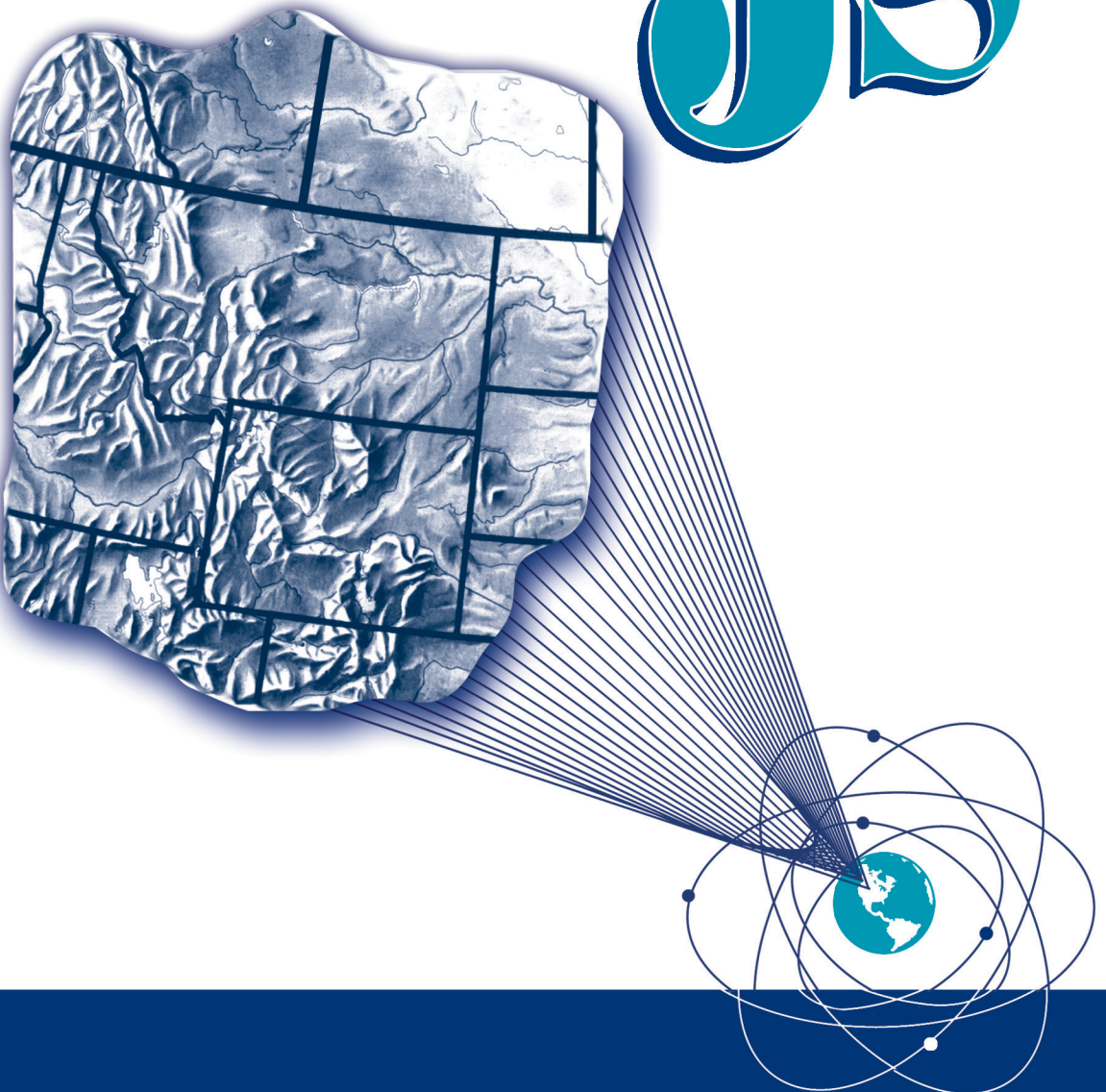


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IJS



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.

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FINANCIAL STATEMENT (1/01/10 - 12/31/10)

Balance 01/01/10	\$6,277.65
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Income:	
Regular Member	60.00
Student Member	6.00
Library Subscriptions	\$325.00
Life Member	300.00
Subscriptions Total	\$691.00
Page Charges	\$7,190.00
Reprints	\$491.07
Back Issue Sales	\$16.00
Total Income	\$8,388.07
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Expenses:	
Design and Printing	\$11,643.58
Postage	\$343.82
P. O. Box Rent	\$96.00
Administrative and Bank Fees	212.40
Reprints and Layout	792.69
Website Maintenance	89.86
Refund	25.00
Total Expenses	\$13,203.35
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Balance 12/31/10	\$1,462.37

Fred Nelson, Business Manager

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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 copy 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.

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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 Gary Dusek, the EIC (gnpdusek@msn.com), 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)

A TRACER INVESTIGATION OF PHEROMONE DISPERSION IN LODGEPOLE AND PONDEROSA PINE FOREST CANOPIES

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ABSTRACT

Tracer experiments were conducted in 2000 and 2001 to study spread of insect pheromone plumes in forest canopies. The field sites consisted of lodgepole pine (*Pinus contorta*) and ponderosa pine (*P. ponderosa*) canopies in 2000 and 2001, respectively. Ranges of temperature, wind speed, and turbulence conditions were similar in the two campaigns, and field data showed comparable variability on near-instantaneous time scales of wind speed, wind direction, and plume behavior. We developed simple empirical equations to estimate average horizontal and vertical plume spread as functions of standard turbulence statistics, downwind distance from the source, and wind speed. For horizontal plume spread, predicted dispersion coefficients were within a factor of 3, or better, for 97 percent of the observed values in the combined dataset from 2000 and 2001. Likewise, 99 percent of the predicted vertical dispersion coefficients were within a factor of 3 of the observed data.

Key words: average plume spread, bark beetles, *Dendroctonus*, dispersion coefficients, forest canopy, mountain pine beetle, pheromones, tracer experiments

INTRODUCTION

Bark beetle populations are currently distressing forests throughout the Rocky Mountain region and elsewhere. Tree mortality attributed to bark beetles in the western United States increased from ~ 1.4 million ac in 1997 to 10.7 million ac in 2003 (USDA Forest Service 2004). In Montana forests alone, beetle-caused mortality was estimated at 820,400 ac in 2005 (USDA Forest Service 2006) and at 1.9 million ac in 2008 (USDA Forest Service 2009a).

Lodgepole pine (*Pinus contorta*) and ponderosa pine (*P. ponderosa*) serve as hosts for bark beetles (Hicke et al. 2006), and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has been linked to major infestations in the United States (USDA Forest Service 2000, 2004, 2006, 2009b). Mountain pine beetles are

considered as “aggressive” species because they attack and kill living trees (Byers 1996).

Bark beetles and other insects communicate using gaseous semiochemicals known as “pheromones.” The USDA Forest Service and others have developed techniques of pest control using natural and synthetic pheromones as alternatives to traditional insecticides (Suckling 2000, Bentz et al. 2005). Proper application and effectiveness of pheromones for pest control, however, require a fundamental understanding of the transport and diffusion of gases through forest canopies (Aylor 1976, Farrell et al. 2002). In addition, quantifying absolute concentrations of pheromones in the field is difficult (Van der Pers and Minks 1993, Thorpe and Tcheslavkaia 2001); hence, we have been

using tracers to study short-term diffusion and time-averaged dispersion of gaseous plumes in a variety of forest types (Peterson et al. 2004, Smith et al. 2004, Strand et al. 2009, Thistle et al. 2002a, 2002b, and 2004).

This is the second in a series of Intermountain Journal of Sciences papers regarding recent research efforts to understand and model behavior of insect pheromones in forest canopies. Previously, Peterson et al. (2004) described tracer experiments conducted during July 2000 at the Potomac site, a lodgepole pine forest located in western Montana. Winds in the canopy were erratic, and diffusion patterns were intermittent and complex on instantaneous time scales. Time-averaged plume profiles were approximately Gaussian in shape, and a simple empirical equation was developed to relate average horizontal plume spread to 3-dimensional wind data measured at the source.

In particular, the horizontal dispersion coefficient (σ_y) was estimated as:

$$\sigma_y = 2.06(\sigma_u^2 + \sigma_v^2)^{0.5} \frac{X}{U} \quad (1)$$

Where σ_y represented the standard deviation of a Gaussian plume profile in the horizontal direction; σ_u and σ_v were standard deviations of wind speed in the horizontal u and v directions; X was downwind distance from the tracer or pheromone source; and U was average wind speed. In this equation, we measured wind speed and turbulence statistics at source height, and the 2.06 factor was empirically determined from a subset of six experiments. Predicted σ_y values were then compared to observed data for 158 plume profiles. Approximately 96 percent of the predicted dispersion coefficients were within a factor of 2 of the observed values, and 99 percent were within a factor of 3.

The remainder of this paper addresses two important research needs. First, microclimates in canopies are complex and influenced by factors such as tree density and vertical forest structure (Thistle et al. 2004, Strand et al. 2009). As illustrated by

our tracer data, wind speed and turbulence at the source play an important role in affecting dispersion on scales studied here; however, Equation 1 was developed and tested in a lodgepole pine forest; thus, it is necessary to evaluate performance for additional canopy types. Second, for modeling purposes, vertical spread of pheromone plumes must also be characterized.

STUDY AREAS

As described in Peterson et al. (2004), we conducted field experiments in July 2000 amid a lodgepole pine forest located ~ 16 km east of Missoula, Montana. Elevation of the Potomac site was 1200 m above sea level. The stand was uniform with an average height of 30 m and a density of 1521 stems/ha with little or no underbrush. Based on data from a plant canopy analyzer (PCA), the average leaf area index (LAI) for the Potomac site ranged 0.8-3.3 with an average of 2.18; based on the hemispheric photographic technique (HPT), LAI ranged 1.0-6.1 with an average of 2.50.

During June 2001, the experimental site was a forested area ~ 50 km south of Bend, Oregon. Elevation at LaPine was 1450 m. The canopy consisted of ponderosa pine with an average height of 35 m and a density of 389 stems/ha. The vertical structure of the site included large gaps in the canopy with underbrush as high as 1.5 m (Strand et al. 2009). During the LaPine campaign, ranges of LAI measurements were 1.1-3.2 and 2.1-6.4 from the PCA and HPT, respectively; and the corresponding average LAI values were 1.8 and 3.3.

METHODS AND MATERIALS

Equipment and experimental layouts were similar for the Potomac and LaPine campaigns. Sulfur hexafluoride (SF_6) was the tracer gas used to simulate a generic insect pheromone in both studies. At a height of 1.2 m above the ground, SF_6 emitted from the center of an array of air sampling units arranged in three concentric circles with radii of 5, 10, and 30 m. We designed these source and sampling locations with the goal

of reproducing pheromone diffusion in the trunk space of the canopy on scales similar to bark beetle attacks, and both experimental sites included buffer zones to minimize microclimate responses due to edge effects (Gehlhausen et al. 2000).

Most of the samplers were deployed at a height of 1.2 m above the ground to characterize the horizontal spread of the plume; however, some were elevated to capture vertical concentration profiles. During the Potomac campaign, for example, samplers were elevated at heights of 2.4 and 4.1 m along the 10-m arc at azimuths of 0 and 180°. In LaPine, additional sampling units were allocated for capturing vertical plume profiles at a height of 4.1 m on the 5-m arc at azimuths of 90 and 270°, and at heights of 4.1 and 7.5 m along the 10-m arc at azimuths of 0, 90, 180, and 270°.

Air samplers used in this research were based on the design of Krasnec et al. (1984) with 30-cc hypodermic syringes to collect air samples. Over a period of 4.5 hr/day, the sampling units simultaneously deployed nine sequential syringes at a rate of 30 min/syringe. After the ninth test each day, we quantified tracer concentrations in the syringes using a calibrated, fast-response SF₆ analyzer with an electron capture detector (Benner and Lamb 1985).

In addition to 30-min average concentrations in the syringe samples, a fast-response SF₆ analyzer measured near-instantaneous concentrations in the field at a rate of 1 Hz. We placed this analyzer within the sampling array along the 5- or 10-m arcs with an inlet height of 1.2 m.

For characterizing winds during the tests, a 3-dimensional sonic anemometer operated in the center of the sampling array at a height of 1.2 m, and three anemometers were installed on a tower at heights of 1.5, 14.5, and 24.9 m above the ground. In all cases, anemometer sampling rate was 10 Hz.

RESULTS

Regarding meteorological conditions throughout the two studies, ranges of ambient temperature at the source locations were similar (280-300 K and 281-303 K for

the Potomac and LaPine sites, respectively); ranges of average wind speed at the 1.2-m height were 0.17-1.11 m s⁻¹ and 0.25-1.63 m s⁻¹. General trends for both campaigns followed the insolation cycle with cooler temperatures and lower wind speeds occurring during morning hours with maxima in afternoon (Fig. 1); however, LaPine data exhibited more variability than the Potomac data.

Standard deviation of wind speed is a measure of atmospheric turbulence. In particular, σ_u and σ_v are indicators of horizontal eddying motions in the airflow passing over a sensor, and σ_w is an indicator of vertical air movements. Again, variability at LaPine was greater than at Potomac, but features were quite similar with lowest levels of turbulence in early morning (Fig. 2). Following onset of convection, turbulence statistics increased 2-5 times by mid afternoon. In terms of magnitudes, horizontal wind fluctuations were about twice the levels of vertical turbulence in the canopy.

Table 1 describes test conditions for one day (21 Jun 2001) during the LaPine study. The lowest average wind speed was 0.77 m s⁻¹ at 1030 PDT, and the highest was 1.24 m s⁻¹ at 1300 PDT. In terms of turbulence statistics, the smallest σ_u , σ_v , and σ_w values were observed during the first tests of the day, and the largest were observed during the last tests.

Figure 3 illustrates example data for Period 6 on 21 June 2001 (Test L621P6). Wind speed varied between 0 and 4 m s⁻¹ during the 30-min test (Fig. 3a), and wind direction fluctuated with several dramatic changes of $\geq 360^\circ$ over short time scales (Fig. 3b). Based on the fast-response SF₆ analyzer located along the 10-m arc at a receptor angle of 90°, instantaneous exposure was intermittent as the narrow plume passed back-and-forth across the receptor, primarily during the first 10 min of the test (Fig. 3c). In agreement with most experiments in the LaPine and Potomac campaigns, average plume profiles along the 5- and 10-m arcs were nearly Gaussian in shape (Fig. 3d).

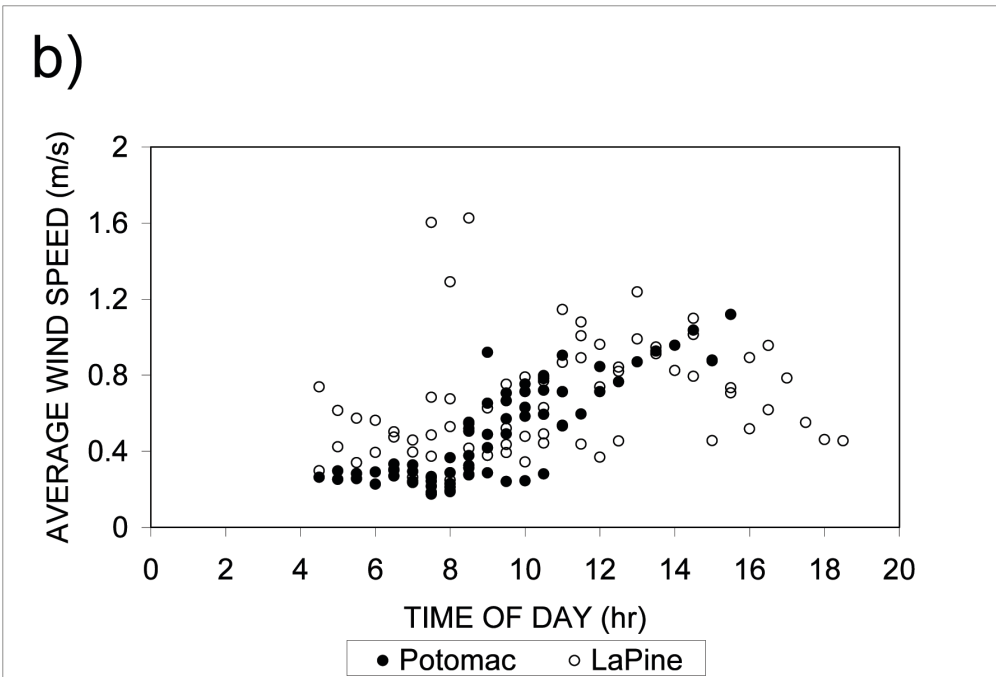
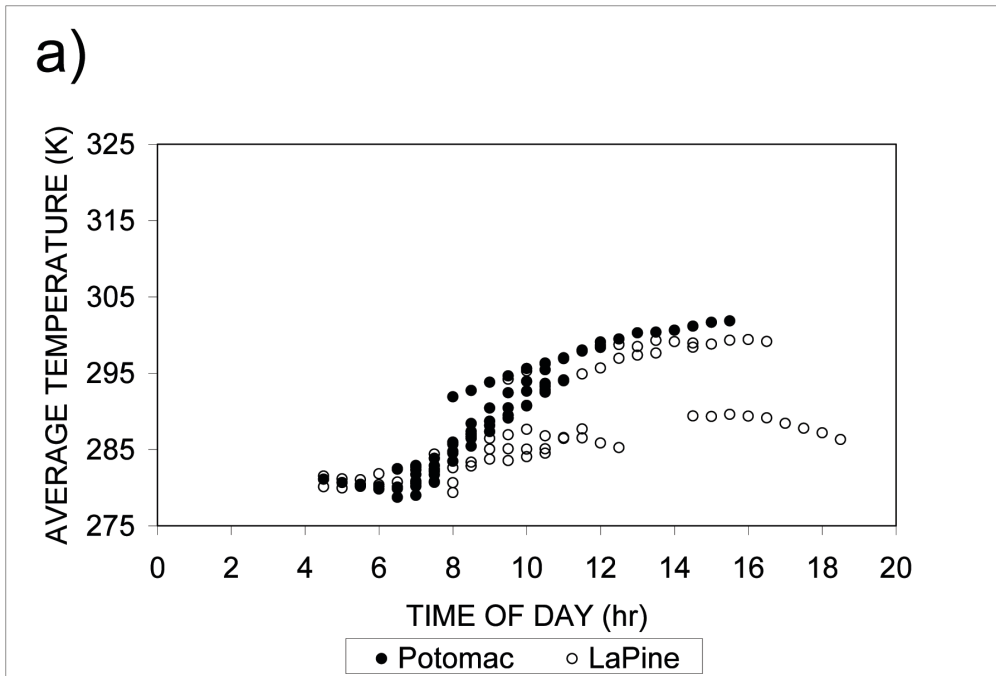


Figure 1. Meteorological conditions of a) average temperature and b) wind speed versus time of day during the Potomac and LaPine campaigns of 2000 and 2001, respectively.

We tested the ability of Equation (1) to predict average plume spread in the LaPine study, and compared results to the Potomac study. Equation 1 tended to overestimate σ_y in the LaPine study more

frequently compared to the Potomac study (Fig. 4) probably because of higher levels of turbulence in the canopy, but most of the data fell within the 3:1 and 1:3 lines of correspondence. More specifically, the

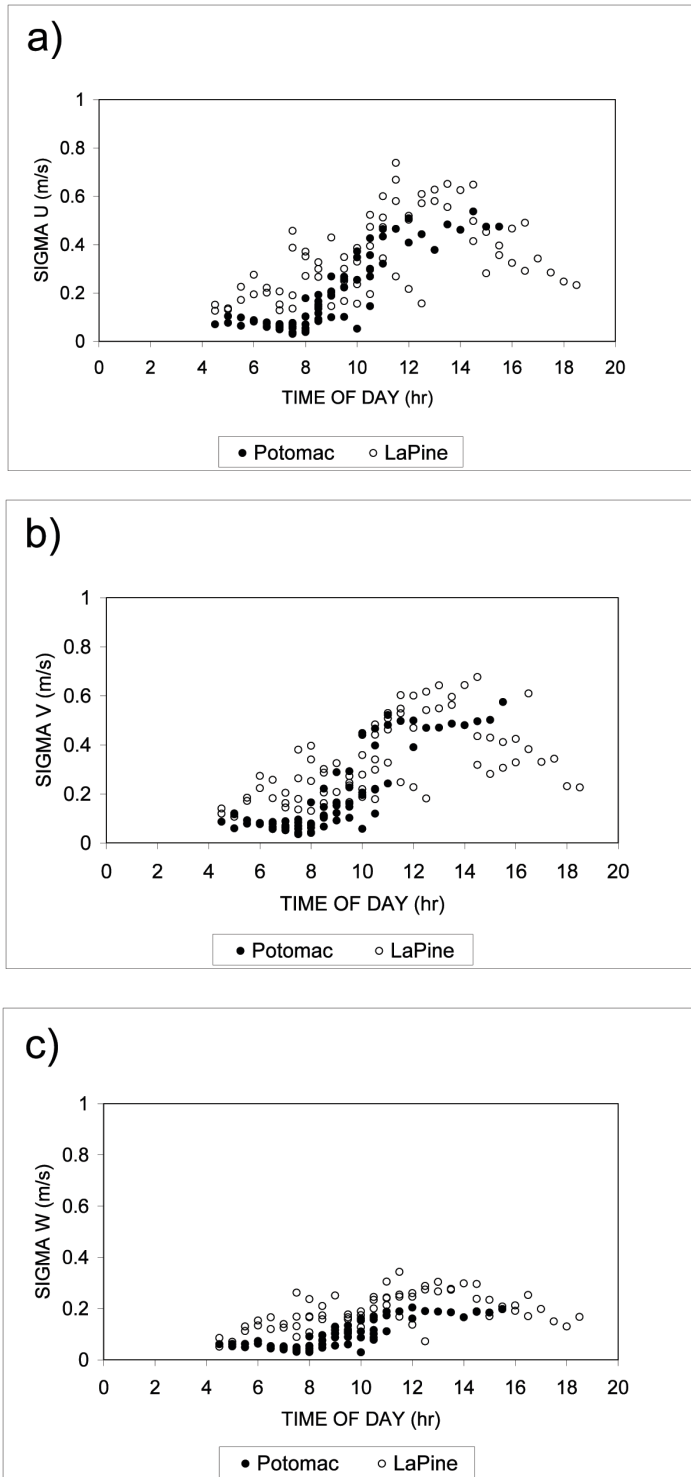


Figure 2. Standard deviation of wind speed versus time of day for the a) horizontal u component, b) horizontal v component, and c) vertical w component for the Potomac and LaPine campaigns of 2000 and 2001.

