exposure concentrations, length of exposures, etc. There are also other factors that can influence ash/char concentrations measured within a home, including home ventilation rates and surface cleaning activities.

Residential wood stoves or other combustion devices can also be a source of biomass smoke inside homes. During the routine operation of a wood stove, loading and stoking activities can release wood smoke particles inside the home (Ward et al. 2008). These residential heating wood smoke particles may be similar to those deposited (and subsequently measured) within the home during forest fire smoke events. Although wood stoves were present in a small number of homes (<5) sampled, their presence does not explain our overall findings of char in most houses.

Conclusions

There is a growing body of evidence from human and animal studies that suggest that exposure to wood smoke poses a risk to human health (Ezzati and Kammen 2002, Zelikoff et al. 2002, Lewtas 2007, Naeher et al. 2007). In addition to human health concerns, Moffett (2008) details the damaging impact that forest fire soot can have on the contents of a home. Suspended particles can penetrate upholstery, drapes and insulation and can also electrostatically adhere to electronic components. The chemical makeup (including acidity) of forest fire smoke particles can damage the contents of a home, causing discoloration, corrosion and overall damage (Moffett

2008). In addition to the corrosive properties of wood smoke, odors from forest fire smoke can also persist long after the smoke has cleared, causing an ongoing nuisance problem.

During the summer of 2011, smoke from the Las Conchas wildfire impacted downwind communities at varying frequencies and durations. Given that char was measured within 50 of the 64 homes that were investigated in this study, it is likely that additional homes in the surrounding areas were similarly impacted. As illustrated from the concentration gradient map we were unable to identify downwind areas that were completely free of smoke measured within homes (noted by the presence of char)(Fig. 2).

Although forest fires are a large source of $PM_{2.5}$ and other pollutants to the ambient environment, the impact on the indoor environment is often overlooked and misunderstood. This is concerning in that most people spend ~95 percent of their time indoors (Fishbein and Henry 1991, Jenkins et al. 1992). In homes impacted by smoke, there is also a concern about secondary and ongoing exposures within the home. Perhaps understated in previous reports, $PM_{2.5}$ that has settled indoors can be re-entrained into the air by even small disturbances, leading to continued human exposures inside the home. All of these factors suggest that in addition to concerns with smoke impacting the homes during the wildfire event, there are additional concerns regarding the indoor environment to consider even after the wildfire has been extinguished.

Assessing the impact of forest fire smoke on residential environments is important, whether it be in support of an insurance claim (to assess damages prior to restoration) or in estimating human wood smoke exposure and its effects on health. The use of wipe samples in this project demonstrated some of the advantages as well as the limitations of this technique. Wipe samples collected from areas downwind of the Las Conchas wildfire showed that the majority of the homes sampled measured char. However, results from this study cannot determine how much exposure each of the homes and residents received throughout the forest fire event. Given the practicality and lower expenses of the wipe sampling/analytical method, the findings from this project demonstrate that collecting wipe samples can be qualitatively used to assess $PM_{2.5}$ wildfire smoke impacts within homes in lieu of a more comprehensive and expensive residential air sampling program. In support of the wipe sampling program, an initial survey that controls for confounders (open burning outside the home, presence of wood stove or ventilation system, etc.) and an observational survey performed during wipe sampling to validate the lack or presence of confounders should be conducted in an effort to further explain overall findings.

Acknowledgements

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