Table 1. Test Conditions on 21 June 2001 of the LaPine Field Experiments

Test	Date	Start Time	U	σ_u	σ_v	σ_w	T	Q_{SF_6}
	(D/M/YR)	(PDT)	(m s ⁻¹)	(m s ⁻¹)	(m s ⁻¹)	(m s ⁻¹)	(K)	($\mu\text{g s}^{-1}$)
L621P1	21/06/2001	1030	0.77	0.39	0.34	0.17	297.2	84
L621P2	21/06/2001	1100	1.15	0.47	0.46	0.24	297.7	84
L621P3	21/06/2001	1130	1.08	0.58	0.53	0.25	298.4	147
L621P4	21/06/2001	1200	0.74	0.52	0.60	0.26	299.1	146
L621P5	21/06/2001	1230	0.84	0.61	0.62	0.29	299.5	146
L621P6	21/06/2001	1300	1.24	0.58	0.55	0.27	299.2	146
L621P7	21/06/2001	1330	0.91	0.56	0.60	0.27	299.4	146
L621P8	21/06/2001	1400	0.82	0.63	0.64	0.30	299.7	146
L621P9	21/06/2001	1430	1.10	0.65	0.68	0.30	299.8	146

Test duration - 30 min

U - average wind speed

σ_u - standard deviation of horizontal wind speed in the u direction

σ_v - standard deviation of horizontal wind speed in the v direction

σ_w - standard deviation of vertical wind speed in the w direction

T - ambient temperature

Q_{SF_6} - release rate of tracer gas

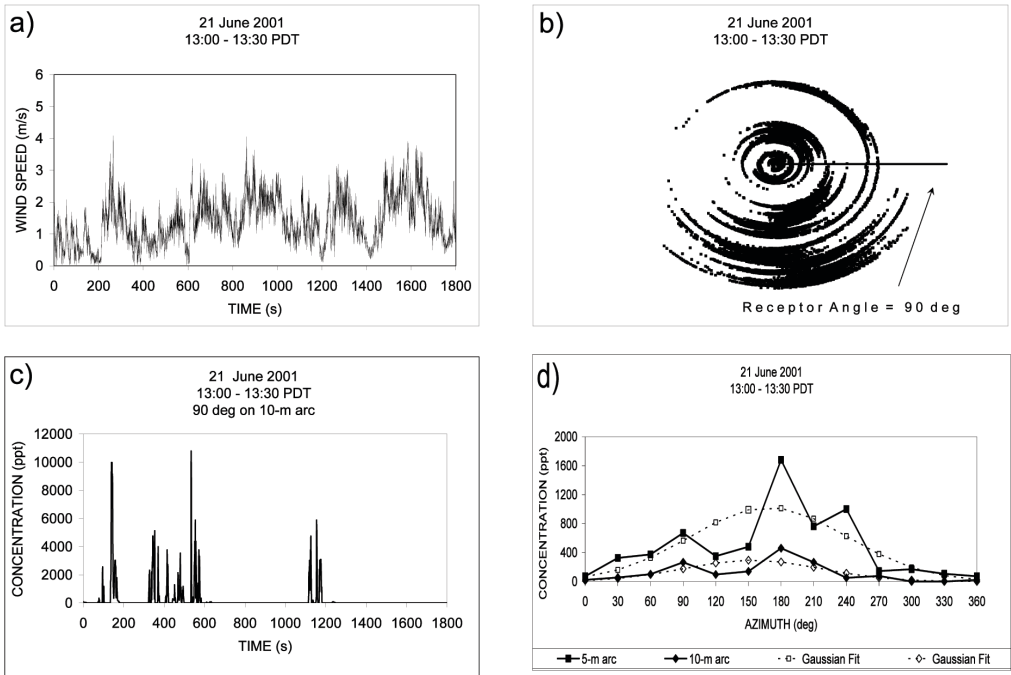


Figure 3. Measurements of a) wind speed and b) wind direction, c) instantaneous concentration, and d) average concentration profiles during Test L621P6 of the LaPine study.

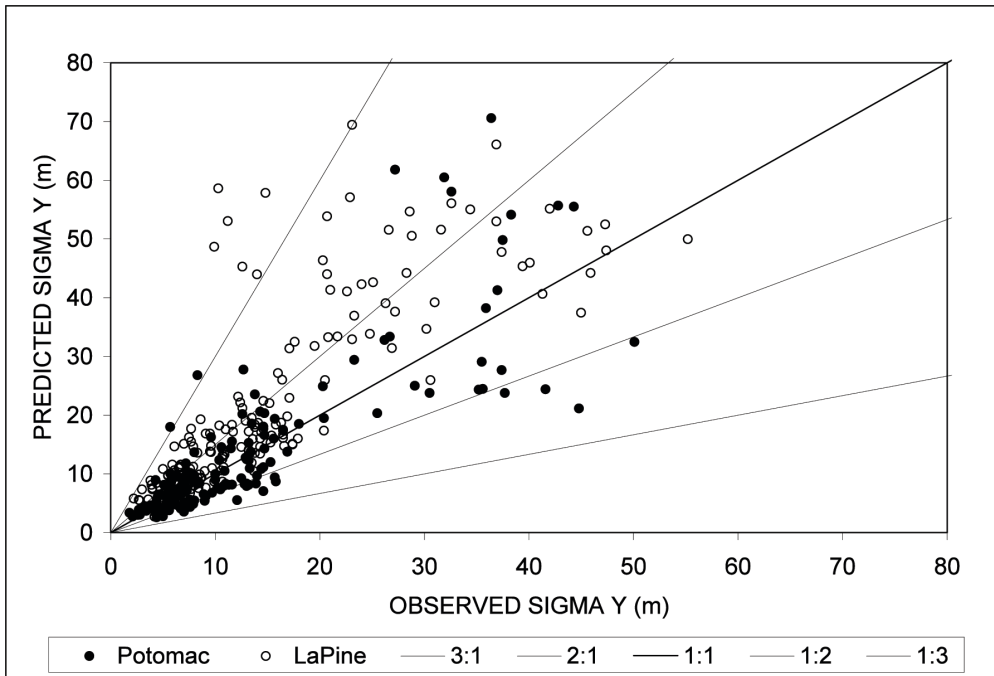


Figure 4. Predicted horizontal dispersion coefficients from Equation (1) versus observed values for the datasets from the Potomac and LaPine field campaigns. Also shown are the 3:1, 2:1, 1:1, 1:2, and 1:3 lines-of-correspondence.

average predicted-to-observed ratio (P:O) was 1.46 for LaPine data, and 88.6 and 96.5 percent of the predicted values were within a factor of 2 and 3, respectively, of the observed values. The combined dataset of 361 profiles resulted in an average P:O of 1.29 with a standard deviation of 0.61. In addition, 93.1 percent of the predicted values were within a factor of 2 of the observed data, and with 97.5 percent within a factor of 3.

Based on these results, our simple approach provided realistic estimates of average horizontal dispersion rates for the range of conditions tested at the Potomac and LaPine sites. Vertical dispersion of pheromone plumes, however, is also important for modeling purposes. Applying a technique similar to the method developed for horizontal dispersion (Peterson et al. 2004), we examined vertical dispersion for a subset of tests from the LaPine dataset.

Figure 5 depicts vertical concentration profiles along the 10-m arc for Test L621P6. Most of the sampler data inferred

concentrations decreasing with height in a Gaussian manner; thus, vertical dispersion coefficients (σ_z) were calculated as follows:

$$\sigma_z = \frac{(Z_2 - Z_1)}{\left(-2.0 \ln \frac{C_2}{C_1}\right)^{0.5}} \quad (2)$$

where C_1 and C_2 were concentrations measured at heights Z_1 and Z_2 , respectively. Individual σ_z values ranged 2.34-4.88 m (Table 2). Because airflow in a forest canopy is not homogeneous, we expect some variation in σ_z and the average coefficient for data collected during Test L621P6 was 3.15 m with a standard deviation of 0.92 m.

Similar to horizontal dispersion data in Peterson et al. (2004), our tracer plumes spread vertically with increasing downwind distance, and a regression of the data resulted in the following empirical equation to predict an average vertical dispersion coefficient as a function of the vertical

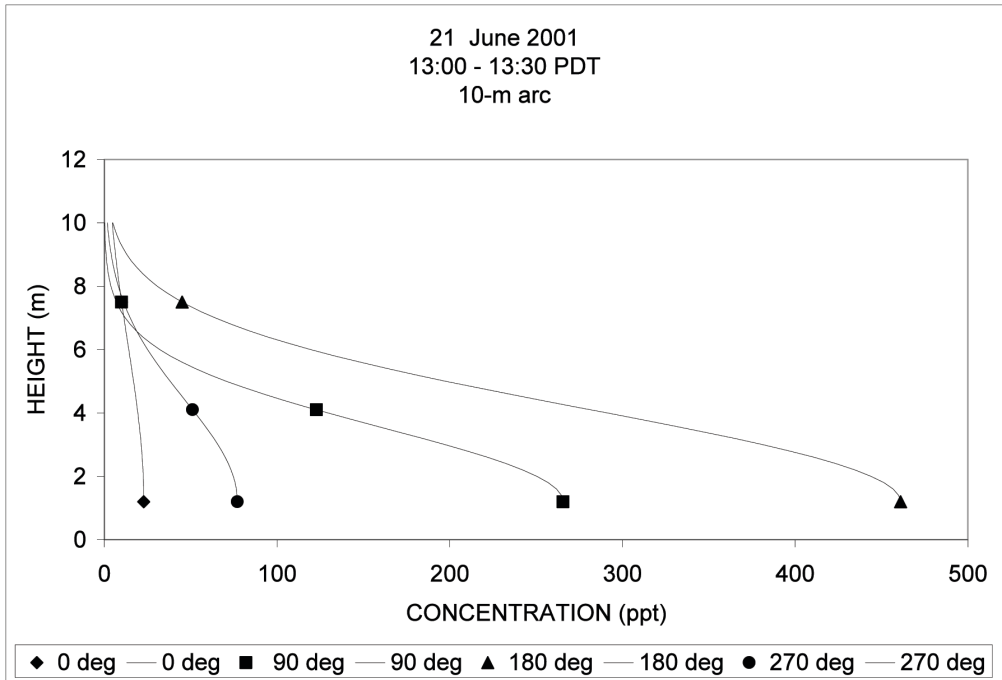


Figure 5. Vertical concentrations along the 10-m arc at azimuths of 0, 90, 180, and 270 deg for Test L621P6 of the LaPine study. Shown are sampler data and Gaussian profiles generated with calculated σ_z values.

Table 2. Vertical Dispersion Data on 10-m Arc for LaPine Test L621P6

Azimuth (deg)	Height Z (m)	Concentration (ppt)	Profile σ_z (m)	Average σ_z \pm std dev (m)
0	1.2	23		
0	7.5	10	4.88	
90	1.2	266		
90	4.1	123	2.34	
90	7.5	10	2.46	
180	1.2	461		
180	7.5	45	2.92	
270	1.2	77		
270	4.1	51	3.20	
270	7.5	10	3.12	
				3.15 \pm 0.92

Profile σ_z – Vertical dispersion coefficient as calculated using Eq. (2)

turbulence statistic (σ_w), downwind distance (X), average wind speed (U):

$$\sigma_z = 1.21\sigma_w \frac{X}{U} \quad (3)$$

where R² was 0.56 for the nine tests on 21 June 2001. In this case, predicted and observed dispersion coefficients were within 0.08 m at best, and within 1.12 m at worst, for the 5-m and 10-m arcs (Table 3). In addition, Equation (3) predicted similar temporal changes of σ_z during the nine, sequential, half-hour periods on 21 June 2001.

To test the method against other dispersion measurements, we compared predicted σ_z values from Equation (3) to data from 131 profiles within the LaPine dataset and 56 profiles within the Potomac dataset (Fig. 6). On average, this method tended to overestimate σ_z for the 10-m arc with average P:O values of 1.24 and 1.42 for LaPine and Potomac, respectively, as compared to an average P:O of 1.05 for the 5-m arc. However, 82.1-89.4 percent of the

predicted data were within a factor of 2 of the observed values, and 98.5-100 percent were within a factor of 3. The combined dataset of 187 profiles resulted in an average predicted-to-observed ratio of 1.17 with a standard deviation of 0.50. In addition, approximately 87 and 99 percent of the predicted coefficients were within a factor of 2 and 3, respectively.

CONCLUSIONS

In this paper, we examined dispersion in bark beetle habitats for two canopy types with different conditions of stand density and vertical forest structure. Dispersion coefficients in the horizontal and vertical directions were modeled as functions of wind speed and turbulence statistics measured at the source. When tested against field data, Equation (1) predicted within a factor of 2 for 93 percent of the observed profiles for horizontal dispersion, and within a factor of 3 for 97 percent of the cases. Likewise, for vertical dispersion, Equation (3) predicted values within a factor of 2 in 87 percent of the observed profiles, and within a factor of 3 in 99 percent of

Table 3. Vertical Dispersion Data on 21 June 2001 of the LaPine Field Experiments

Test	σ_z-5m (m)	σ_z-5mp (m)	σ_z-10m (m)	σ_z-10mp (m)
L621P1	1.74	1.33	2.84	2.66
L621P2	1.81	1.28	3.18	2.56
L621P3	1.54	1.37	2.83	2.75
L621P4	1.83	2.12	3.67	4.25
L621P5	1.82	2.06	3.00	4.12
L621P6	1.97	1.30	3.16	2.60
L621P7	2.46	1.80	3.28	3.61
L621P8	2.66	2.18	3.99	4.36
L621P9	1.81	1.62	3.98	3.25

σ_z-5m - Observed vertical dispersion coefficient along the 5-m arc

σ_z-5mp - Predicted vertical dispersion coefficient along the 5-m arc using Eq. (3)

σ_z-10m - Observed vertical dispersion coefficient along the 10-m arc

σ_z-10mp - Predicted vertical dispersion coefficient along the 10-m arc using Eq. (3)

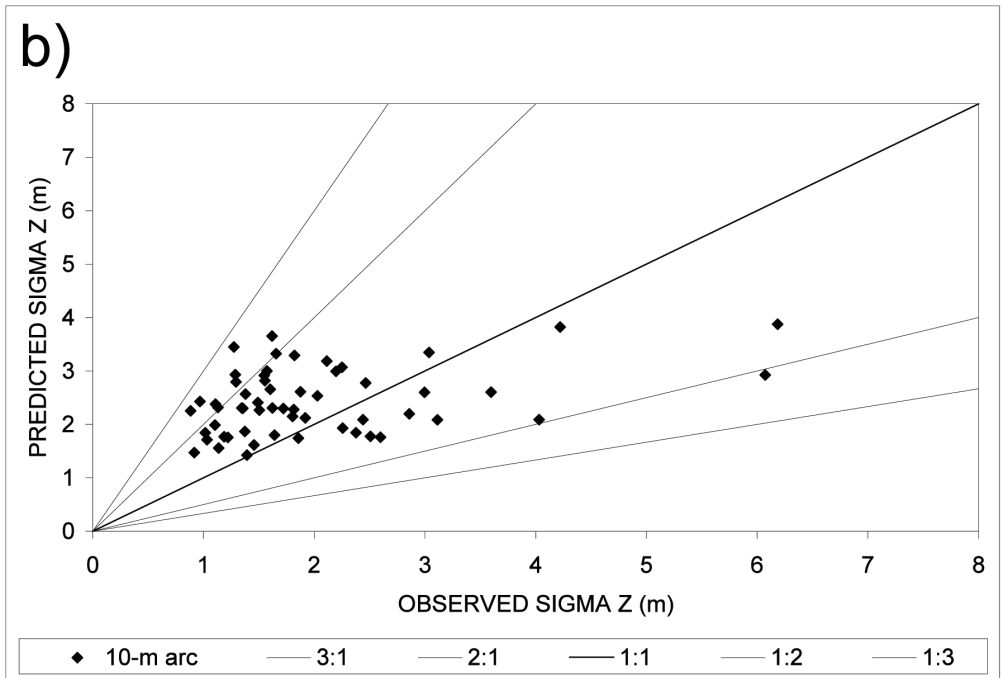
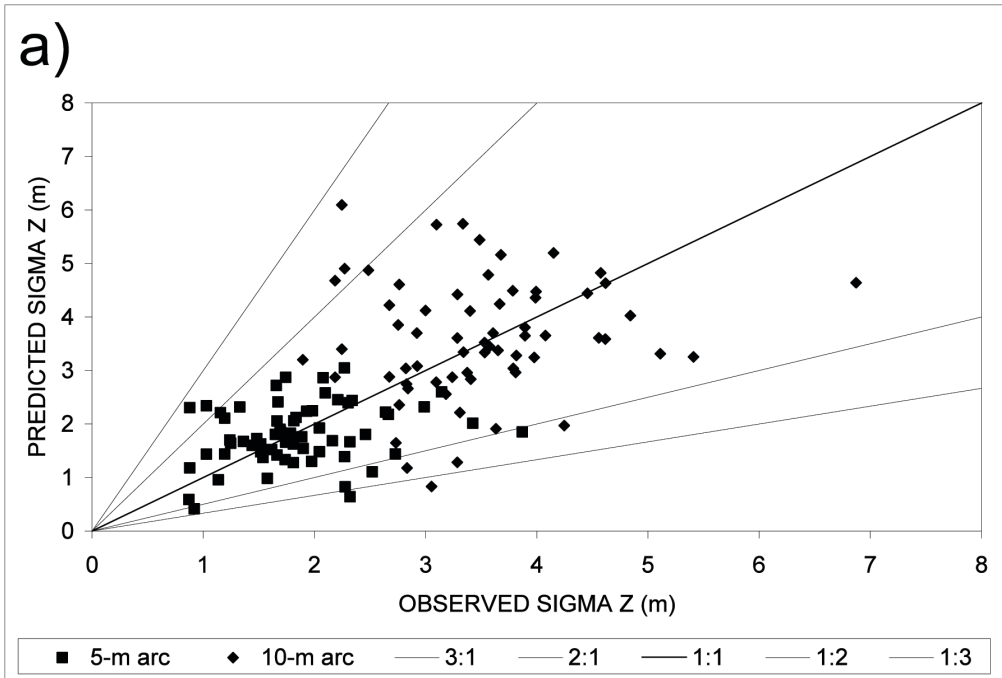


Figure 6. Predicted vertical dispersion coefficients from Equation (3) versus observed values for the datasets from the a) LaPine and b) Potomac field campaigns. Also shown are the 3:1, 2:1, 1:1, 1:2, and 1:3 lines-of-correspondence.

the cases. Even though canopy conditions were dissimilar at the two sites, we were able to model plume spread using the same empirical equations. This conclusion led directly to the question addressed in our next paper in this series: how do changes in stand density at a particular site affect microclimate and dispersion of insect pheromones?

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PLUME DISPERSION IN FOUR PINE THINNING SCENARIOS: DEVELOPMENT OF A SIMPLE PHEROMONE DISPERSION MODEL

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ABSTRACT

A unique field campaign was conducted in 2004 to examine how changes in stand density may affect dispersion of insect pheromones in forest canopies. Over a 14-day period, 126 tracer tests were performed, and conditions ranged from an unthinned loblolly pine (*Pinus taeda*) canopy through a series of thinning scenarios with basal areas of 32.1, 23.0, and 16.1 m²ha⁻¹. In this paper, one case study was used to visualize the nature of winds and plume diffusion. Also, a simple empirical model was developed to estimate maximum average concentration as a function of downwind distance, travel time, wind speed, and turbulence statistics at the source location. Predicted concentrations from the model were within a factor of 3 for 82.1 percent and 88.1 percent of the observed concentrations at downwind distances of 5 and 10 m, respectively. In addition, the model was used to generate a field chart to predict optimum spacing in arrays of anti-aggregation pheromone dispensers.

Key words: Pheromones, tracer experiments, forest canopy, stand density

INTRODUCTION

Recent outbreaks of bark beetles in North America have focused interest on forest management to prevent large-scale infestations by improving forest health. Twenty-five years ago, Nebecker and Hodges (1985) discussed thinning as a technique to reduce tree mortality caused by southern pine beetle (*Dendroctonus frontalis* Zimmermann). Today, however, mechanisms by which this occurs are still not understood, but they probably consist of multiple, perhaps even synergistic, factors.

Tools for managing bark beetles and their habitats continue to be developed, especially those that use a group of semiochemicals known as “pheromones” to manipulate beetle behavior (Werner and Holsten 1995). There have been many successful applications of semiochemicals

to manage beetles and many failures (Shea et al. 1992, Amman 1993, Borden 1995). Causes of failures remain largely unexplored, but bark beetle communication systems are complex, involving insect and host physiology, pheromone chemistry, and microclimate processes in the forest stand. An increased understanding of how meteorological variables behave in a forest canopy, and in turn, how they are affected by changes in stand density, will undoubtedly improve the ability of forest managers to mitigate forest damage from these important pests.

BACKGROUND

In lieu of research initiated in the late 1970s and early 1980s, mitigation efforts that emphasize thinning of pine stands have recently been renewed. In fact, guidelines

to reduce residual stand densities now exist and are a cornerstone of current prevention programs (Nowak and Kleipzig 2007). Although mechanisms through which thinning reduces tree mortality are not completely clear, changes in the dispersion of pheromone plumes possibly play an important role.

All tree-killing bark beetles must attack a host *en masse* to reproduce. This requires “aggregation” of beetles to a source tree, a process directed by a suite of attractive semiochemicals (Geiszler et al. 1980). One type of management strategy to reduce tree attack is to use anti-aggregation pheromones. Holsten et al. (2003), for example, released 3-methyl-2-cyclohexen-1-one (MCH), a synthetic anti-aggregation pheromone of the spruce beetle (*Dendroctonus rufipennis* Kirby), in a forest canopy in south-central Alaska. The experimental design consisted of 25 MCH-dispensing devices deployed in a 5 by 5 array with 9-m spacing. The MCH release rate of each dispenser was 2.6 mg day^{-1} ($0.03 \text{ } \mu\text{g s}^{-1}$), and results at the end of the summer showed 87 percent decrease in tree attacks by the spruce beetle. Because airflow and turbulence conditions may be dramatically different elsewhere, the experimental design of Holsten et al. (2003) might not have been as effective if they had conducted the experiment in a different forest canopy. In other words, for widespread application of this type of management strategy, a better understanding of plume dispersal patterns is necessary for optimizing pheromone release rates and/or for deciding on spacing and required number of pheromone dispensers for a field site.

Fares et al. (1980) used Gaussian modeling to describe pheromone dispersion in a forest, and Elkinton et al. (1987) evaluated the utility of time averaged models to this end. More recently, Farrell et al. (2002) created a model including high frequency dispersion of pheromone plumes, and Strand et al. (2009) developed a puff model to describe in-canopy pheromone movement on near-instantaneous time frames. Dispersion in a realistic plant

canopy is complicated on many levels, however, and modeling efforts remain to be a challenge (Edburg 2005).

While modeling has helped, most of what we understand about plume dispersion in forest canopies has been determined experimentally. In addition to our previous campaigns (Thistle et al. 2004, Peterson et al. 2004), others have studied in-canopy plumes in a variety of forest types (Aylor 1976, Aylor et al. 1976, Murlis and Jones 1981). This paper addresses one important question that has not been studied extensively in the field: how do changes in stand density affect dispersion of semiochemicals on near-source scales? Another related question is: can we take stand density and/or plume dispersion into consideration and develop tools for improving the success of field applications involving anti-aggregation pheromones?

EXPERIMENTAL DESIGN

Similar to the campaigns described by Thistle et al. (1995, 2004) and Peterson et al. (2004), we conducted field experiments for this project using sulfur hexafluoride (SF_6) as a tracer to simulate a generic insect pheromone. The configuration was to surround a point source of SF_6 with a dense array of air samplers and to monitor meteorological conditions.

Sulfur hexafluoride gas was chosen as the tracer gas because SF_6 is non-toxic, non-radioactive, with low detection limits in the parts-per-trillion (ppt) range. Also, a large body of scientific literature exists including examples of SF_6 as a gaseous tracer in the field of air pollution (i.e., Peterson and Lamb 1992, 1995, Peterson et al. 1990, 1999, 2003). Sulfur hexafluoride is conservative (non-reactive) in the atmosphere over the short distances studied here.

Throughout the experiments, we released a continuous stream of SF_6 from a gas cylinder through a mass flow controller. Release height in the trunk space was 1.2 m above the ground, and to investigate dispersion of SF_6 in our experiments, we deployed 50-60 sampling units based on the design of Krasnec et al. (1984). Each

sampler collected nine sequential samples of air in 30-cc syringes with an averaging time of 30 min/syringe; thus, each trial day lasted 270 min (4.5 hr). By conducting experiments on 14 trial days in May of 2004, we acquired data for 126 individual (30-min) tests.

For the receptor array, we positioned samplers in concentric circles around the SF₆ source at radial distances of 5, 10, and 30 m. We located samplers every 30° of the compass along the 5-m arc, and every 15-30° along the 10-m and 30-m arcs. Most of the samplers operated at a height of 1.2 m above the ground, but we also positioned elevated samplers at 4.0- and 7.6-m heights every 90° along the 5- and 10-m arcs, respectively.

In addition, we operated a calibrated, fast-response SF₆ analyzer based on the design of Benner and Lamb (1985) at one location along the sampling array, usually along the 10-m arc. At a height of 1.2 m above the ground, real-time concentration data were collected at a frequency of 1 Hz. Following each trial day, another calibrated SF₆ analyzer measured time-averaged concentrations in the syringe samples.

In terms of meteorological equipment, 3-dimensional sonic anemometers (ATI, Longmont, Colorado) collected wind vector and turbulence data at a rate of 10 Hz throughout the study. The anemometers were deployed in a vertical profile on a meteorological tower with one instrument in the trunk space at a height of 2.6 m above the forest floor, one near the vertical canopy density maximum at a height of 16.6 m, and one near the average canopy top (22.9 m). A fourth sonic anemometer was co-located with the SF₆ source at a height of 1.2 m in the center of the sampling array. Net radiation (R.E.B.S, Seattle, WA) was also measured.

Regarding forest characteristics in a canopy, leaf area index (LAI) is a unitless term defined as “the total one-sided area of leaf tissue/unit ground surface area” (Breda 2003). For this campaign we made leaf area measurements using two methods. The plant canopy analyzer (PCA) method estimates

foliage amounts based on the attenuation of diffuse sky radiation as it passes through the canopy. The LI-COR 2000 Plant Canopy Analyzer (LI-COR, Inc. Lincoln, Nebraska) measures light attenuation at five zenith angles. Due to concerns about the accuracy of the PCA, especially in coniferous canopies, we also employed the hemispherical photographic technique (HPT) of Evans and Coombe (1959). Stem maps were created and basal area (with units of m² ha⁻¹) was measured for each stand condition.

EXPERIMENTAL SITE

The forested site for the field campaign (31° 53' 23.3" N, 92° 50' 39.9" W) was located in the Winn District, Kisatchie National Forest, outside of Winnfield, LA. Local terrain was level with a dirt road adjacent to the site to the northeast. The canopy consisted of an overgrown loblolly pine (*Pinus taeda*) plantation with canopy top between 15 and 25 m in height with an average of 20 m.

The tracer campaign consisted of 14 trial days reflecting four canopy scenarios (Table 1). We conducted Trials 1-4 in the original (unthinned) forest conditions. After the deciduous understory was removed from the site over an area of about 1.13 ha, Trials 5-7 were run in the canopy with a basal area of 32.1 m² ha⁻¹. The canopy was then thinned again, this time to a basal area of 23.0 m² ha⁻¹, and three more tests were performed (Trials 8-10). After the final thinning, the last four trials (11-14) corresponded to a basal area of 16.1 m² ha⁻¹.

RESULTS

Canopy Metrics

The plant canopy analyzer estimated average leaf area index values ranging from 3.71 in the unthinned canopy to 1.47 after the third thinning, and the hemispheric photographic technique produced average LAI values between 3.18 and 1.08 (Table 1). The resulting thinning ratios for our three successive stages in the campaign were similar for both methods (0.71, 0.53,

Table 1. Canopy Data

Canopy Description	Trail Days			
	1-4 Lobloly Pine (unthinned)	5-7 Lobloly Pine with understory removed (1st thinning)	8-10 Lobloly Pine (2nd thinning)	11-14 Lobloly Pine (3rd thinning)
Basal Area (m ² ha ⁻¹)	--	32.1	23.0	16.1
Density (stems ha ⁻¹)*	1219	975	569	325
LAI Measurements from PCA				
Range	3.2-4.7	2.0-3.3	1.6-2.5	1.0-2.0
Average	3.71	2.63	1.98	1.47
Standard Deviation	0.34	0.31	0.19	0.26
Thin Ratio	1.00	0.71	0.53	0.40
LAI Measurements from HPT				
Range	2.2-5.3	1.4-3.0	1.1-2.0	0.8-1.4
Average	3.18	2.11	1.57	1.08
Standard Deviation	0.73	0.30	0.18	0.13
Thin Ratio	1.00	0.66	0.49	0.34

* Stems greater than 7.6 cm
 LAI - Leaf Area Index
 PCA – Plant Canopy Analyzer
 HPT – Hemispheric Photographic Technique

and 0.40 from the PCA, and 0.66, 0.49, and 0.34 from the HPT). Generally, both of these approaches to measuring LAI are most accurate when canopy light is not directional. As the canopy was thinned and larger gaps appeared, accuracy of these measurements probably fell. However, these LAI estimates were comparable to values found elsewhere (Teske and Thistle 2004).

Example Field Data

Figures 1 and 2 illustrate the types of field data collected during one 30-min test of the campaign. The start time for this period was 1230 EDT on Trial Day 2 (15 May 2004), and conditions included a net radiation of 96 W m⁻² and an ambient temperature of ~ 25 °C. Average wind speeds were 0.30, 0.46, and 1.68 m s⁻¹ at the 2.6-, 16.6-, and 22.9-m heights, respectively, on the meteorological tower.

Figures 1a and 1b depict the fluctuating nature of winds in the canopy during the test. Corresponding to anemometer data in Figure 1a, average wind speed at the source was 0.38 m s⁻¹ with standard deviations of 0.18 and 0.06 m s⁻¹ in the horizontal and vertical directions, respectively. According to the radial time series (Fig. 1b), wind direction at the source was primarily toward the south, southwest, and southeast throughout this 30-min period.

In terms of dispersion characteristics, plume profiles were nearly Gaussian in shape in the horizontal (Fig. 2a) and vertical (Fig. 2b) directions. Maximum average concentrations (normalized by SF₆ release rate) along the 5-m arc were 0.16 s m⁻³ based on the sampler data and 0.13 s m⁻³ based on the Gaussian best-fit curve. Along the 10-m arc, the maximum concentration was 0.04 s m⁻³. Horizontal

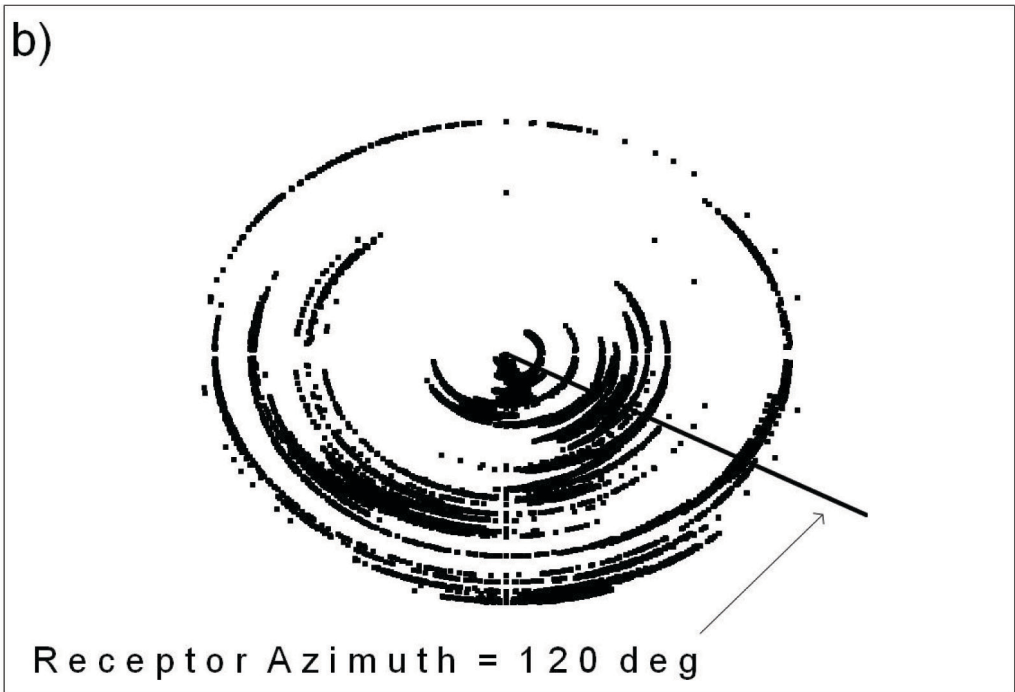
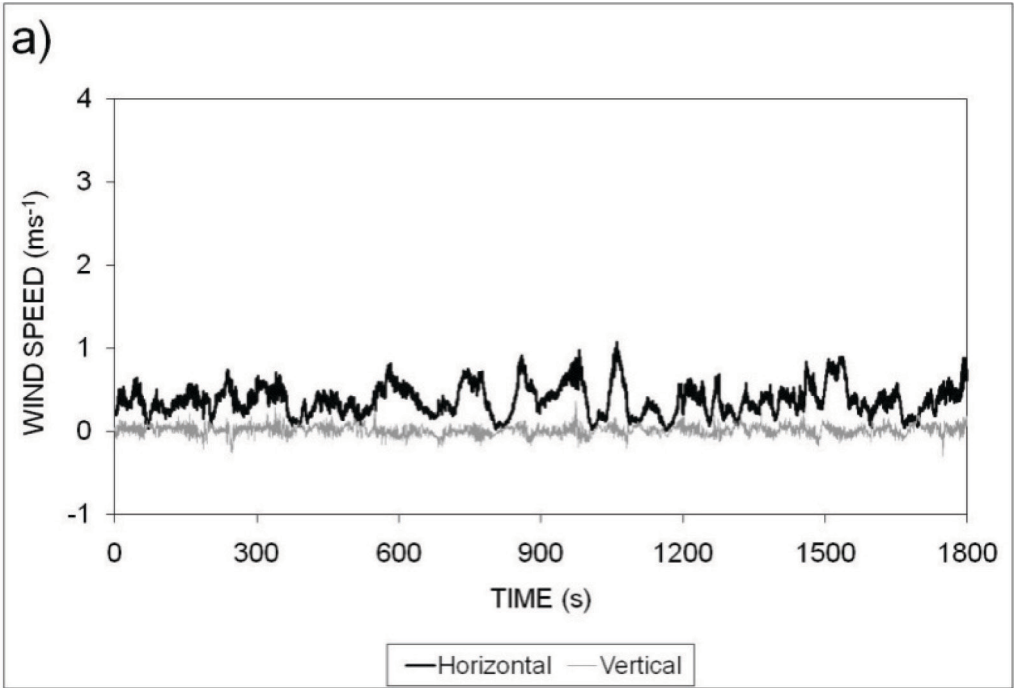


Figure 1. Measurements during 1230-1300 EDT on Trial Day 2 for: a) wind speed at the source, and b) radial wind direction at the source.

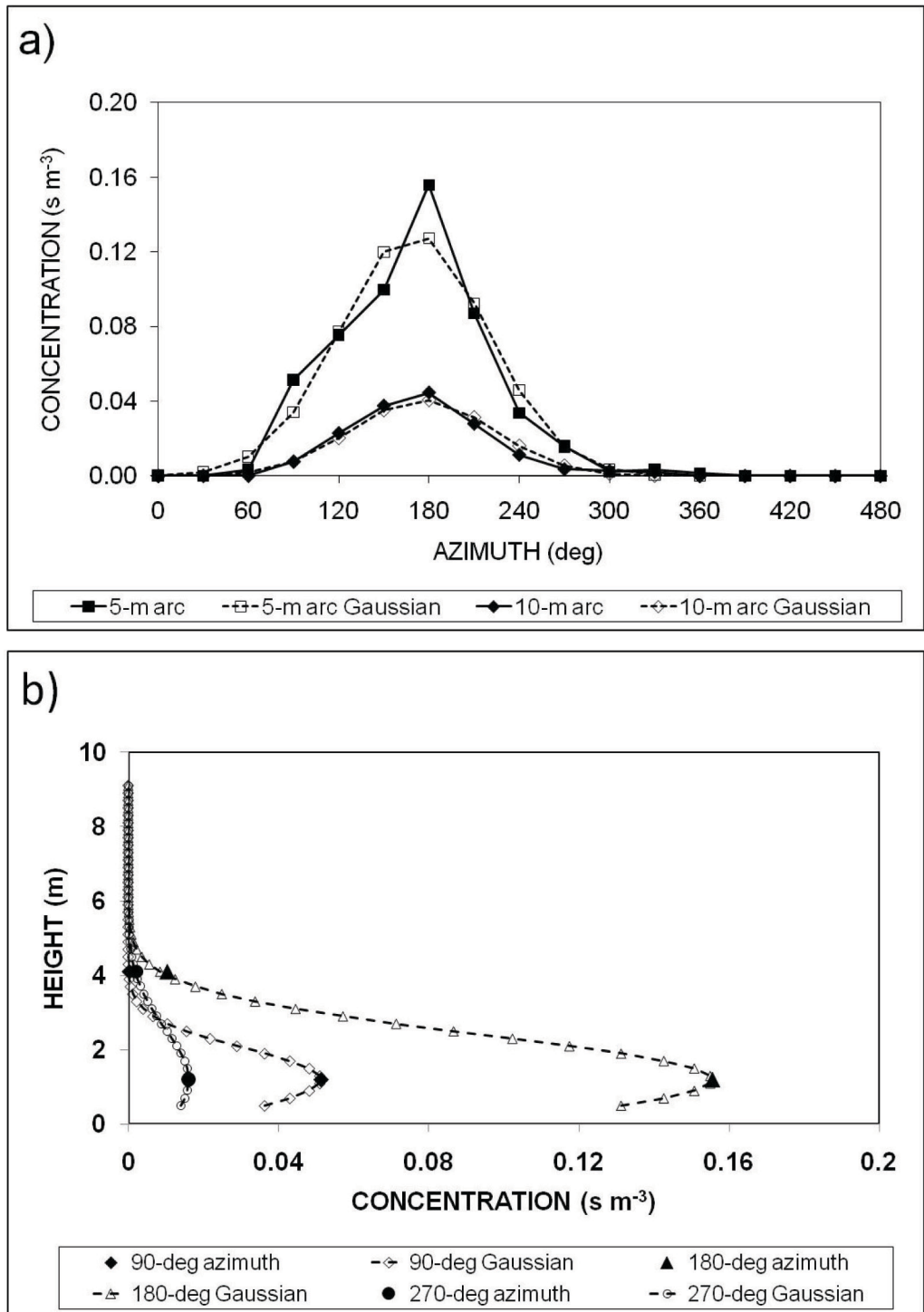


Figure 2. Measurements during 1230-1300 EDT on Trial Day 2 for: a) horizontal plume profiles along the 5- and 10-m arcs, and b) vertical plume profiles on the 5-m arc.

dispersion coefficients (σ_y values) for the 5- and 10-m arc profiles in Figure 2a were 4.2 and 8.2 m, respectively. Vertical dispersion coefficients (σ_z values) for the 5-m arc in Figure 2b were 0.84, 1.20, and 1.38 m from the samplers at the 90-, 180-, and 270-deg azimuth locations.

Winds Statistics at the Source

Wind speed and turbulence statistics from the sonic anemometer at the source varied as a function of time of day throughout the 14 trial days (Figure 3). In general, we observed higher wind speeds and more turbulence with each successive stage of thinning. As depicted in Figure 3a, average wind speed ranged 0.19-0.48 m s⁻¹ in the unthinned canopy (Trials 1-4), 0.27-0.63 m s⁻¹ during Trials 5-7, 0.20-0.66 m s⁻¹ during Trials 8-10, and 0.26-0.73 m s⁻¹ during Trials 11-14.

Standard deviations of wind speed, σ_u and σ_w , are measures of turbulence in the horizontal and vertical directions, respectively. Corresponding to data in Figures 3b and 3c, ranges of σ_u and σ_w were 0.09-0.24 m s⁻¹ and 0.03-0.08 m s⁻¹ during Trials 1-4, 0.11-0.39 m s⁻¹ and 0.07-0.19 m s⁻¹ during Trials 5-7, 0.09-0.38 m s⁻¹ and 0.04-0.20 m s⁻¹ during Trials 8-10, and 0.14-0.40 m s⁻¹ and 0.06-0.25 m s⁻¹ during Trials 11-14.

Model Development and Application

Pheromone concentrations in a canopy should decrease with increasing distance from the source in response to two processes: 1) dilution from the wind speed, and 2) dispersion from the turbulence. In the field of air pollution, a Gaussian approach is often utilized for modeling concentrations downwind of an industrial smokestack using the Gaussian plume equation (Turner and Schultz 2007):

where C_{xyz} is average concentration at a receptor with coordinates x,y,z ; Q is mass release rate of the pollutant; σ_y and σ_z are horizontal and vertical dispersion coefficients, respectively; U is mean wind speed, usually at stack height; and H_e is effective source height (physical stack height plus plume rise). Versions of Equation (1) are incorporated into air pollution models used by the United States Environmental Protection Agency (USEPA) and others to predict average concentrations downwind of industrial sources with averaging times as small as 1 hour, and as large as 1 year (USEPA 1995).

Dispersion coefficients (σ_y and σ_z) in air pollution models reflect the horizontal and vertical spread of the plume. As described by Turner and Schultz (2009), they are normally estimated using empirical equations that are functions of downwind distance and atmospheric stability class, i.e., Pasquill classes A-F/G, or they can be estimated using equations that are functions of turbulence statistics and travel time ($t = x/U$). Dispersion coefficients in the models for air pollution purposes represent downwind distances much longer than distances applicable for near-source pheromone processes; the Gaussian approach, however, was a logical starting point for development of a simple pheromone dispersion model.

Similar to tracer data in Figures 2a and 2b, all of the horizontal and vertical concentration profiles in our dataset were approximately Gaussian in shape. We assumed σ_y and σ_z for our profiles should be functions of turbulence statistics at the source and travel time [i.e., $\sigma_y = f(\sigma_u t)$ and $\sigma_z = f(\sigma_w t)$]. Following the general framework of the Gaussian plume equation, we assumed maximum normalized concentration (C/Q) at each downwind distance should therefore be a function of $\pi\sigma_u\sigma_w tU$.

$$(1) \quad C_{xyz} = \frac{Q}{2\pi\sigma_y\sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left\{ \exp\left[-\frac{1}{2}\left(\frac{H_e - z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H_e + z}{\sigma_z}\right)^2\right] \right\}$$

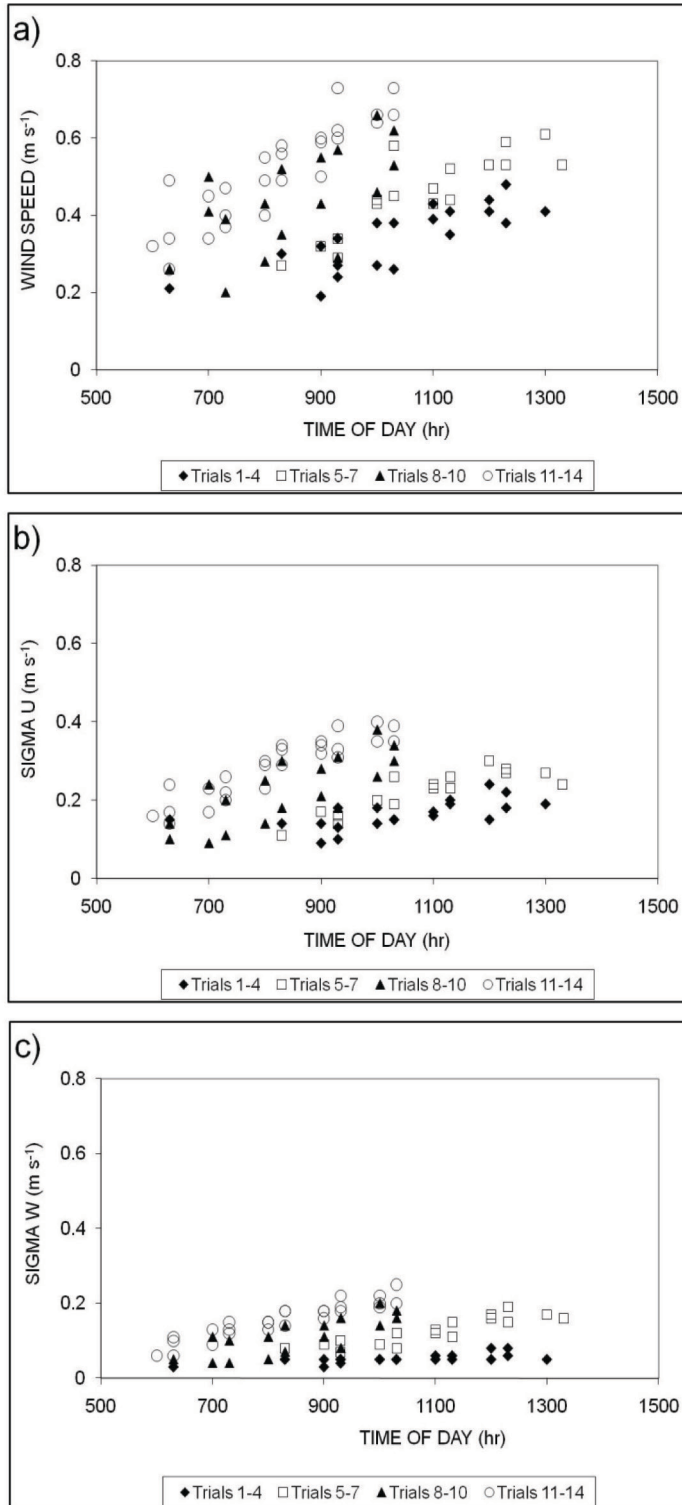


Figure 3. Graphs of: a) average wind speed, b) standard deviation of the horizontal wind speed, and c) standard deviation of vertical wind speed at the source versus time of day for all tests.

Figure 4 shows graphs of “concentration versus $\pi \alpha_u t \sigma_w t U$ ” for the 5-m and 10-m arcs with trials segregated, including the lines for best-fit regressions. Based on curve-fitting, equations for the 5-m and 10-m arc, respectively, were:

$$(2) \quad \frac{C}{Q} = \frac{0.4184}{(\pi \alpha_u t \sigma_w t U)^{1.630}}$$

$$(3) \quad \frac{C}{Q} = \frac{1.6406}{(\pi \alpha_u t \sigma_w t U)^{1.627}}$$

with R^2 correlation coefficients of ~ 0.6 on the 5-m arc, and ~ 0.7 on the 10-m arc.

We also analyzed the relationship between the numerators (0.4184 and 1.6406)

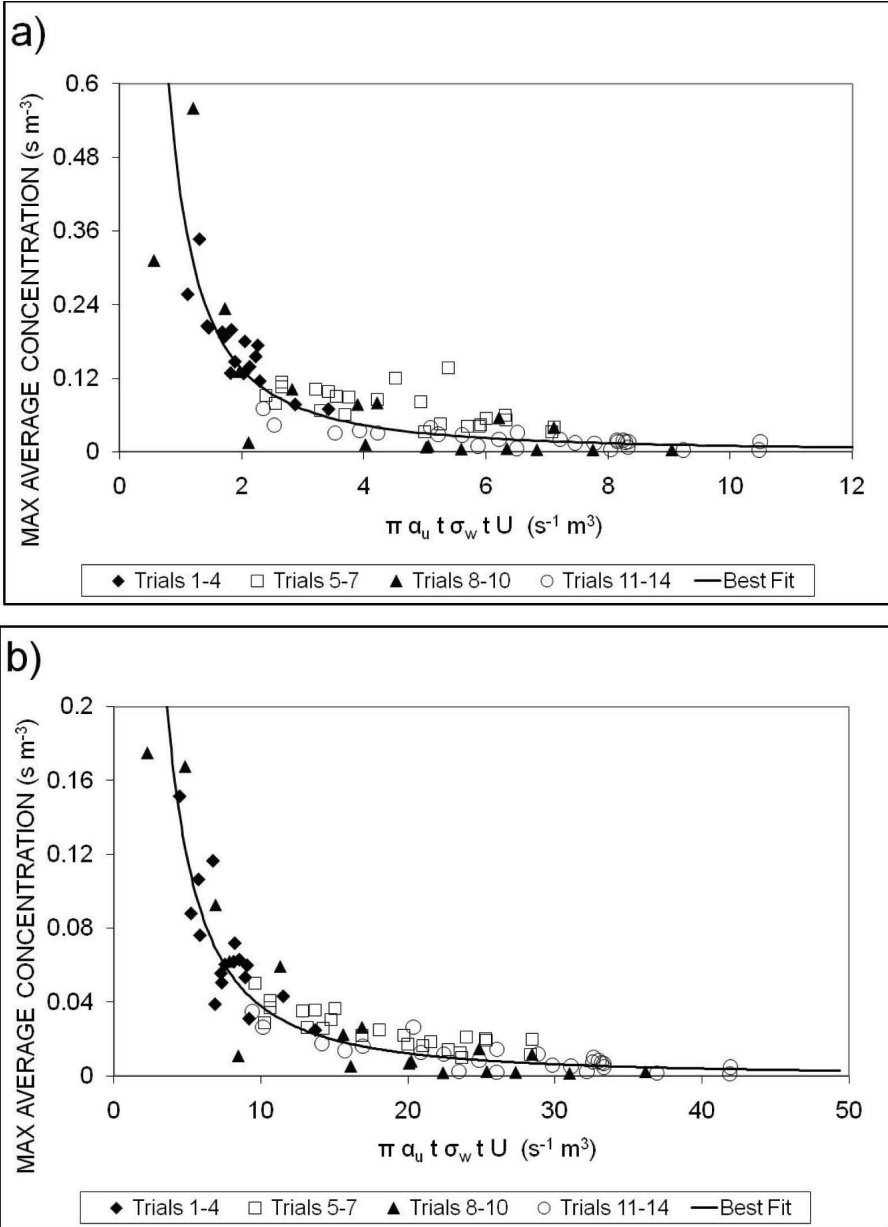


Figure 4. Maximum average concentration versus $\pi \alpha_u t \sigma_w t U$ for the: a) 5-m arc, and b) 10-m arc for all tests.

in Equations (2) and (3) as a function of downwind distance (x), and the resulting equation to predict maximum average concentration at any distance was

$$(4) \quad \frac{C}{Q} = \frac{0.0175x^{1.97}}{(\pi\sigma_u t \sigma_w t U)^{1.63}}$$

where U , σ_u , and σ_w correspond to meteorological conditions at the source location.

Figure 5 shows modeled concentrations from Equation (4) as a function of downwind distance from the tracer source for the 30-min test beginning at 1230 EDT on Trial Day 2. Concentration decreased quickly within the first 2 m. At distances of 5 and 10 m, predicted concentrations of 0.11 and 0.05 $s\ m^{-3}$, respectively, were similar to the observed concentrations of 0.16 and 0.04 $s\ m^{-3}$.

Concentrations from Equation (4) were compared to observed values from all of the tracer experiments. On the 5-m arc, predicted and observed concentrations were within a factor of 2, or better, for 67.8 percent of the profiles, and within a factor

of 3 for 82.1 percent of the distributions. On the 10-m arc, predicted and observed values were within a factor of 2 in 78.1 percent and within a factor of 3 in 88.1 percent of the cases.

As an investigation of how our model could be used by forest managers or others, Equation (4) was rearranged to solve for downwind distance x :

$$(5) \quad x = \left[0.002708 \frac{Q}{C} \left(\frac{U}{\sigma_u \sigma_w} \right)^{1.63} \right]^{0.775}$$

and the field chart of “ x versus C/Q ” in Figure 6 was developed for $U(\sigma_u \sigma_w)^{-1}$ values ranging 10-60 $s\ m^{-1}$. With this chart and with minimal on-site data, the method was designed to be a simple way to incorporate plume diffusion into decisions about how closely to space pheromone dispensers in anti-aggregation applications.

For example, assume average wind conditions at a site are described by 0.30, 0.15, and 0.05 $m\ s^{-1}$, for U , σ_u , and σ_w , respectively; and assume each dispensing unit will have a pheromone release rate

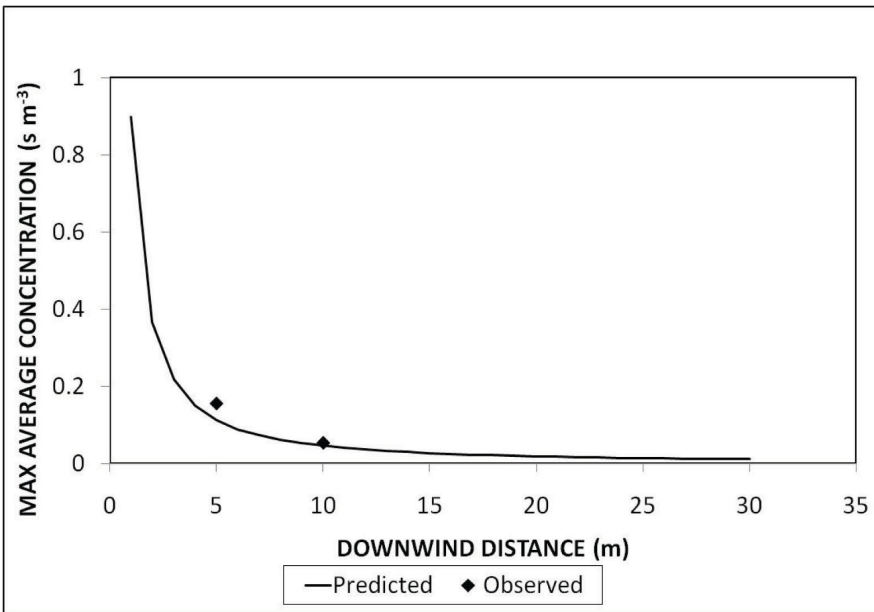


Figure 5. Predicted concentrations from Equation (4) and observed data versus downwind distance for the test conducted at 1230-1300 EDT on Trial Day 2.

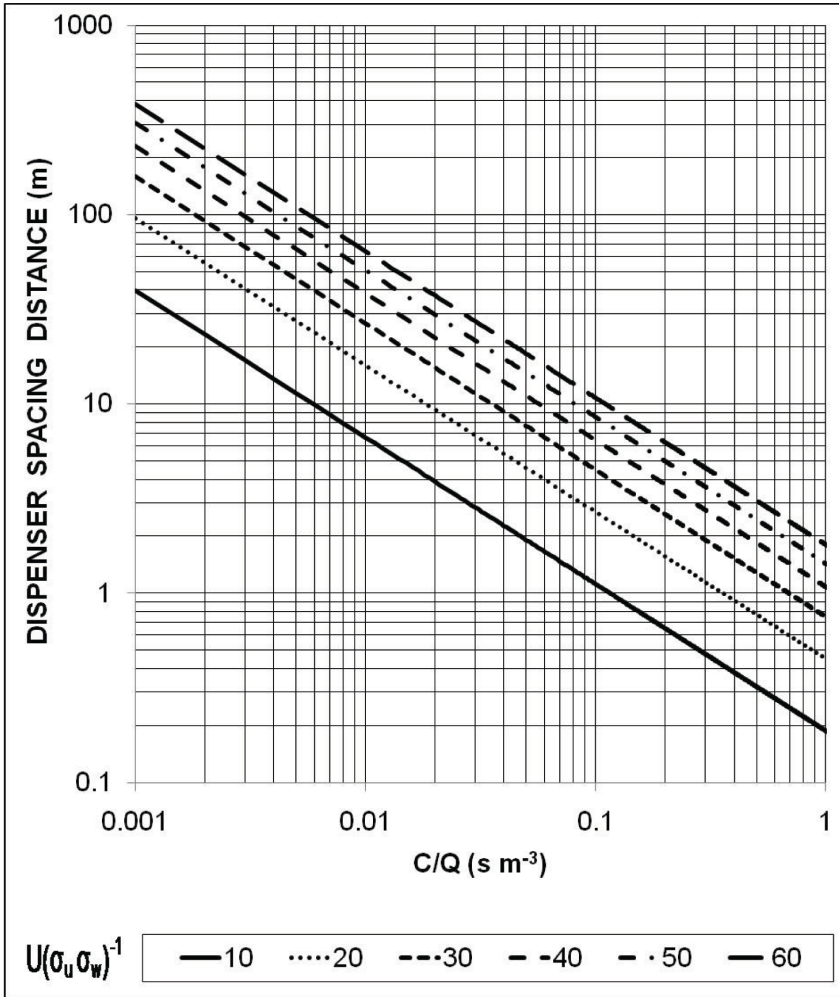


Figure 6. Example field chart of dispenser spacing distance versus maximum average concentration for $U(\sigma_u \sigma_w)^{-1}$ ranging between 10 and 60. [Units on $U(\sigma_u \sigma_w)^{-1}$ are $s\ m^{-1}$.]

of $0.03\ \mu\text{g}\ s^{-1}$. To design an array for concentrations greater than or equal to $0.0017\ \mu\text{g}\ m^{-3}$, these data correspond to

$$\frac{U}{\sigma_u \sigma_w} = \frac{0.30\text{ms}^{-1}}{(0.15\text{ms}^{-1})(0.05\text{ms}^{-1})} = 40\text{sm}^{-1}$$

$$\frac{C}{Q} = \frac{0.0017\ \mu\text{g}\ m^{-3}}{0.03\ \mu\text{g}\ s^{-1}} = 0.06\text{sm}^{-3}$$

and

$$x = \left[0.002708 \left(\frac{1}{0.06\text{sm}^{-3}} \right) (40\text{sm}^{-1})^{63} \right]^{0.775} = 9.6\text{m}$$

using Equation (5) directly; or, if estimating a value from Figure 6, we would choose a pheromone dispenser spacing of about 10 m.

Regarding limitations of the method at this time, conditions in our tracer campaign corresponded to a release height of 1.2 m above the ground, and $U(\sigma_u \sigma_w)^{-1}$ values at this height were between 6.72 and 70.37 $s\ m^{-1}$.

Therefore, until we can research this further, we caution against using Equation (5) or Figure 6 in canopies with turbulence data outside of this range.

SUMMARY

In this paper, we described a unique field project in which tracer technologies were applied to study pheromone dispersion in a forest canopy. While we have conducted similar experiments in other forest types, this is the first campaign designed specifically to examine effects of stand density.

During our campaign, 126 tracer experiments were conducted over a 14-day period in which the forest stand ranged from an unthinned loblolly pine canopy (with dense understory) through a series of thinning scenarios reflecting basal areas of 32.1, 23.0, and 16.1 m²ha⁻¹. Each successive thinning resulted in higher wind speeds and more turbulence in the trunk space near the ground, and these conditions translated to increased dispersion and lower concentrations in the tracer plumes.

Our field data were used to develop a simple pheromone dispersion model describing how plume concentrations decreased as a function of downwind distance based on wind speed and turbulence data measured at the source. Predicted concentrations from the model were within a factor of 3 for 82.1 and 88.1 percent of the observed concentrations at downwind distances of 5 and 10 m, respectively.

Lastly, our model equation was rearranged to predict downwind distance as a function of release rate, concentration, and wind statistics. From this equation, a field chart was developed to predict optimum spacing for dispenser arrays in applications of anti-aggregation pheromones.

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BIOLOGICAL SCIENCES – AQUATIC

MONTANA CHAPTER OF THE AMERICAN FISHERIES SOCIETY 43RD ANNUAL MEETING IN 2010 LINKAGES ACROSS LANDSCAPES: THE ECOLOGICAL ROLE OF FISH IN MONTANA

INVITED AND CONTRIBUTED ABSTRACTS

Over 220 fisheries professionals, both members and non-members of the Montana Chapter of the American Fisheries Society gathered in Bozeman, Montana, February 8th-12th, 2010 for the 43rd annual meeting of the Chapter. The meeting was organized around the theme of **Linkages Across Landscapes: The Ecological Role Of Fish In Montana**. The opening plenary session included six very unique papers discussing science, history and policy related to this topic. Paul Schullery opened with a historical look at the human dimension influencing fisheries management and then Daniel Schindler set the stage of ecosystem processes and services related to fish communities. While Wyatt Cross, Merav Ben-David and Chuck Schwartz continued and extended the ecosystem linkage theme from invertebrates to mammals. Trending into the importance of taking management actions with species introductions in wilderness lakes by Jonathan Klein and the importance of bringing sportsmen into the decision making process by Tom Reed. Finally, Wayne Hubert brought the group a historical and timely talk on fisheries paradigm shifts to more ecosystem based management with restoration potential that will bring us into the next century of freshwater fishery research.

The following abstracts presented at the 2010 annual meeting cover a large range of topics from Montana's largest river fishes to freshwater mussels, from game and native fish management and restoration to research on non-game fishes. This diversity of abstracts truly demonstrates the wide reaching, important and timely work being conducted by Montana's fisheries professionals and students. Based on this and past meetings, there is little doubt that the dedicated individuals, agencies, and organizations represented by the Montana Chapter of the American Fisheries Society will continue to strive to meet the challenges posed by a changing future.

David Stagliano, Associate Editor - Aquatic Ecosystems, of IJS and member of the Montana Chapter of the American Fisheries Society.

FISH CULTURE AND HUMAN CULTURE: HISTORIC CONTEXTS OF MODERN RESEARCH AND MANAGEMENT

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The intellectual and social foundations of three overlapping enterprises—fisheries science, fisheries management, and sport fishing—are incredibly complex. Practitioners of each of the three confront vexing, yet stimulating, instances of this complexity as they attempt to interact with practitioners of the other two. Historically, comparatively little scholarly

attention has been paid to coming to terms with the character of these essential interactions. This paper reinforces the urgency of advancing such scholarly attention. The paper will invoke C.P. Snow's provocative "two cultures" lecture (1959) on the persistence and power of such "incomprehensibility gaps" as now often exist among the "three cultures" of science, management, and sport fishers. The paper will also critique H. Jones' contemporaneous and controversial Maxim on Field Research (1957) as a way of proposing at least some means for a better understanding among the three cultures—and countless subcultures—of human/fish endeavors. Results will include a fast-and-loose overview of random but helpful if not inspiring cases that indicate possible directions for improvement of this difficult situation. The talk's tone will not be anything like this abstract.

THE IMPORTANCE OF LANDSCAPE AND POPULATION DIVERSITY FOR ECOSYSTEM SERVICES ASSOCIATED WITH FISHES

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One of the most pervasive themes in ecology is that biological diversity stabilizes ecosystem processes and the services they provide to society; a concept that has become a common argument for biodiversity conservation. In particular, species-rich communities are thought to produce more temporally stable ecosystem services because of the complementary or independent dynamics among species that perform similar ecosystem functions. These arguments have focused on the effects of species diversity on ecosystem stability but have generally not considered the importance of biologically relevant diversity within individual species. Current rates of population extirpation are probably at least three orders of magnitude higher than species extinction rates so there is pressing need to clarify how population and life history diversity affect the performance of individual species in providing important ecosystem services. Furthermore, heterogeneity in habitat conditions buffers the effects of regional scale climate change on aquatic organisms because of complementary filtering of climate by different habitat types. Taken together, habitat heterogeneity and the associated diversity of populations that inhabit aquatic landscapes, enhance resilience in ecosystems and the human economies that rely on these ecosystems.

RELATIONSHIPS BETWEEN FISH AND BENTHIC COMMUNITIES: A CALL FOR MORE EXPERIMENTS IN THE CONTEXT OF ADAPTIVE MANAGEMENT

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Fish are important components of most freshwater ecosystems and can interact strongly with their prey, potentially driving changes in system structure and function. Less appreciated, however, is the reciprocal role of prey availability and quality in limiting and/or structuring fish communities. Understanding both sides of these interactions is critical for predicting changes to aquatic ecosystems as a result of species invasions, extinctions, and well-intentioned management practices. I will focus on fish-benthos relationships in streams and rivers with emphasis on salmonid-invertebrate interactions. First, I will argue that despite a large literature in this area, generalizations remain elusive because of broad differences in scale and study design. Next, I will present a food web approach (and case study from the Grand Canyon) that can help elucidate key pathways of interaction between fishes and their

prey. Finally, I will discuss the critical role of ecosystem experiments in management and argue that exciting opportunities abound in Montana for leading the way in science-based adaptive management of streams and rivers.

AQUATIC-TERRESTRIAL LINKAGES: FORMATION, IMPORTANCE, AND DISRUPTION

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We can no longer regard ecosystems as discrete entities in space. Similar to human societies, the natural environment is a product of a wide range of transport, propagation, and communication processes. Spatial coupling of ecosystems through cross-habitat fluxes of energy and matter may modify food web interactions, change ecosystem function, and alter community diversity. Lateral fluxes of matter and energy between discrete ecosystems have been shown to elicit variable responses in the recipient ones depending on trophic position, ecological process, biotic and abiotic conditions, and the ratio between the subsidy and local resources. In some cases, cross ecosystem nutrient fluxes can be as important as transfers within individual ecosystems. Some of the best documented ecosystem linkages occur in aquatic-terrestrial systems. For example, terrestrial animals feeding in freshwater and marine habitats transfer nutrients from these aquatic to adjacent terrestrial ecosystems leading to increases in primary production in the latter. Such increases in production are comparable in magnitude to positive effects of moderately elevated local herbivory observed in some systems or nitrogen fixation by alder. Nonetheless, recent human-induced ecosystem alterations result in disruption of the spatial continuity of ecosystem linkages. Here I evaluate the current knowledge on the formation and importance of aquatic-terrestrial linkages and provide examples of the consequences of discontinuity in these transport processes.

ECOLOGICAL IMPORTANCE OF CUTTHROAT TROUT TO THE YELLOWSTONE GRIZZLY BEAR

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The importance of cutthroat trout (*Oncorhynchus clarkii*) to the Yellowstone grizzly bear (*Ursus arctos*) has changed over the decades. Early records from the 1930s suggested bears were foraging on cutthroat trout, but studies from the 1950s and 1960s found no evidence of fish use. Bears at that time likely did not use fish because their diets were composed primarily of garbage from park dumps. Following dump closure in the early 1970s, bear use of fish increased and likely peaked in the late-1980s, coinciding with a peak in the cutthroat population in Yellowstone Lake. Researchers estimated that about 44 grizzly bears fished on 61 percent of the 124 tributary streams. Female bears consumed most of the fish but females consuming fish had lower reproductive rates when compared to females not consuming fish. Bear use of fish began to decline as the cutthroat trout population declined as a result of predation from introduced lake trout (*Salvelinus namaycush*). Bear use of cutthroat trout was very low in the late 1990s and most fish were consumed by male bears. DNA capture mark recapture studies estimated that 68 individual bears used the area around Yellowstone Lake. Results from a recent study (2007-2009) suggest the number of bears using the area has not changed, but fish are no longer available or consumed by bears. They have shifted their diet to other natural foods including elk calves (*Cervus elaphus*) in habitat created by

the 1988 fires. Demographic studies of the Yellowstone grizzly bear during the decades of the 1980s-2000s suggests this dynamic flux in fish availability and use by grizzly bears did not abate population growth and range expansion.

STOCKING WILDERNESS LAKES – THERE’S SOMETHING FISHY GOING ON?

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The Wilderness Act of 1964 set aside lands to be managed and protected so as to preserve their natural conditions. Yet, many historically fishless lakes within designated wilderness continue to be stocked with native and non-native fish by state fish and game agencies in order to provide recreational fishing opportunities. This practice is controversial because stocking programs can compromise ecological and social values of Wilderness. Stocking is commonly accomplished without adequate cooperation and consultation between state and federal agencies. A better understanding of wilderness impacts from fish stocking, as well as improved cooperation between agencies may help balance opportunities for recreational fishing with wilderness values.

SPORTSMEN AND THE WORLD WE LIVE IN

Tom Reed, Trout Unlimited

It’s no secret to the historian that sportsmen and women have long had a role in public lands policy. Certainly, the public lands legacy that has been left to us in this country is a legacy of sportsmen before us; Roosevelt was a hunter, Pinchot was a fisherman. But in recent years, sportsmen have again stepped into the lead, particularly on public lands issues that challenge our society to balance our growing country and our need to have places to get away, places of retreat. Trout Unlimited has been instrumental in guiding and driving much of the good public lands decisions that have been made in the recent past. In particular, the Wyoming Range Legacy Act, sponsored by Sen. John Barrasso, R-Wyoming, is case in point. Located just south of Jackson, Wyoming, and running ~ 125 mi north-south to near the town of Kemmerer, the range is home to three subspecies of cutthroat trout including the Colorado River, the Snake River and the Bonneville. The Bridger-Teton National Forest cloaks some 1.2 million ac of the range. A group led by TU called Sportsmen for the Wyoming Range pushed for withdrawal legislation; legislation that would allow one use of the public’s land—mineral extraction—to be taken off the table. Whereas some of the range was previously leased for oil and gas exploration, much of the range was not. The Act did two things: it provided for no new leasing on unleased land, and it allowed for private buy-out of existing leases while not preventing drilling of valid existing leases. The Act passed as part of the Omnibus Public Lands bill that was signed by the President in March 2009. Today, some 1.2 million ac of public land will never see a drill rig whereas ~ 60-70,000 ac is targeted for buy-out or light development. Senator Jon Tester, D-Montana, introduced a bill last summer that TU is very supportive of and has some similarities to the Wyoming Range Legacy Act. The Forest Jobs and Recreation Act seeks to mandate logging on 100,000 ac of federal USDA Forest Service land, create some 670,000 ac of designated big ‘W’ wilderness, and 330,000 some ac of motorized recreation area. For TU, the bill fits our mission perfectly: Protect, Reconnect, Restore and Sustain. Protect: Wilderness and recreation designation

would set aside the headwaters of some of Montana's most fabled trout streams. Reconnect: Stewardship logging would pay for much-needed culvert removal for fish passage. Restore: Stewardship logging would pay for road removal or realignment where interfering with fisheries habitat. Sustain: The Act would maintain Montana lifestyles for those who like to fish and do other activities outside. TU is fully supportive of the bill for not only the mission fit, but also because of its grassroots nature, its collaborative process, its bipartisan nature, and its Montana-based common-sense solution.

CHANGES IN AQUATIC SPECIES INTRODUCTIONS WITH EVOLUTION FROM MSY TO ECOSYSTEM-BASED FISHERIES MANAGEMENT

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The American Fisheries Society was formed in 1870 to promote the development of fish culture in North America, and inland fisheries management was focused on stocking to maintain populations and introductions to create new fisheries. The primary philosophy for inland fisheries management evolved during the 20th century to maximum sustained yield (MSY) and was then tweaked to the notion of optimum sustained yield (OSY) with little change in attitude toward aquatic species introductions. Late in the 20th century, fisheries managers began to recognize the consequences of habitat alterations and aquatic species introductions on aquatic ecosystems, as well as the need to maintain the components and processes of ecosystems. Over the last decade there has been increasing focus by fisheries managers on preservation and restoration of ecosystems, management goals confounded by intended and unintended species introductions. Preservation of rare species, control of undesired exotic species, and prevention of further introductions of aquatic species, including fish, invertebrates, pathogens, and aquatic plants, are becoming dominant goals in fisheries management programs. Many questions can be asked about the future of inland fisheries management as we begin to recognize the linkages across landscapes. This talk delves into questions pertinent to the education and practices of fisheries managers as maintenance and restoration of linkages across landscapes become a larger focus into the 21st century.

A MODULAR IN-STREAM BARRIER STRUCTURE TO LIMIT UPSTREAM FISH PASSAGE

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Fisheries management objectives that include segregation of native and introduced fish species often depend upon installation of a physical in-stream barrier with a long functional design life. Fish barrier sites are typically located in remote locations and reflect varied topographic and hydrologic conditions. A modular fish barrier, consisting of commercially available pre-cast concrete box culverts and slabs, was developed for relatively low-cost, permanent installations at multiple locations around the State. The barrier is comprised of upright culverts connected to form a weir and abutments and slabs to form splash pads. Structural design elements include: weir width; abutment height; and structure stability against overturning. Passage impedance design elements include: weir height; preventing pool

formation at the structure base; and restrictive velocity when leap constraints are exceeded. Topographic design elements include: channel-to-weir transitions and grading between the abutments and adjacent ground. This barrier has recently been installed on Whites Gulch near Canyon Ferry; barriers on Seepay and Magpie Creeks near Dixon and Cottonwood Creek near Wolf Creek are in various design phases. This paper presents the basis for the structural, passage impedance and topographic design elements as well as design lessons learned from the installed barrier.

EFFECTIVENESS OF FLOW MANAGEMENT AND RAINBOW TROUT HARVEST ON LONG-TERM VIABILITY OF NATIVE YELLOWSTONE CUTTHROAT TROUT IN THE SOUTH FORK SNAKE RIVER

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The South Fork Snake River supports one of the last remaining large-river populations of Yellowstone cutthroat trout (YCT, *Onchorynchus clarkia bouvierii*). Rainbow (*O. mykiss*) and rainbow x cutthroat hybrid trout (collectively, RHT) established a self-sustaining population in the upper South Fork in the mid-1980s. In 2003, density of each species was 1400 fish per mile. In 2004, U.S. Bureau of Reclamation began delivering a spring “freshet” from Palisades Dam, and Idaho Department of Fish and Game removed harvest limits on RHT. We evaluated current and future effectiveness of these management actions with a stochastic simulation model parameterized with observed data. Total RHT + YCT recruitment is positively correlated with winter flow, and RHT recruitment is negatively correlated with maximum freshet flow. There is little temporal overlap in spawning, and hybridization alone does not explain the observed RHT invasion rate. Nonetheless, continued removal of RHT from spawning tributaries is necessary to prevent long-term loss of YCT. A model of juvenile competition between the two species based on experimental results of Seiler and Keeley explains observed invasion rates. Current densities of 1700 YCT/mi and 925 RHT/mi indicate reversal in population trends since 2004, and our analysis suggests that this is due primarily to harvest of RHT, which increased from 7 percent in 2003 to 20 percent in 2005. About 15 percent exploitation on RHT is required to prevent YCT extinction. We considered a likely future scenario to include mean winter flow of 1600 cfs (72% of 1987-2007 mean but necessary to enable the freshet operation), maximum freshet flow averaging 20,000 cfs, and RHT harvest at 20. Assuming environmental variance as observed since 1987, the 25-yr population projection is about 1100 fish/mi of each species. Increased percentage of YCT requires higher RHT harvest and/or higher maximum flows, and increased abundance requires higher winter flows.

MOVEMENTS OF SPAWNING AND NON-SPAWNING SHOVELNOSE STURGEON IN THE MISSOURI RIVER ABOVE FORT PECK RESERVOIR

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During the last 40 yrs there has been a lack of pallid sturgeon (*Scaphirhynchus albus*) recruitment in the upper Missouri River (UMR). However, shovelnose sturgeon (*Scaphirhynchus platorynchus*) continue to exhibit recruitment in the UMR. Understanding the recruitment dichotomy between species is receiving much attention throughout their range. The objectives of this study were to identify the effects of varying discharge on spawning locations and spawning movements for pallid and shovelnose sturgeon. Two female pallid sturgeon, 32 gravid female shovelnose sturgeon, and 32 non-reproductively active female shovelnose sturgeon were radio tagged at three locations and tracked from 1 May to 5 July 2009. Unfortunately, no data are available for spawning pallid sturgeon movements because fish were not reproductively active. Upstream movement by gravid shovelnose sturgeon varied from 20 percent of the fish tagged at Judith Landing to 56 percent of the fish tagged at Coal Banks Recreation Area (CBRA). Mean maximum upstream movement of gravid shovelnose sturgeon varied from 35.7 km at CBRA to 87.9 km at Fred Robinson Bridge (FRB), mean maximum downstream movement varied from 24.9 km at FRB to 80.3 km at CBRA. Reproductively inactive shovelnose sturgeon exhibited lower mean maximum movements than reproductively active fish (mean maximum distance 5.7 km). Shovelnose sturgeon in the UMR exhibit both upstream and downstream movements prior to spawning and are using several spawning areas. Thus, maintaining spawning habitat throughout a regulated river is important with regard to shovelnose sturgeon conservation.

SPATIAL DRIFT DYNAMICS OF SHOVELNOSE STURGEON AND PALLID STURGEON PRELARVAE IN THE TRANSITION ZONE OF FT. PECK RESERVOIR

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Habitats in reservoir headwaters may cause high mortality of sturgeon prelarvae. Short inter-reservoir reaches export drifting prelarvae from hatch locations into reservoirs. However, flooded vegetation could entrain prelarvae. We used 2 day post hatch (dph) shovelnose sturgeon (*Scaphirhynchus platyrhynchus*) and 1-dph pallid sturgeon (*Scaphirhynchus albus*) to determine the spatial dynamics of drifting prelarvae. We released 220,000 2-dph shovelnose sturgeon 4 km upstream of Ft. Peck Reservoir and 135,000 1-dph pallid sturgeon 2.5 km upstream of the reservoir the following day. We recaptured shovelnose sturgeon prelarvae with nets deployed along three transects of the transition zone and within the headwaters of the reservoir. We sampled 5148.2 m³ of water and recaptured 323 prelarval shovelnose sturgeon for a recapture rate of 0.14 percent. Fifty-nine percent of recaptured prelarvae were recaptured from the thalweg, 12 percent from the flooded vegetation-main channel interface, 9 percent from the channel border, and 19 percent from the zero-velocity area of Ft. Peck Reservoir. We recaptured pallid sturgeon prelarvae with nets deployed along one transect of the transition zone and within the headwaters of the reservoir. We sampled 6608.5 m³ of water and recaptured 397 pallid sturgeon prelarvae for a recapture rate of 0.29 percent. Twenty-one percent of prelarvae were recaptured within the thalweg, 0.25 percent were recaptured along the channel margins, and 79 percent from the zero-velocity area of Ft. Peck Reservoir. Although recapture rates were low, the majority of prelarvae were captured in the thalweg and transported to the headwaters of Ft. Peck Reservoir. The drift dynamics observed in this study provide a springboard for further research.

DISTRIBUTION AND POPULATION STATUS OF MUSSELS IN EASTERN MONTANA: NEW FINDINGS AND UPDATES ON FIVE SPECIES EAST OF THE DIVIDE

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The first 2 yrs of the SWG state-wide mussel surveys focused on the western pearlshell, but we've also collected distributional and population data on five other mussel species

occurring in the state, two native—fatmucket (*Lampsilis siliquoidaea*) and giant floater (*Pyganodon grandis*)— and three introduced species (black sandshell, mapleleaf and creek heelsplitter). Eastern Mussel Surveys in 2008 and 2009 focused on the Missouri, Milk, Marias and Yellowstone River Watersheds. Survey reaches were chosen opportunistically based on accessibility, previous mussel sightings and suitable mussel habitat (depositional areas and gravel run/glides). Aquascopes were used for shallow water transects, while SCUBA was utilized for deeper water (>1 m). Mussel data recorded during transects were standardized by time (CPUE, man-hour) and distance (mussels per 50 m). Rivers with excellent populations of native mussels include the Missouri River between Fort Benton and Fort Peck, the Marias River above Lake Elwell and within 10 mi of the confluence. In the Yellowstone River Watershed, the Tongue and Bighorn Rivers reported viable fatmucket populations, while catch rates of the fatmucket on the Yellowstone mainstem were low (avg. ~1/hr compared to ~7 /hr in the Missouri). We documented the first records of the giant floater in the Yellowstone Basin at three tributary sites (O’Fallon, Little Porcupine, Tongue River), but no evidence of this species in the mainstem. The introduced mapleleaf (*Quadrula quadrula*) has high densities in the Tongue River, but was not found live in the mainstem Yellowstone. Further population analysis and state conservation rank status will also be presented.

O’DELL CREEK HEADWATERS – FIVE YEARS OF STREAM AND WETLAND RESTORATION

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Since 2005, River Design Group, Inc., has collaborated with resource agencies and landowners to develop and implement comprehensive stream and wetland restoration strategies in the O’Dell Creek Headwaters Wetland Complex southeast of Ennis, Montana. An important spring creek tributary to the Madison River, historical land management practices resulted in the degradation and loss of wetland habitats and physical changes to O’Dell Creek including channel downcutting and incision, bank erosion, and simplification of instream aquatic habitat. Projects have included reclaiming over 3.0 mi of irrigation and diversion ditches, reconstructing over 6.7 mi of spring creek, restoring 254 ac of prior converted wetlands, and improving the function of an additional 256 ac of wetland habitat in the project area. These activities have significantly improved habitat conditions for target fish species including brown trout and rainbow trout. Aquatic habitat improvements included modifying the channel geometry to a lower width-to-depth ratio configuration with riffle, run, pool and glide features. Coarse wood habitat structures and large roughness elements included roughened riffles were incorporated to diversify channel habitats. Wildlife habitat improvements enhanced existing and created additional palustrine emergent and scrub shrub wetlands throughout the project area, with emphasis on breeding, migration and stop-over habitats for neo-tropical migrant birds. In summary, this multi-year restoration effort has improved aquatic habitat complexity, reduced the supply of sediment loading to O’Dell Creek and the Madison River, re-established functional wetlands, and increased the quality and availability of habitat for a variety of migratory bird species.

EFFECTS OF FISH RESTORATION PRACTICES ON AMPHIBIANS IN YELLOWSTONE NATIONAL PARK, WYOMING

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Throughout the Western United States, fisheries managers are attempting to restore native cutthroat trout (*Onchorynchus clarkii*) populations by removing nonnative fish species. A new formulation of the EPA approved piscicide rotenone (CFT Legumine) is increasingly being used as a method to accomplish this removal. Because fish restoration projects bring about an abrupt change to aquatic environments, it is important to consider their immediate and long-term effects on non-target species, such as amphibians. We assessed the effects of fish removal on amphibians in Yellowstone National Park (YNP) by investigating the toxicity of rotenone to and the long-term impacts of removing fish on local amphibian populations. CFT Legumine (5% rotenone) was applied to High Lake in YNP (2006) to remove stocked Yellowstone cutthroat trout (*O. c. bouvieri*). To determine toxicity, amphibian surveys were conducted immediately prior to the treatment to obtain pre-treatment tadpole population estimates. Post-treatment surveys were conducted both immediately, for assessing treatment-related mortality (during and after application), and 1, 2, and 3 years following to obtain tadpole abundance estimates in the years after application and to address the long-term effects of fish removal and reintroduction. The results of the toxicity trials revealed that in the 24 hrs following application, rotenone was lethal to gill-breathing amphibian tadpoles and non-lethal to non-gill breathing metamorphs, juveniles, and adults. In the years following, tadpole repopulation occurred at levels above the pre-treatment abundance estimate, though both tadpole abundance and distribution appeared correlated with fish presence.

THERMAL ADAPTATION OF WESTSLOPE CUTTHROAT TROUT

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Populations of westslope cutthroat trout (*Oncorhynchus clarkii lewisi*), a State species of special concern, have declined throughout their native range. Genetic introgressions, mainly from rainbow trout (*O. mykiss*), but also from Yellowstone cutthroat trout (*O. c. bouvieri*), and habitat loss are believed to be the leading causes of this decline. Populations that remain are often small and isolated, thereby increasing their risk of inbreeding depression and extinction. Translocation projects may offer a solution by infusing new genetic material into populations and potentially increasing their probability of persistence. However, local adaptations must

be considered when selecting a donor population. We investigated thermal adaptations of four wild populations of westslope cutthroat trout from the Missouri River drainage and one hatchery population from the Washoe Park Trout Hatchery, Anaconda, Montana. Two wild populations were deemed to be from warm streams and two from cold streams. Fish were spawned streamside and at the hatchery. The resulting embryos were placed in experimental systems at 8, 10, and 14 °C. Survival was monitored throughout incubation. Post-embryonic growth was measured 90 days after hatching. Relationships between population performance and natal stream thermal characteristics were examined for adaptive differences.

OBSERVING THE EFFECTS OF INBREEDING AND LOCAL ADAPTATION ON FITNESS IN WESTSLOPE CUTTHROAT TROUT POPULATIONS IN A COMMON GARDEN

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Montana Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*, WCT) populations, particularly those east of the continental divide, are predominantly small and isolated from one other. Small population size inevitably leads to a more inbred population and can lead to lowered fitness (inbreeding depression). Isolated populations may experience local adaptation, which increases the fitness of a population within its native habitat. If inbreeding is the greatest threat to a population, introducing individuals from another population might be the best management decision. However, if local adaptation has also occurred, introducing new individuals might lower the fitness of the population. Our goal was to evaluate the relative importance of inbreeding and local adaptation on fitness in several WCT populations. This study combines eggs from several populations of WCT into several different natural habitats. Remote-site incubators were used to introduce eggs to six sites over four years in the Cherry Creek drainage. Each year a colder and warmer site was selected to test for the potential of local adaptation to stream temperature. Electrofishing was used to sample above and below introduction sites one, two, and three years after eggs were introduced. DNA sequencing of microsatellite loci in parents and offspring were then used to determine the population of origin of 511 offspring sampled in Cherry Creek in 2008 and will ultimately be used for over 750 offspring sampled in 2007 and 2009. Preliminary results suggest that a colder common habitat produces larger differences in relative fitness than a warmer habitat.

PERFORMANCE OF WESTSLOPE CUTTHROAT TROUT RELEASED INTO THE UPPER CHERRY CREEK DRAINAGE USING REMOTE STREAM INCUBATORS

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A major effort to conserve westslope cutthroat (*Oncorhynchus clarkii lewisi*; WCT) is underway throughout Montana. One of the larger WCT conservation projects is ongoing in the Cherry Creek drainage of the Madison River. About 105 km of stream and a mountain lake are being treated with piscicides to remove nonnative trout, and WCT are being introduced into the drainage using remote stream incubators (RSIs). We are evaluating the relative success of different wild and hatchery stocks of WCT released into Cherry Creek. Here, we report on survival, abundance, growth, condition, and dispersal of WCT in the upper Cherry Creek drainage during the first three years of releases. Two streams of similar size, upper Cherry Creek and Cherry Lake Creek, meet to form main Cherry Creek. Cherry Lake Creek is colder than upper Cherry Creek (average August temperature about 3°C colder). Known numbers of WCT embryos were placed into RSIs at two sites in upper Cherry Creek during 2006 and 2007, one site in Cherry Lake Creek during 2006 and 2007, one site in Pika Creek (a tributary to Cherry Lake Creek) during 2008, and in an un-named spring-fed tributary to main Cherry Creek just below the mouth of Cherry Lake Creek during 2008. Fry that hatched in each RSI were captured and counted prior to release. Population abundances were estimated by single and multiple-pass electrofishing in 100-m sample sections located systematically throughout the upper reaches of the drainage. Estimated survivals from egg to fry, fry to age-1, age-1 to age-2, and age-2 to age-3 ranged from 13 to 80 percent, 7 to 80 percent, 21 to 100 percent, and 100 percent, respectively. Survivals in the colder stream, Cherry Lake Creek, were lower than in the warmer stream. Over 3500 WCT occupied the upper Cherry Creek drainage by 2009. Fish dispersed short distances upstream and long distances downstream, but downstream dispersal appeared relatively discrete, with WCT filling available habitat near RSIs before occupying reaches further downstream. Early growth of WCT was much slower in colder streams, but by age-3 little difference existed among streams. Conversely, condition factors of WCT were slightly lower in upper Cherry Creek (averaging 0.88 to 0.95) than in Cherry Lake Creek (0.92 to 1.11). The introduction of WCT in upper Cherry Creek has been successful to date; however, natural reproduction by introduced WCT has not yet occurred, but is expected to occur next year.

WESTERN LAKE TROUT – JUST SAY WHOA!

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In Montana lake trout (*Salvelinus namaycush*) are a self-sustaining introduced species in approximately 20 lakes west of the Continental Divide. Less than half those lakes were intentionally stocked and lake trout naturally invaded the others through connected

waterways. Lake trout populations are a detriment to native fish recovery in the majority of waters where they occur, including large lakes in Glacier National Park as well as Flathead, Swan, Whitefish, and others. In lakes with threatened native bull trout (*S. confluentus*), lake trout management runs headlong into the Endangered Species Act. In addition, ongoing lake trout expansion ranks high amongst future threats to bull trout in the Clearwater lakes (Salmon, Seeley, Alva, Inez, etc.), Lindbergh Lake, Holland Lake, Lake Koocanusa, and others. In oligotrophic lakes of the Columbia Basin, introduced lake trout are well adapted and reproduce liberally, preying upon and competing with other native and sport fishes. Lake trout preference for deepwater habitat and in-lake spawning limits their exposure to land-based and avian predators. Lake trout are long-lived, hardy and resistant to starvation. In systems where *Mysis relicta* are added to the mix, a tipping point has often been exceeded for maintaining a diverse native ecosystem. Historically, lake trout management strategies were often designed to produce both maximum yield and trophy specimens. A recent review of seven western states revealed agencies are increasingly implementing strategies to reduce lake trout populations in attempts to minimize their impacts. However, management action to deter proliferation of lake trout has often been too little, with too few viable options, too costly, and sometimes too late. In addition, marginal support for lake trout suppression from an unhappy and divided angling public is also an issue.

AN EVALUATION OF LAKE TROUT SUPPRESSION IN YELLOWSTONE LAKE, YELLOWSTONE NATIONAL PARK

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Introduced lake trout (*Salvelinus namaycush*) threaten to extirpate native Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) from Yellowstone Lake, Yellowstone National Park. A National Park Service gill netting program has removed nearly 400,000 lake trout from Yellowstone Lake since 1995. Lake trout population size has not been estimated; therefore, it is difficult to determine the proportion that has been removed. Our objectives were to (1) examine catch as a function of effort to determine if the suppression program has caused lake trout abundance to decline, (2) determine if certain population metrics have changed over time as a function of harvest, and (3) develop age-structured models to determine the level of mortality required to cause population growth rate to decline below 1.0 (replacement). Catch has continued to increase as a function of effort, indicating lake trout abundance is increasing. Population metrics were not clearly indicative of a response to harvest, but were comparable to North American lake trout populations where harvest has occurred. Results from an age-structured matrix model determined the rate of population growth was 1.1 given the current rate of fishing mortality and that population growth rate would be 1.3 in the absence of fishing mortality. The current rate of population growth is positive; however, it is slower than it would be in the absence of lake trout suppression. Fishing mortality needs to increase by at least 10 percent to reduce population growth rate below 1.0 in the future.

TRENDS IN CHARACTERISTICS OF YELLOWSTONE LAKE CUTTHROAT TROUT, ASSOCIATED FACTORS, AND EVIDENCE OF A POPULATION SHIFT

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Comprehensive time-series data for Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*; YCT) based on samples taken between 1977 and 2007 from the spawning run (spring; $n = 29$ yrs) of a tributary (Clear Creek) of Yellowstone Lake or caught in gill nets set (fall; $n = 30$ years) at established locations in the lake were examined to identify (1) associations between population characteristics within and between capture methods, as well as temporal trends in those characteristics, (2) evidence of informative shifts in population characteristics, and (3) factors that may have importantly affected the dynamics of the lacustrine-adfluvial YCT population of the tributary. Temporal increases in mean TL of YCT in the spawning run and of prespawners, i.e., YCT whose gonads indicated the fish would have spawned the next year, in the gillnet catch and concurrent declines in run size and prespawner catch were suggestive of an effect of YCT population density on the somatic growth of the fish. Similarly, a concurrent increase in mean TL of gillnetted YCT 100-199 mm long was indicated by the polynomial regression results, which also suggested statistical change points in the temporal trends for each of those variables. Contrasting those trends was that for mean TL of gillnetted YCT 200-299 mm long, whose general decline during the past two decades was attributed to predation by nonnative lake trout (*Salvelinus namaycush*). Collectively, these trends provided evidence of a YCT population shift. Correlation results indicated YCT in the spawning run could not be unequivocally assigned to any particular lake region. Multiple regression analyses showed that Clear Creek run size was strongly affected by parental run size 5 yrs earlier and a measure of climate 5 yrs earlier.

A MODEL OF A STORIED, LACUSTRINE-ADFLUVIAL CUTTHROAT TROUT POPULATION OF YELLOWSTONE LAKE: DEVELOPMENT, PARAMETER ESTIMATION, AND POPULATION PREDICTION

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A dynamic, age-structured model of the lacustrine-adfluvial Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) population of Clear Creek, a tributary of Yellowstone Lake in Yellowstone National Park, Wyoming, was developed and its key parameters estimated on the basis of data taken from fish in the spawning run during each of two periods, “pre lake trout” (1977–1993) and “lake trout” (1994–2007). The illegally introduced, reproducing, nonnative lake trout (*Salvelinus namaycush*) were discovered in the lake in 1994. Separate fitting of the model to data from each period allowed assessment of the robustness of the procedures employed and the rigor of conclusions. The model—of the time-variant, nonlinear

linear, Leslie form—explained 72 percent of the variation in observed annual run size during the lake trout period when fitted to data from the pre-lake trout period. Conversely, the model explained 70 percent of the variation in observed annual run size during the pre-lake trout period when fitted to data from the lake trout period. The models each explained 85 percent of variation in observed run size when the two periods were combined. Results strongly suggested that climate (as indexed by total-annual atmospheric degree-days measured on the lake's north shore) had an important effect on recruitment of age-0 Yellowstone cutthroat trout to subsequent spawning runs. Characteristics of climate that individually or collectively affected first-year survival of YCT are unknown. Results also suggested that the effect of lake trout predation on the YCT population was small. Ongoing efforts to control lake trout in Yellowstone Lake may be importantly limiting lake trout predation on YCT.

IS HABITAT TYPE A USEFUL PREDICTOR OF THE OUTCOME OF INTERACTIONS BETWEEN *TUBIFEX TUBIFEX* AND *MYXOBOLUS CEREBRALIS*, THE CAUSATIVE AGENT OF SALMONID WHIRLING DISEASE?

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The aquatic oligochaete *Tubifex tubifex* is the intermediate host for the parasite, *Myxobolus cerebralis*, which causes salmonid whirling disease (WD). Although the relationship between WD severity in salmonids and infection in *T. tubifex* is not well understood, previous research suggests that variation within local stream populations of *T. tubifex* may be an important determinant of parasite success. Our goals were to examine relationships among habitat features, abundance, infection prevalence, genetic diversity and susceptibility of *T. tubifex*, and WD risk in Yellowstone cutthroat trout spawning tributaries in Yellowstone National Park, where *M. cerebralis* was detected in 1998. Abundance of tubificids and *T. tubifex*, and infection prevalence in *T. tubifex* were higher in unconfined habitat types than in confined habitat types. *Tubifex tubifex* belonging to mtDNA lineages III, which are considered moderately susceptible to *M. cerebralis*, were also more abundant in unconfined habitats than confined habitats. We assessed the susceptibility of four genetically distinct strains of lineage III *T. tubifex* to *M. cerebralis* in the laboratory. Strains were established from field collected *T. tubifex*. All strains were susceptible to infection by *M. cerebralis* and strains from unconfined habitats amplified the parasite only slightly more than strains from confined habitats. These results suggest habitat type may influence variability in WD risk by affecting the outcome of interactions between *T. tubifex* and *M. cerebralis* in the field.

A CONCEPTUAL MODEL FOR PREDICTING AREAS WITH HIGH POTENTIAL FOR LAKE TROUT SPAWNING HABITAT IN YELLOWSTONE LAKE

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The presence of non-native lake trout (*Salvelinus namaycush*) has become a serious threat to native salmonid populations in many lakes throughout the West. Costly and time consuming suppression efforts have been undertaken by agencies in several of these systems with concern regarding their efficacy expressed by fisheries managers. Frequently, mature lake trout are interspersed with the native fishes, hindering removal efforts because of bycatch of fishes meant to be the beneficiary of suppression efforts. One method of improving suppression efforts that could reduce negative impacts on other species is to target areas where sexually mature lake trout congregate for spawning activities. Using theory that water movements within lakes influence habitat formation, parameters describing lake trout spawning habitat in published literature, and the capability of a GIS to mesh spatially-explicit geographical datasets, a conceptual lake trout spawning habitat model was developed for Yellowstone Lake. Important inputs to this model include detailed bathymetry of Yellowstone Lake, a sedimentation model that predicts erosion and deposition of particles within lake systems, and data on primary wind direction over the lake. The model predicts that 4.4 percent of the surface area of Yellowstone Lake has excellent potential, 8.9 percent has some potential, and 86.7 percent has no potential to contain lake trout spawning habitat. Additional data layers can be easily incorporated as new information becomes available on lake trout requirements for successful spawning. This model can be used to identify suitable spawning areas for monitoring and control, and has potential to be applied on other lakes experiencing lake trout invasion.

MONTANA'S CRUCIAL AREAS AND CONNECTIVITY ASSESSMENT: AN UPDATE AND DEMONSTRATION OF THE CRUCIAL AREAS MAPPING SERVICE

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Montana Fish, Wildlife and Parks (FWP) completed the Comprehensive Fish and Wildlife Conservation Strategy (CFWCS) in October 2005 as a landscape level plan to identify aquatic and terrestrial focus areas important to species and habitats of "Greatest Conservation Need." As implementation of the CFWCS began, FWP saw a need to refine the conservation scale and include terrestrial game and sport fish, FWP lands, and other recreational values into a Comprehensive Plan for Conservation. The "Crucial Areas and Connectivity Assessment"

is an attempt to refine the conservation scale and identify important game and nongame fish and wildlife habitats, critical corridors, and valued recreational areas using a combination of empirical data, modeling based on these data, and expert opinion. The goal of this project is to identify and display critical and important habitats for fish and wildlife. Multiple benefits are perceived through achievement of this goal: increased efficiency in planning and commenting on development proposals, effective targeting and planning for the conservation of valued habitats, and increased opportunity for coordination with other agencies states. FWP spent the past year developing data layers, vetting the layers both internally and within the scientific community. Layers available to date include: game quality, game fish life history, watershed integrity, species of concern, aquatic connectivity, angler use, terrestrial species richness, and core area index. In parallel, FWP has developed an interactive Crucial Areas Mapping Service (CAMS) that depicts these resource values and allows users to relate each resource value to risk factors including energy development, urbanization, and subdivision. As the project develops and nears completion, best management practices and policy related to critical habitats will be produced. In mid-March, we plan to release CAMS to the public as a pre-planning tool and comprehensive decision support system.

EFFECTS OF TOPOLOGY, NUMBER AND LOCATION OF NODES, POPULATION DENSITY, AND STOCKING DURATION ON HYBRIDS? DISPERSAL ACROSS A NETWORK

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Hybridization between native cutthroat trout (*Oncorhynchus clarki* sp.) and introduced rainbow trout (*O. mykiss*) has been a topic of fisheries research for decades in the northern Rocky Mountains, USA. Several studies suggest that the likelihood of introgression at any location in a stream network is influenced by the distance between that location and the source of non-native genes, e.g., stocking locations or areas dominated by non-native or introgressed fish. The relationship between “distance to non-native source” and hybridization rates, however, is rarely quantified. Studies that attempt to quantify the relationship generally ignore the potential influence of stream network topology on gene movement. We have developed and applied an agent-based model that tracks the lineage and breeding location of individual fish over time, this simulating the movement of non-native genes among spawning locations within a stream network. The model considered both distances between spawning sites and network topology in determining non-natal spawning site selection by stocked and straying fish. Model results suggest that stream network topology has a strong influence on the relationship between “stream distance from genetic source” and “degree of hybridization” at spawning locations. However, the importance of topology varies depending on underlying model assumptions about, stocking duration, number and location of spawning grounds, population density, and spawning site fidelity, i.e., “straying rates,” within the river system.

MEETING RESOURCE NEEDS FOR WHITEWATER RECREATION AND STREAM FISHERIES AT THE MYSTIC LAKE HYDRO PROJECT

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West Rosebud Creek is a valuable resource to both fishery and whitewater interests. It provides about 25 mi of trout habitat and several miles of late season, Class IV and Class V whitewater boating. Located approximately 90 mi from Billings and 150 mi from Bozeman, it is available to large populations of fishermen and boaters. Flow enhancement for whitewater recreation was identified as an issue early in the public relicensing process for the Mystic Lake Hydro Project. PPL Montana (PPLM) initiated a collaborative whitewater study and planning process with five stakeholder entities in 2004. In 2007 test flows and a paddler survey were used to identify desired flows, and in 2008 and 2009, test flows were used to develop the mechanics of providing the flows and investigate the effects of the whitewater flows on fish resources. In 2009 a flow protocol was developed that specifies the hydrologic conditions required for whitewater flow augmentation. PPLM plans to file the Final Whitewater Plan with the FERC in December 2009. A key to reaching agreement from all parties was the setting of a relatively high minimum flow to protect fish habitat. We will present the setting, constraints, methods, results, and initial experience of developing, testing, and implementing the whitewater flow plan.

THE SCIENCE OF FELT: A LOOK AT THE RESEARCH DRIVING THE MOVE TO ELIMINATE FELT SOLED WADERS

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One key to preventing new aquatic invasive species (AIS) introductions is to understand introduction pathways in order to implement prevention strategies. Significant evidence suggests that some AIS are being transported by wading anglers and many new introductions can be traced to this pathway. Research conducted in New Zealand and Montana has provided a better understanding of how AIS are likely spread by anglers and what might be required to reduce the risk of angler transport. The most significant finding is that the felt material glued to the soles of wading boots is a very problematic material and is far more likely to viably transport AIS than any other material used in waders. Based on this research, New Zealand instituted a national ban on the use of felt soles in October 2008. In the US, Alaska has announced a ban for parts of the state beginning in 2011 and New Mexico is considering a statewide ban. This presentation will provide an overview of the research into felt soles and will summarize how companies, agencies, policy makers and the public are reacting to the use of felt.

CLEAN, DRAIN AND DRY! WHAT ABOUT THE BIOLOGISTS?

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One of the main ways invasive species are introduced to new habitats is through the movement of boats, field gear, and equipment from water body to water body. We ask the public to clean their gear and boats but are we leading by example? A field crew can enter multiple water bodies during a day without cleaning and disinfecting their gear. VHS, zebra mussels, chytrid fungus, New Zealand mudsnails, Eurasian watermilfoil and terrestrial weed seeds among others can be easily transported by field staff. How can we expect the public to be concerned about how their actions spread invasive species when natural resource agencies and workers aren't taking preventative steps? Agencies and biologists need to develop and follow guidelines to prevent the movement of invasive species. Contracts with private companies and consultants should contain clauses that require disinfection of gear. The Montana Chapter of the American Fisheries Society has a role to play. As a society that represents aquatic resources and professionals, AFS can promote cleaning and disinfecting protocols and procedures and educate its members about the need. I suggest that the Montana Chapter of AFS develop a policy statement and guidelines to limit the spread of invasive species by field workers. Only by leading, will the public follow the necessary steps to prevent the introduction of new invasive species to Montana.

EFFICACY OF TERRAMYCIN® 200 FOR FISH (OXYTETRACYCLINE DIHYDRATE) FOR THE SKELETAL MARKING OF RAINBOW TROUT

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In 2009, we conducted a study to evaluate the efficacy of Terramycin® 200 for Fish (TM200; 44.1% active oxytetracycline dihydrate) administered in feed at a target dosage of 3.75 g/100 lbs fish/day for 10 days for the skeletal (fluorescent) marking of fingerling rainbow trout (*Oncorhynchus mykiss*). The in-life phase of the study was conducted indoors at a mean water temperature of 10.3 °C and comprised a 1-day acclimation period (no feed administered), 10-day treatment period (TM200-treated feed fed to six treated tanks; nontreated control feed fed to three control tanks), and 22-day post-treatment period (control feed administered to all tanks). At the end of the posttreatment period, all fish were collected and individually frozen. One month later, all fish were thawed, and two vertebrae were extracted from each fish. Each vertebra extracted was cleaned and then evaluated under ultraviolet light and a dissecting scope for the presence and quality of a fluorescent mark. All vertebrae extracted from TM200-treated fish ($n = 120$) had clearly visible marks, whereas no vertebrae extracted from control fish ($n = 60$) were marked. Consequently, in this study, TM200 administered in feed at a target dosage of 3.75 g OTC/100 lbs fish/d for 10 day was effective for the skeletal (fluorescent) marking of fingerling rainbow trout. Results will be used to support a U.S. approval of an expanded skeletal marking claim for TM200.

QUANTIFYING TEMPORAL VARIABILITY IN STREAM HABITAT DATA: IMPLICATIONS FOR RESTORATION AND MONITORING

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Quantifying natural and anthropogenic-induced levels of temporal variability is essential for robust trend analyses and for evaluating the effectiveness of restoration activities or changed management actions. Here, we used data collected as part of the Pacfish/Infish Biological Effectiveness Monitoring Project to evaluate the extent of temporal variability in instream habitat collected at the reach scale. We integrated habitat data collected yearly (2001-2009) at 50 sites experiencing a range of management activities into our analyses to better understand the consistency of temporal variability in watersheds with inherently different landscape characteristics and disturbance regimes. We initially decomposed variance estimates to remove site-to-site variability, sampling error, and year effects and use the remaining variance as a measure of site-specific temporal variability. We then relate this temporal variability to landscape, management, and climate attributes at multiple scales to better understand which characteristics result in more or less variability in habitat attributes at specific sites. Our results suggest temporal variability differs significantly across individual sites and attributes within sites, indicating our ability to detect significant changes as a result of management changes and/or restoration efforts are context dependent. The spatial scale of landscape attributes, e.g., stream buffer vs. catchment, related to temporal variability also varied across individual attributes. Our efforts highlight the importance of considering site-specific measures of temporal variability as they relate to specific restoration and management goals.

MONTANA DEQ'S APPROACH TO A STANDARDIZED SEDIMENT ASSESSMENT PROTOCOL: A BIOLOGICAL CONSIDERATION IN THE 303(D) LISTING PROCESS

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The Montana Department of Environmental Quality (DEQ) has been delegated by the Environmental Protection Agency (EPA) to implement provisions of the Clean Water Act. This includes submitting a 305(b) report every two years to the EPA describing the condition of all waters within the state's jurisdiction and creating a 303(d) list of impaired waters. This reporting process involves assessing water quality for various parameters including sediment, metals, and nutrients. DEQ is currently reforming the assessment process by addressing inconsistencies in the way assessments were performed in the past and writing standardized protocols that will lead to more consistent decisions regarding impairment determinations. Here we focus on the assessment protocol being developed for sediment; a pollutant that can cause harm to aquatic life and fisheries. DEQ has applied the "Sufficient Credible Data/Beneficial Use Determination" since 2000. This process is well suited for an initial (screening) assessment, but has been challenged on the grounds of rigor and reproducibility by stakeholders when a specific pollutant is identified as harming a beneficial use. Our approach to this reforming process has been to study the literature, what other states have developed for assessment protocol, and methods that have already been developed by DEQ.

Current considerations for what may be included in the assessment protocol will be discussed. We would like this process to be in the open for the public to comment and contribute. DEQ welcomes input in the process via a wiki page found at <http://montanastag.pbworks.com> and/or contacting any of the contributing authors.

EVALUATING WATERSHED CONDITION: BOTTOM UP VS. TOP DOWN APPROACHES?

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Habitat degradation has been identified as one of the major factors affecting the declines of fishes in the Columbia River Basin. The condition of physical habitat and the biotic integrity of stream systems are often directly correlated with substantial alterations to key landscape attributes. As such, numerous approaches to measure watershed condition have been developed. Here, we compare two separate measures of watershed condition: 1) a GIS-based measure of condition, i.e., top down; and 2) a ground based assessment of condition, i.e., bottom up), using field data collected across 1200 sites in the Interior Columbia River Basin under the PIBO Effectiveness Monitoring Project. With our GIS approach, we integrate land management and natural disturbance from watershed upstream of sample reaches into an overall watershed condition score. With our bottom-up approach, we integrate stream temperature data, indices of macroinvertebrate health, and an index of physical habitat condition from reach-level field data into an overall condition score. Our results indicate significant differences in assessments of condition across the two methods, as the GIS approach ranked considerably more watersheds with management activities into a low condition category than found in the bottom-up approach. Conversely, the GIS approach also categorized most watersheds with no or minimal management activities, i.e., reference, as low risk, while the field-based, bottom up approach illustrated a wide range of condition of reference sites due to natural disturbances. Our results suggest GIS-based approaches tended to quantify the ‘risk’ rather than condition within watersheds. The bottom-up approach tended to quantify actual conditions within streams, without consideration of potential risks associated with land management activities. Here, we advocate the most beneficial approach that would be some combination of the two to help guide and prioritize restoration activities to enhance habitat conditions and minimize risk of catastrophic disturbances.

BIAS ASSOCIATED WITH ELECTROFISHING ESTIMATES FOR MOUNTAIN WHITEFISH IN RIVERS: FOUR DIFFERENT WAYS WE KILLED WHITEFISH THIS SUMMER

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Habitat loss, competition from exotic species, and a warming environment clearly are changing cold-water aquatic communities in western North America. As a result, the need to accurately quantify and detect trends in many species, rather than just threatened and endangered salmonine stocks whose low densities often preclude statistical certainty, is critical. Conventional monitoring has ignored many sympatric species, like mountain

whitefish (*Prosopium williamsoni*). One challenge to monitoring other species is a lack of information on how to accurately sample their densities and monitor population status. Despite their broad distribution and locally high densities across their range in western North America, anecdotal evidence suggests their densities are declining and their distributions are changing, similar to those of sympatric salmonines. However, other anecdotal evidence suggests they may be more sensitive to electrofishing than salmonines. Thus, conventional monitoring may lead to biased estimates. We evaluated effects of capture technique, handling, and density on the survival of caged mountain whitefish in four separate week-long simulated mark recapture estimate studies in three sections of the Bitterroot River, Montana. In each study mountain whitefish succumbed to a variety of stressors and mortality ranged from 46-87 percent. Mortality was significantly greater than compared to paired treatments with rainbow trout (*Oncorhynchus mykiss*), where none died. As a result of the effects of a variety of stressors on survival and condition, we caution against mark recapture estimates for mountain whitefish in rivers.

INVESTIGATION INTO BIAS AND VARIABILITY IN ESTIMATES OF POPULATION SIZE AND BIOMASS WHEN CATCHES OF INDIVIDUALS ARE LARGE RELATIVE TO THE TOTAL POPULATION

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Biomass of fish populations has traditionally been estimated by multiplying the average weight of captured fish by the estimated number of fish, with its variance estimated as the product of two variances. We present a method for estimating fish biomass in small streams (< 5 m wetted width) that uses a finite population correction factor (FPC) to take advantage of the fact that a relatively high proportion of the total population is normally captured and can be weighed during removal estimates. For these captured fish, measurement error is related to scale accuracy and field conditions. For the portion of the population that is not captured, we used a randomly stopped sums estimator (RSS) to estimate the total weight and variance of this non-captured proportion of the population. We also evaluated FPC and RSS methods individually to determine which of the four methods—(1) combination of FPC and RSS (FPCRSS), (2) traditional (hereafter OLD), (3) FPC, or (4) RSS—performed best. We also incorporated biomass estimates for fish that were captured, but not weighed, using length-weight regression predictions (FPCRSSreg). Performance of these estimators was evaluated using both simulated and field data. We based performance on reduction in the coefficient of variation (CV) of the biomass estimate and coverage of 95-percent confidence intervals (proportion of trials for which the 95-percent estimated biomass confidence intervals included the true biomass). The FPCRSS method had the narrowest CVs and the OLD method had the widest CVs for both the field and simulated data. Because of the high variance for the OLD method, 95-percent CIs for this method included the true biomass for a higher proportion of trials (nearly 100%) than 95-percent CIs for the FPCRSS method, but the coverage of the FPCRSS method for two-pass removal estimates was 80 percent or better for capture probabilities of 0.5 or higher. Using simulated data, we found that removal

estimators are biased and that these biases are more pronounced at lower capture probabilities and lower population sizes. This bias in removal population estimators causes a bias in biomass estimates and was partly responsible for poorer coverage of 95-percent CIs. Our attempts to correct for population estimate bias resulted in much wider confidence intervals for both population and biomass estimates. For 607 field biomass estimates where all captured fish were weighed, the median CV for the FPCRSS method (0.05) was significantly lower (Wilcoxon sign-ranked test: $P < 0.001$) than the OLD method (0.76). When a portion of captured fish was not weighed, but estimated using length-weight regression relationships, the FPCRSSreg method had significantly lower CVs (median = 0.06; Wilcoxon sign-ranked test: $P < 0.001$, $n = 130$) than the old method (median = 0.86).

USING FIXED AND PORTABLE HALF-DUPLEX PIT TAG ANTENNAS TO EVALUATE FISH MOVEMENT IN A STREAM NETWORK: A CASE STUDY IN THE UPPER BIG HOLE RIVER BASIN

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Passive integrated transponder (PIT) technology is commonly used to evaluate the movement, habitat use, and dynamics of stream fish populations and assemblages. One distinct advantage of this technology is the ability to collect information over the life span of individually identifiable fish using passive monitoring sensors. In the upper Big Hole River basin, we used a combination of fixed and portable half-duplex PIT tag antennas to evaluate salmonid movement and habitat use at multiple spatial and temporal scales. In the summer and autumn of 2009, we used a network of 15 fixed stations and a series of portable antenna surveys to relocate PIT-tagged fish in the mainstem Big Hole River and tributaries within the valley-bottom. We used multiple antenna designs to account for the considerable range in stream size (~ 2-60 m wetted width). We directly evaluated the detection efficiency of our portable antennas in five tributaries and one reach of the mainstem. Overall, we conservatively estimated a 54 percent ($n = 6$, $SD = 0.13$) detection efficiency for one-pass surveys, with detection efficiencies varying among fish species and, to a lesser extent, among sites. Detection efficiency estimates for shed tags were consistent among sites and averaged 93 percent ($n = 4$, $SD = 0.10$). Challenges, successes, and failures in implementing these antennas will be discussed. Overall, using a combination of fixed and portable antennas proved a useful and efficient approach to evaluating fish movement in this stream network.

AQUATIC POSTER SESSION

EFFECTS OF CARBON DIOXIDE ON RAINBOW TROUT LARVAE: APPLICATION FOR INVASIVE FISH ERADICATION

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Currently, efforts are underway to eradicate invasive fish species that threaten the ecological integrity of aquatic ecosystems. Several studies have examined the effects of anesthetizing fish for easier handling, surgical procedures, tagging and management. Carbon Dioxide (CO₂) is an approved and efficient anesthetic for adult fish in medicine and aquaculture and is favorable due to lack of residues, zero withdrawal period and does not need to be registered as its classification is generally regarded as safe (GRAS). Carbon dioxide has also shown to have lethal effects on other life history stages of fish. In this study, various early life stages of Rainbow trout (*Oncorhynchus mykiss*) larvae were exposed to CO₂ in the form of dry ice pellets to determine the critical period of sensitivity for mortality in a model salmonid species. Studies were conducted in aluminum tanks ($n = 3$ tanks per treatment, with three chambers in each tank with 40 larvae per chamber) with 68 liters of filtered creek water (dissolved CO₂ = 4 mg/l, dissolved O₂ = 8.125 mg/l, pH = 7.78, temperature = 12.9 °C, conductivity = -55 mV, Total alkalinity as CaCO₃ = 160 mg/l). Larvae exposed at post hatch day 10 had increased susceptibility to CO₂, when compared with earlier embryonic stages. The results of the experiment indicate that early rainbow trout life history stages are susceptible to CO₂ but only at late embryonic stages and may have implications for systematically eradicating invasive salmonids.

LONG-TERM TRENDS IN THE RELATIVE ABUNDANCE AND SIZE STRUCTURE OF SPORT FISHES IN THE FLATHEAD RIVER, MONTANA, FOLLOWING CHANGES IN KERR DAM OPERATIONS

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We studied long-term trends in relative abundance and size structure of four sport fish taxa in the Flathead River, Montana, following changes in operations at Kerr Dam. In 1997 Kerr Dam was changed from a power-peaking and load-following facility to a base-load facility. New base-load operations were designed to reduce fluctuations by establishing within- and between-day ramping-rate restrictions, i.e., maximum hourly and daily rates of change. We monitored spring and autumn trends in the relative abundance of two size classes (substock and stock) of northern pike (*Esox lucius*), *Oncorhynchus spp.*, brown trout (*Salmo trutta*), and smallmouth bass (*Micropterus dolomieu*) from 1998-2008 using nighttime

electrofishing. We documented significant ($P < 0.05$) increasing trends in the autumn catches/unit effort (fish/hr) of both substock and stock sizes of all taxa, except stock northern pike. Trends in spring relative abundances were similar to those in autumn, except that increases in smallmouth bass catch rates were not significant ($P > 0.05$). We also examined long-term patterns in the size composition of fishes following changes in dam operations. All four taxa had either an initial strong downward shift in annual median total length or a decrease in the minimum sizes of fish captured, or both, a pattern consistent with enhanced survival of smaller fishes and highly suggestive of benefits from changes in dam operations. Our results imply that modifications in the operation of Kerr Dam led to significant increases in relative abundance of four sport fish taxa in the Flathead River.

THE EFFECT OF HUMAN ACTIVITY ON THE MOVEMENT OF THE IDAHO GIANT SALAMANDER IN THE LOCHSA DRAINAGE OF CENTRAL IDAHO

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Movement influences fundamental ecological and evolutionary processes including population persistence and gene flow. It is, however, relatively unknown how fragmentation of habitats by anthropogenic disturbances influences movement of stream organisms. We examined the relationship between presence of road culverts and movement patterns of a large stream salamander (*Dicamptogon aterrimus*), along two streams in the Lochsa River watershed of central Idaho. With this research, we tested whether road culverts affect frequency of movement. To determine movement patterns, we conducted a mark-recapture survey of 30-m reaches above and below road culverts and in reaches away from culverts during the summers of 2008 and 2009. Using a multi-strata model and Akaike's information criterion for model selection, we estimated survival and transition probabilities within and among stream reaches. We found that presence of road culverts does not effectively halt movement along the stream channel and, therefore, should not stop gene flow among local populations. It may, however, hinder important demographic contributions, but this is in need of further study. Additionally, frequency of movement between reaches separated by culverts varied significantly between the two streams indicating that *D. aterrimus* populations may each react differently to presence of road culverts. This research shows the need to understand variations in response of distinct populations of stream organisms to human disturbance for effective amphibian conservation practices to be implemented.

EFFECTS OF ELECTRICITY AND ALTERED CONDUCTIVITY ON RAINBOW TROUT EMBRYOS: A STUDY TO DETERMINE EFFICACY OF ELECTRICITY FOR ERADICATION OF INVASIVE SALMONIDS

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Electricity has been an applied means of facilitating capture and removal of invasive fishes for many years. Current methods involve use of electrodes to establish a current through which passing fish will be susceptible to a brief shock to stun. This method, however, only affects free swimming individuals and is not inclusive of early life history stages such as embryos within spawning substrate. This study evaluates the susceptibility of embryonic and larval stage rainbow trout (*Oncorhynchus mykiss*) to direct DC current between 2-20v/cm in varying conductive waters to determine lethality for invasive salmonid eradication efforts. Rainbow trout embryos ($n = 10$ embryos/exposure) were initially exposed to homogeneous electric fields for 5 sec with a water conductivity of 220uS/cm from 1 day post fertilization (DPF)/ 27 temperature units (TU) to 15 DPF/405TU. Mortality was assessed 24 hrs post exposure and the LV50 (lethal voltage) at 220uS/cm was determined for each TU. Embryos from six periods of development were then exposed to their respective LV50 voltages in varying conductive waters (20-600uS/cm). Susceptibility to direct DC voltages increased with voltage but overall susceptibility decreased with development. Susceptibility to a constant voltage increased with increasing conductivity and was consistent throughout early development (81TU-292TU), but the effects of increased conductivity were not enhanced in eyed embryos after 364TU. Results indicate that direct DC current applied prior to eyed embryonic stages, the period of greatest trout embryo susceptibility, is an effective means of eradicating invasive and nuisance salmonids

THE EFFECTS OF ULTRAVIOLET LIGHT ON RAINBOW TROUT EMBRYOS

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There currently exists a need to develop new approaches to control aquatic invasive and nuisance species. The effects of light radiation such as ultra-violet wavelengths of light have shown negative effects, such as increased embryo mortality in early embryonic salmonid larvae. This study explores the use of light radiation for eradication of invasive fish. Experiments were conducted to evaluate dose and critical period of sensitivity for mortality of rainbow trout (*Oncorhynchus mykiss*) embryos after exposure to visual and ultra-violet light radiation. Endpoints recorded include exposure intensity, effective distance from source, duration of exposure, malformations and mortality. Introduced light may be an effective and feasible eradication technique of early life history stages of fish and invertebrate invasive species in situ, as light can be implemented and removed with minimal environmental impact.

EFFECT OF HATCHERY REARING ENVIRONMENT ON SURVIVAL AND PERFORMANCE OF OUTPLANTED WESTSLOPE CUTTHROAT TROUT USED FOR POPULATION RECOVERY

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Reintroduction of native fish stocks is an important management tool used to mitigate the effects of invasive species and loss of habitat. One means of reintroduction is the use of hatchery fish to create or supplement native populations in areas of their historic range. The use of hatchery fish for reintroduction can be inefficient as low survival and competition with wild fish has been noted. This study has attempted to develop and evaluate the effectiveness of enriched hatchery rearing strategies on increasing the efficiency and effectiveness of hatchery reintroductions by examining behavioral, morphological, and physiological differences among westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) reared in varying levels of enriched environments. Social behavior, predator avoidance, cover seeking behavior, fin condition, growth, stress response, immune function, and muscle content have been evaluated during the first phase. Preliminary results show divergence in growth, fin condition, and social and cover seeking behaviors among the different rearing environments. Findings have suggested that manipulating hatchery rearing environments can alter behavior and morphology but determining if these alterations improve survival once outplanted is currently unknown.

SEASONAL FISH LOSSES THROUGH HAUSER DAM, MONTANA, 2007-2008

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Management of fish populations in Hauser Reservoir, Montana, is hindered by undesirable and unpredictable downstream fish entrainment through Hauser Dam. We quantified fish entrainment through the dam using hydroacoustics at turbine intakes from July 2007 to November 2008 and over the spillway from 21 May to 18 July 2008. Species composition was characterized using multiple netting gears. Total estimated entrainment was $145,470 \pm 6,204$. Annual entrainment from summer to autumn was higher in 2007 ($n = 79,031 \pm 4378$) than in 2008 ($n = 52,513 \pm 3,966$). Spillway entrainment was 19 percent of annual entrainment in 2008 and was correlated with spillway discharge; turbine entrainment was not. Turbine entrainment increased from summer to autumn in both years, probably in response to autumn turnover and releases of hatchery rainbow trout (*Oncorhynchus mykiss*). Spill entrainment in 2008 resulted in similar entrainment between summer and autumn, but autumn turbine entrainment increased in 2008. About 60 percent of entrained fish were smaller than 220 mm. We applied species composition by size to the hydroacoustic data to identify fish species entrained, but many fish ($n = 55,529 \pm 4,397$) could not be reliably assigned to species because concurrent net catches did not include individuals of similar size. Total entrainment of identified fish was made up of mostly rainbow trout (*Oncorhynchus mykiss*; 33.3%) and

walleye (*Stizostedion vitreum*; 30.2%). Identification of patterns in spatial and temporal fish losses affords fishery managers the ability to make more informed decisions about operation of this dam.

A MULTIMEDIA INFORMATION AND EDUCATION TOOL ON THE IMPORTANCE OF BULL TROUT AND THE RELATIONSHIP BETWEEN BULL TROUT AND THE SALISH AND PEND D'OREILLE PEOPLE

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The Confederated Salish and Kootenai Tribes have undertaken a large-scale watershed restoration project in an effort to benefit bull trout (*Salvelinus confluentus*) in the Jocko River drainage. An important component of this comprehensive project is education and outreach. In this poster and an accompanying digital presentation we will give an overview of a multimedia information and education project that describes the ecology and importance of bull trout, the relationship between bull trout and the Salish and Pend d'Oreille people, and the Tribes' current efforts to restore habitats. The project is composed of an integrated set of educational materials that will include an interactive DVD entitled "Explore the River: Bull Trout, Tribal People and the Jocko River", a curriculum, a website, a storybook "Bull Trout's Gift", and an accompanying field journal to be published by the University of Nebraska Press.

BIOLOGICAL SCIENCES – TERRESTRIAL

PLENARY SESSION ABSTRACTS IN ORDER OF PRESENTATION

WILDLIFE MANAGEMENT WITH A CAPITALISTIC OR A SOCIALISTIC FLAVOR: A COMPARISON OF MONTANA WITH NORWAY

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Montana and Norway passed laws in 1897 and 1899, respectively, which set the stage for today's wildlife management. These laws were part of an effort to conserve dwindling populations of large ungulates. The Montana Legislature decided that the responsibility of wildlife management would rest primarily with the State, whereas the Norwegian Parliament decided that it would rest with the landowner. These efforts to conserve native large ungulates were successful in both Montana and Norway, but the choice of philosophically different ways to accomplish it led to very different management systems. I argue that Montana chose a socialistic system, in the sense that everyone has the same right to hunt and fish. Norway chose a capitalistic system with the landowners owning the hunting and fishing rights. I will argue that this has had major implications for the differences between these two entities in political support for wildlife, hunting methods and ethics, and wildlife conservation in general.

FIVE MANAGERS, FIVE CONTINENTS, PERSPECTIVES SHARED

Kurt Alt, Montana Fish, Wildlife and Parks, 1400 S. 19th Ave., Bozeman, Montana 59718

Wildlife management and conservation are dynamic, solving problems on landscapes where people live, work and recreate. Manager to manager exchanges are as relevant to advancing conservation knowledge as professional publications, but have yet to reach the same institutional/cultural application within our profession. Many in the world focus on total protection and protected areas as the basis for conservation, i.e. the Yellowstone model. Today, a new focus is emerging on conservation through management, recognizing that most of the world's land base occurs outside of protected areas. This presentation will focus on shared experiences between wildlife managers on five continents. It will begin with introduced species (red deer) management and plant/rangeland ecology in the Patagonia region of Argentina; then disease concerns, wildlife tolerances, livestock husbandry in the Serengeti, Mara and Mara Conservancy areas of Tanzania and Kenya. It will bring perspectives to hunting season management of red deer and relationships to Amur tiger conservation in the Russian Far East. Finally, it will land in northern Europe to discuss livestock (reindeer) predation experienced by the Sámi people of Norway and Sweden, and their reindeer loss reimbursement approach. The experiences and perspectives gained and shared by Montana wildlife managers and biologists will be discussed, as they have changed our season setting applications and are refining predator/ prey/livestock management in Montana. In today's time, manager to manager exchanges may become the most relevant approach to advancing new management and conservation thoughts, philosophies, research initiatives, and policies.

BEYOND BORDERS: WORLD WILDLIFE FUND'S TRANSBOUNDARY WILDLIFE CONSERVATION PROJECTS IN THE NORTHERN GREAT PLAINS

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The World Wildlife Fund's (WWF) Northern Great Plains Program (NGP) spans five states and two provinces across 279,000 mi² of mixed-grass prairie. Since its inception as an ecoregional program in 2003, the WWF NGP has been engaged in numerous multi-jurisdictional and cross-border initiatives designed to foster communication and coordinate actions to achieve biodiversity conservation in the shared landscapes. From black-footed ferret restoration, long-billed curlew migration, and cougar research to climate change adaptation and conservation economics, we collaborate, financially contribute to, and lead over 50 projects with as many domestic and international partners. One set of partnerships is centered in northern Montana, southwest Saskatchewan, and southeast Alberta focused on conserving crucial habitats and connectivity for pronghorn. This project area is also home to other partnerships WWF participates in, such as the Prairie Pothole Joint Venture, Northern Mixed Grass Transboundary Conservation Initiative, and its successor, Crossing the Medicine Line Network. While these initiatives share the common objective of fostering biodiversity conservation across boundaries, there are differences between them involving varied historical and cultural backgrounds, legal, and regulatory regimes. Nature does not recognize county, state, tribal, governmental, or international borders, thus transboundary collaboration is essential to successfully achieving common conservation objectives.

THE SWAN VALLEY GRIZZLY BEAR CONSERVATION AGREEMENT: A CASE HISTORY OF COLLABORATIVE LANDSCAPE MANAGEMENT

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The Swan Valley Grizzly Bear Conservation Agreement (SVGBCA) was initiated in 1995 between the USDI Fish and Wildlife Service, Flathead National Forest, Plum Creek Timber Company and the Montana Dept. of Natural Resources and Conservation to address grizzly bear habitat management concerns on ~ 370,000 ac of intermingled ownership located between the Mission Mountain and Bob Marshall Wilderness areas in northwestern Montana. The general objective of the SVGBCA is to implement a multi-landowner management plan that would contribute to the conservation of grizzly bears (*Ursus arctos horribilis*) while still allowing cooperating landowners to realize the economic benefits of their lands. The specific biological goals are to maintain connectivity between the Bob Marshall and Mission Mountain wildernesses and minimize the risk of death or injury to grizzly bears using suitable habitat within the valley. The general conservation approach is to designate linkage zones to

facilitate bear movement between wilderness areas, rotate forestry activities in the landscape to minimize disturbance, limit open road densities, and implement habitat management guidelines at the landscape and site-specific levels. Research and monitoring was initiated in 2002 with the inclusion of MDFWP in telemetry studies of grizzly bears using the SVGBCA. Detail on SVGBCA implementation and effectiveness monitoring is presented. Key findings are that connectivity objectives are being met regarding both east-west connections between the wilderness areas and north-south movements between important habitats outside the Swan Valley. Bears stayed in the Swan Valley generally, with little altitudinal migration. Grizzlies used all ownerships in the valley and habitat use varied between nocturnal and diurnal activity periods. High levels of mortality were documented in 2003 and 2004. Landownership changes within the 15-year-old SVGBCA resulting from the Montana Legacy Conservation Land Sale are discussed.

GENERAL ABSTRACTS
ALPHABETICAL BY FIRST AUTHOR'S LAST NAME
(* DENOTES PRESENTER)

EPIDEMIOLOGIC FINDINGS AND MANAGEMENT RESPONSE DURING A BIGHORN SHEEP DIE-OFF IN THE ELKHORN MOUNTAINS OF WEST-CENTRAL MONTANA

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Bighorn sheep (*Ovis canadensis*) were introduced into the Elkhorn Mountains of west-central Montana in the mid 1990s. The population increased in number to approximately 250 animals until the winter of 2007-2008 when about 84 percent of the population died from a pneumonia related epizootic. Management actions during the die-off were geared toward removing as many sick animals as possible in efforts to reduce overall mortality. Due to the stage of the epizootic removal of sick sheep was not effective in interrupting the die-off. Samples were collected from bighorn sheep, domestic sheep, mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*) and domestic goats utilizing the same winter range. *Pasteurella* spp, *Moraxella ovis* and *Mycoplasma ovipneumonia* were isolated from lung tissue of dead bighorns and pharyngeal swabs collected from domestic sheep occupying similar range during the epizootic. Both the bighorn sheep and domestic sheep also shared similar gastro-intestinal parasites including *Nematodirus* spp and *Eimeria* spp. Testing tissues and fecal samples from sympatric mule deer suggested no shared bacterial pathogens and limited shared gastrointestinal parasites. Evaluation of fecal samples from domestic goats and elk also occupying bighorn sheep range identified few shared parasites that may have contributed to the epizootic.

BRUCELLOSIS IN THE GREATER YELLOWSTONE AREA: A MULTI-STATE ISSUE WITH VARYING MANAGEMENT PARADIGMS INFLUENCING MANAGEMENT AND POSSIBLE ERADICATION OF THE DISEASE IN WILDLIFE

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Brucellosis, caused by the bacteria *Brucella abortus*, is an infectious disease of cattle, bison (*Bison bison*) and elk (*Cervus elephus*). The Greater Yellowstone Area (GYA) is the last known reservoir of the disease in the lower 48 states. Recent cases of the disease in cattle herds of Idaho, Montana and Wyoming have been attributed to exposure from wild elk and have brought increased focus on management and eradication of the disease from wildlife populations. Elk management programs within the three states of Idaho, Montana and Wyoming differ in response to the disease. Efforts to manage the disease within the GYA are greatly influence by management actions taken within individual states. The differing management actions and the potential influence on brucellosis management and possible eradication are discussed.

STATUS REVIEW AND CONSERVATION INITIATIVES FOR AMERICAN BISON: A CONTINENTAL PERSPECTIVE

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Five hundred years ago, there were tens of millions of American bison (*Bison bison*) roaming free on the plains of North America from Alaska to northern Mexico. The decimation of the American bison in the late 1800s inspired the first recovery of bison and an entire conservation movement that protected wildlife and wild places across North America. As of 2008, there were ~ 400,000 bison in commercial herds in North America, some 93 percent of the continental population. There were 61 plains bison conservation herds containing ~ 20,500 animals, and 11 conservation herds of wood bison, containing nearly 11,000 animals. Little progress has been made in recent decades to increase the number of animals in conservation herds. Many factors affect survival of bison populations, including limited habitat and severe winters. Yet, the greatest challenge is to overcome the common perception that the bison, which has had a profound influence on the human history of North America, socially, culturally and ecologically, no longer belongs on the landscape. The key to recovery of this species is recognition that the American bison is a wildlife species and needs to be conserved as wildlife. Recently a new conservation strategy was developed by the IUCN bison specialist group and a new vision for the ecological restoration of bison was described by the Wildlife Conservation Society under our American Bison Society initiative. A new Continental vision for the American bison is inspiring a second recovery and helping to restore functional grassland ecosystems.

LIFE ON THE FRINGE: MUSKOXEN IN THE ALASKAN ARCTIC

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The Arctic is experiencing some of the most dramatic temperature changes on the planet. Species at the edge of their range often confront conditions that differ from those in the center—to the extent that the persistence of peripheral populations might be more challenged if bioclimatic factors rule. An indisputable Arctic-adapted species are muskoxen (*Ovibos moschatus*) which occur at their historic southwestern terminus in Arctic Alaska. We instigated a multi-year project to assess sources of variation in demography, attendant life-histories, and vital rates by contrasting populations on National Park Service and adjacent lands at Bering Land Bridge and Cape Krusenstern. A major challenge of Arctic work is expense; in lieu of handling large numbers of animals, we present a simple non-invasive method to predict body mass in young and sub-adults. We used photogrammetry to document head sizes at known distances and angles on more than 300 wild muskoxen from four age cohorts (1 to 3 yrs, and older). With head size parameters calibrated on captive individuals, 85 percent of the variance in body mass was explained for animals < 4 yrs of age. Accuracy diminished at > 65 meters and as animals reached puberty, the latter because nutrients allocated for skeletal growth are re-directed to meet reproductive demands. We believe that our ability to associate changes in mass/yr with abiotic and biological factors and survival will enhance opportunities to test hypotheses about causes and correlates of variation in population persistence.

HUMAN INFLUENCES ON ELK MOVEMENT RATES AND RESOURCE SELECTION IN THE WILDLAND-URBAN INTERFACE.

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Elk (*Cervus elaphus*) are known to select for refuge from hunting by humans (elk hunting). In many areas in the western U.S., elk hunting is completely excluded in the wildland-urban interface (WUI) as a result of land ownership change and subdivision, thus providing refugia for elk. Many of these WUI elk populations are increasing rapidly, and pose a significant credibility challenge to wildlife managers. The North Hills Elk Herd, in Missoula, Montana, has been growing at ~11 percent since the early 1980s, and the herd now numbers over 300 animals. Landownership is a complex matrix of public and private lands that range from partial to complete exclusion of hunting, thus elk hunting pressure is low and provides multiple refugia. Montana Fish, Wildlife and Parks used elk hunting in this setting to reduce population growth, crop depredation, and habituation. Little is known about the

efficacy of elk hunting on elk movement rates and habitat selection. We used First-Passage Time (FPT) and Resource Selection Functions (RSF) analysis based on nine GPS collared adult female elk during three hunting seasons with increasing hunting pressure (2007-2009) to test relationships between elk movement rates and resource selection in the WUI. Elk FPT decreased annually, if they were accessible, and differed by hunting mode and season. Elk selected for intermediate distances from homes, trails, and weakly avoided access. These data have been used to modify hunting season structure, acquire conservation easements, and develop lasting partnerships in a complex matrix of ownerships.

MAPPING BRUCELLOSIS INCREASES RELATIVE TO ELK DENSITY USING HIERARCHICAL BAYESIAN MODELS

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The relationship between host density and parasite transmission is central to the effectiveness of many management strategies. We applied hierarchical Bayesian methods to an 18-yr dataset on elk (*Cervus elaphus*) brucellosis in the Greater Yellowstone Ecosystem (GYE) and found that increases in brucellosis seroprevalence were strongly correlated with elk densities. Elk that were densely aggregated on supplemental feeding grounds had higher seroprevalence in 1991, but by 2008 many areas distant from the feeding grounds were of comparable seroprevalence. Thus, brucellosis appears to be expanding its range into areas of higher elk density, which is likely to further complicate the United States brucellosis eradication program. The data could not differentiate among linear and non-linear effects of host density, which is a critical area where research can inform management actions. This study is an example of how the dynamics of host populations can affect their ability to serve as disease reservoirs.

MANAGEMENT CHALLENGES FROM PREDATOR-PREY EFFECTS ON THE GALLATIN CANYON ELK HERD

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The Gallatin Canyon elk (*Cervus elephus*) herd northwest of Yellowstone National Park (YNP), is among the most historic and heavily-researched herds in Montana. Counts, classifications, and harvest records extend from 1919 to present, with intensive wolf-elk research conducted over 2001-2006. The herd remained remarkably stable for more than 80 years, averaging ~1900 wintering elk from 1919-1985. After a data gap spanning 1985-

1996, wintering elk counts showed alarming declines, with an average of 960 wintering elk counted over 1996-2010 and 511 counted in 2010. We used harvest records, aerial surveys, and telemetry on elk and wolves (*Canis lupus*) to determine mortality/predation rates and elk numbers, movements and distribution. From these data we developed a variety of population models to quantify effects of wolf predation and hunter harvest on elk in the Gallatin Canyon. Closed population models suggested a yearly elk population decline of 1-15 percent, whereas open population models suggested a decline of 30 percent, indicating losses due to deaths and emigration. Predator-prey ratios in the Gallatin are among the highest recorded in Montana, similar only to the unhunted elk populations of the Madison Headwaters (YNP). Like the Madison Headwaters, the Gallatin elk herd showed declines from direct predation and emigration loss. matrix models suggested hunting has a negligible population effect compared to predation, yet hunting is the only factor MFWP is currently able to moderate. We are left with a management paradox: hunting is not sustainable in this declining population, yet cessation of hunting will not reverse the elk population declines and will eliminate a treasured hunting opportunity that some families have enjoyed for generations.

LINKING LANDSCAPE CHARACTERISTICS TO LOCAL GRIZZLY BEAR ABUNDANCE AROUND GLACIER NATIONAL PARK

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Grizzly bear (*Ursus arctos*) habitat use has been extensively studied, but habitat has rarely been linked to demographic parameters and habitat models have not accounted for variation in detection or spatial autocorrelation. We collected bear hair from bear hair traps and rub trees in and around Glacier National Park (GNP) in northwestern Montana and genotyped the samples to identify individuals. We developed a hierarchical model with 1) explicit landscape and habitat variables that we theorized might influence abundance, 2) separate sub-models of detection probability for each sampling type, 3) covariates to explain variation in detection, 4) a conditional autoregressive (CAR) term to account for spatial autocorrelation, and 5) weights to identify most important variables. Road density and percent mesic habitat best explained variation in female grizzly bear abundance and the spatial autocorrelation term was not supported. Female abundance was higher where road density was lower and where more mesic habitat exists. Detection of females increased with rub tree sampling effort. Road density best explained variation in male grizzly bear abundance and the spatial autocorrelation term was supported. More male bears occurred in areas of low road density. Detection of males increased with rub tree and hair trap sampling effort and decreased with time. Our finding that road density influences abundance concurs with conclusions of earlier studies that road density influences habitat use.

PARALLEL CONSERVATION ISSUES ON OPPOSITE SIDES OF THE EARTH: MONTANA PRAIRIE DOGS AND TIBETAN PIKAS

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Conservation issues often occur in patterns that are replicated spatially as well as temporally. While differing in detail as well as in cultural and regulatory background, issues surrounding conservation and management of black-tailed prairie dogs (*Cynomys ludovicianus*) in central Montana resonate strongly on the far side of the world in the case of plateau pikas (*Ochotona curzoniae*) on the Tibetan Plateau, People's Republic of China. Prairie dogs are well known for their role as ecosystem engineers, facilitating the existence of many other species, yet have faced persecution for decades and even now are only grudgingly provided acceptance by policy and regulation. Unlike in North America, most species of pikas in Asia are steppe dwellers whose presence and burrowing activity provides niches for a wealth of other species. Species for which plateau pikas provide needed habitat features vary from insects to passerine birds; species that depend on them as food sources vary from the small, e.g., (*Mustela altaica*), to the large (*Ursus arctos*). Both prairie-dogs and pikas have an obligate predator, i.e., black-footed ferrets here, Tibetan foxes (*Vulpes ferrilata*) there. Beginning in the 1950s, Chinese policy called for eradication or reductions of plateau pikas, labeling them pests in language similar to that more commonly seen in the context of urban rats. Poisoning campaigns have waxed and waned, but government policy remains antagonistic to pikas even within nature reserves. Both prairie dogs and plateau pikas are keystone species, but neither yet benefits from public policy that prioritizes ecological integrity over short-term expediency.

LAND MOLLUSK FAUNA OF MONTANA: BIOGEOGRAPHY, CONSERVATION STATUS AND PROSPECTS

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Approximately 78 species of land snails and slugs have been reported for Montana, contrasting to 93 for British Columbia, 85 for Idaho, and 43 for Wyoming. Non-natives comprise 14 percent (4 snails, 7 slugs) of the total for Montana, 29 percent (13 snails, 14 slugs) for British Columbia, 19 percent (5 snails, 11 slugs) for Idaho, and 7 percent (2 snails, 1 slug) for Wyoming. Total native species for Montana, British Columbia and Idaho are nearly equal (67, 66, and 69, respectively), but only 40 for Wyoming, reflecting an overall drier and harsher climate. For Montana, 24 species (16 snails, 8 slugs) occur only west of the Continental Divide; the land snail fauna east of the Divide is 43 species, equal to the Wyoming total. Reflecting further the significance of western Montana for mollusk biodiversity, with its moister and more moderate climate, 15 of 24 exclusively western species (7 snails, 8 slugs) are Montana Animal Species of Concern, 5 of which (*Discus brunsoni*, *Oreohelix alpina*, *O. amariradix*, *O. carinifera*, *O. elrodi*) are Montana endemic snails. Land snails require cool and humid environments during their active season, microhabitats most prevalent in mature and old growth forests, riparian corridors, and around springs, but also present in large stable talus slopes. Many of these habitats are vulnerable to a variety

of human-caused and natural disturbances. Some western Rocky Mountain populations are currently considered conspecific with Pacific Northwest coastal populations; genetic analyses are needed to determine if these are sister species, similar to results obtained for several amphibian taxa.

APPLYING NOVEL APPROACHES TO OLD DATASETS: UTILIZING OPPORTUNISTIC OBSERVATIONS TO DESCRIBE SPATIAL-USE PATTERNS FOR THE STELLER SEA LION USING A BAYESIAN POISSON MODEL

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This study utilized a dataset of opportunistic sightings to describe at-sea spatial use patterns for the endangered Steller sea lion (*Eumetopias jubatus*). Although opportunistic sighting data are often dismissed as unusable because of their lack of associated effort records, they often contain a wealth of information about a species' movement patterns and use of time and space. Such is the case with the Platforms of Opportunity (POP) dataset collected by the National Marine Fisheries Service. The POP dataset contains opportunistic at-sea marine mammal observations throughout the entire Pacific Ocean basin. In this study, a novel methodology was developed to overcome the lack of effort records associated with the POP observations and allow for calculation of effort-corrected Steller sea lion encounter rates in 15 km² grid cells covering the species' entire range. A Bayesian Poisson model was used to quantify both the encounter rate and the uncertainty surrounding that rate in each grid cell. Spatial-use patterns specific to the breeding and non-breeding seasons were estimated along with overall year-round patterns. Prior to this analysis no range-wide spatially-explicit information about Steller sea lion habitat use existed.

MOVING BEYOND NICHE MODELS: HABITAT SUITABILITY FOR NESTING WHITE-HEADED WOODPECKERS

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Ecological niche models of habitat suitability are attractive due to their conceptual interpretation and use of presence-only data. Niche models have potential to exploit a variety of presence-only data sources, such as museum records, limited effort surveys, ancillary field observations, and citizen science programs. Limitations of niche models, however, substantially reduce their utility in management situations, in particular, the inability to independently evaluate habitat covariates for their relative influence. Generalized linear models, i.e., logistic regression, provide this ability, but require both presence and absence data. We present an approach that overcomes the limitation of niche models while retaining the use of presence-only data. The generation of pseudo-absences, derived from areas of low suitability as determined by the niche model, allow use of logistic regression to produce robust models of habitat suitability. The approach also has the added benefit of reducing contamination (false absences) among absence data that occurs with simple random sample approaches. We discuss the pseudo-absence approach in an example of modeling habitat suitability for nesting white-headed woodpeckers (*Picoides albolarvatus*).

AVIAN INFLUENZA, AN INTERNATIONAL CONCERN

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The spread of the virulent highly pathogenic avian influenza virus H5N1 Asian strain (HPAI H5N1) throughout Asia and into Europe and Africa since 2004 has resulted in the loss of millions of domestic birds and caused concern about its zoonotic potential. Though the significance of wild birds in the transmission of HPAI H5N1 remains unclear, wild birds are known to be the source of some outbreaks and can serve as an important sentinel for introduction of the virus to new areas due to expansive migration movements. The comprehensive HPAI H5N1 surveillance program, established in 2006 by the USDA and USDI Fish and Wildlife Service in cooperation with the states and tribes, monitors both wild and domestic bird populations to ensure the earliest detection of HPAI H5N1 incursion into the United States. Montana is a priority state in nationwide surveillance because it borders Canada and is divided by the Pacific and Central Flyways. Montana Fish, Wildlife and Parks, USDA/APHIS/Wildlife Services, and USDI Fish and Wildlife Service have conducted AI surveillance in Montana during the last 4 yrs using multiple sampling strategies to optimize the chance of detecting HPAI H5N1. Surveillance targets specific species spatially distributed across the state and temporally distributed across the sampling period. The primary emphasis on wild populations included systematic transects on populations of high priority for morbidity and mortality, along with opportunistically found dead birds, as well as the collection of swab samples from live and hunter-harvested waterfowl. Whereas low pathogenic avian influenza was found in samples each year as expected, no sample tested positive for HPAI H5N1.

FACTORS INFLUENCING THE DISTRIBUTION OF RIPARIAN BREEDING BIRDS ALONG THE YELLOWSTONE RIVER

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Riparian zones provide some of the most diverse and productive habitats for native birds in the western U.S. However, most riparian zones have been significantly modified by human activities. It is important to identify relationships between riparian birds and characteristics of the environment to understand the potential influences of floodplain management on birds. We examined the factors affecting riparian bird species distribution within cottonwood forests along the middle and lower sections of the Yellowstone River in Montana. We investigated the influences of local habitat, forest cover, and land use on the occurrence or abundance of 14 bird species. Furthermore, we considered whether geographical location along the river affected bird species distribution. There was strong evidence that these factors were important to birds, and the relative influences of each factor depended upon life history characteristics of each species. The effect of river location on the occurrence or abundance of species suggests that broad-scale influences may be important predictors of bird distribution along rivers. The

Yellowstone River is one of the few remaining free-flowing rivers in the lower 48 states, and may serve as a reference for understanding the factors influencing the distribution of birds along a river, and provide valuable information for the management of riparian species.

CULLING AS AN EXPLORATORY FIELD TECHNIQUE TO REDUCE OVERALL MORTALITY DURING A PASTURELLA SPP. OUTBREAK IN A MONTANA BIGHORN SHEEP POPULATION

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Several herds of Rocky Mountain bighorn sheep (*Ovis Canadensis*) in the United States and Canada have experienced all-age die-offs during outbreaks of *Pasturella* spp. induced pneumonia. Isolating triggers and remedies for these die-offs remains elusive. Montana Fish, Wildlife and Parks used the statewide Draft Sheep Conservation Strategy as a guide in establishing a field culling-mobile laboratory-media response to a pneumonia/complex outbreak in the East Fork Bitterroot bighorn sheep herd. Montana Fish, Wildlife and Parks employees along with volunteers from the Ravalli County Fish and Wildlife Association, Wild Sheep Foundation and the USDA Forest Service culled 76 sheep from a herd numbering at least 187 animals according to spring 2009 aerial observations. Field personnel discovered six recent bighorn sheep carcasses when culling efforts began in late November. Field personnel discovered one additional bighorn carcass during the three-month culling process. Lab experts conducting onsite necropsies observed evidence of infection in 73 (96%) of the culled sheep. State biologists observed 93 bighorns on this winter range during a cursory aerial survey conducted on 28 December 2009. Preliminary observations from comparing results of sheep selected for culling to field necropsies suggest field personnel detect infected sheep with a high degree of accuracy. We suggest that this technique prevented additional mortalities directly related to pneumonia.

STAGES OF HABITAT STRUCTURAL TREND THAT ARE RELATED TO UNGULATE BROWSING

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To maintain their structural identity, communities of tall-growing trees and shrubs depend on the growth of young plants to replace mature individuals that die. Ungulate browsing influences that structure by permitting or preventing the height growth of young plants. The resulting changes in structure are indicted by the browsing-related architectures of plants that grow within the browse zone, i.e., those ≤ 2.5 m tall. Using examples from six National Wildlife Refuges, we describe six stages of structural trend and their

management implications: 1) Structure is Stable, i.e., all plants have Uninterrupted-growth-type architecture; 2) Early Stage of Structural Decline most or all plants have Arrested- or Retrogressed-type architecture and there is no visible evidence of dieback; 3) Intermediate Stage of Structural Decline, i.e., all plants have Arrested- or Retrogressed-type architecture, dieback is apparent, and live stems extend throughout the lower half of the browse zone; 4) Advanced Stage of Decline, i.e., all plants have Arrested- or Retrogressed-type architecture and live stems are restricted to the lowest part of the browse zone; 5) Structure is Lost, i.e., no live plants; and 6) Recovery of Structural Diversity, i.e., there is evidence that the Early, Intermediate, or Advanced Stage of Decline existed, and that young Uninterrupted-growth type plants are growing into the browse zone. Three factors influence the rate-of-change from one stage to another: Susceptibility, Resistance, and Resilience. Because the stages are independent of species composition, they provide a means of comparing the effect of browsing in diverse habitats across a region.

GRIZZLY BEAR AND BLACK BEAR MARKING BEHAVIOR

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Marking activity is common among ursids but little information has been quantified about this behavior. We describe marking behavior of sympatric grizzly bear (*Ursus arctos*) and black bear (*U. americanus*) populations in a 31,400-km² area in northwestern Montana. We found marking activity in all areas occupied by bears regardless of bear density and land use. Based on examination of > 5000 bear marking sites, rubbing was the most common behavior at these sites. We used genetic analysis of hair collected at rubs to identify species, sex, and individual identity of bears using them and remotely-triggered cameras to observe bear behavior. Both grizzly bears and black bears rubbed; 58 percent of rubs had black bear hair, 25 percent grizzly hair, and 11 percent hair from both species. Bears typically marked standing trees (86%) but sign posts on hiking trails and forest roads, and power poles were also used. Only males rubbed May-June but female use increased substantially by late summer. Although cubs were detected at lower rates than older bears, all grizzly bear sex and age classes participated in rubbing. Many sites were rubbed repeatedly within and between years but there was also continual turnover. One function of rubbing appears to be chemical communication among bears, although this behavior is different from marking behavior observed in territorial species such as canids. With the high frequency of rubbing activity in these sympatric bear populations, hair from bear rubs provides a reliable and efficient way to concurrently sample both species to monitor population trends.

NESTING ECOLOGY OF THE NORTHERN GOSHAWK IN THE BLACK HILLS OF SOUTH DAKOTA

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The nesting ecology of northern goshawks (*Accipiter gentilis*) was studied in the Black Hills of western South Dakota from 2003 to 2009. Goshawk nest territories were found by

broadcasting alarm calls, intensive searches of potential nesting habitat, and visiting historic nesting territories based on information from the USDA Forest Service. During this 7-yr period, 30 active goshawk nesting territories were studied. There were 53 nesting attempts sufficiently monitored to establish that 35 nests fledged young (66% successful). Among these monitored nests, there was an average of 1.1 chicks fledged/nesting attempt and 1.6 chicks fledged/successful nest. Goshawks frequently used alternative nests from one year to the next, and we were not always successful at finding new alternative nests. Alternative nests ranged from 50 yds to 0.7 mi apart. The average number of alternative nests found per nesting territory was 2.2, and in 1 territory there were six nests. Ponderosa pine (*Pinus ponderosa*) was the preferred nest tree with 65 goshawk nests in pine trees and one nest found in a white spruce tree (*Abies glauca*). The average diameter (dbh) of nest trees was 16.8 in dbh. Nest stand characteristics were measured at 21 nest tree sites. Average nest stand dbh was 10.2 in, average nest stand tree density was 266 trees/ac, and the average nest stand basal area was 128 ft²/ac.

PREDICTING THE SPATIAL DISTRIBUTION OF HUMAN-BLACK BEAR INTERACTIONS ACROSS AN URBAN AREA

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Human (*Homo sapiens*)-black bear (*Ursus americanus*) interactions are increasing throughout North America. Information that assists managers in developing methods to reduce conflicts is lacking. We used human-bear incident data, i.e., phone complaints and conflicts, collected in Missoula, Montana, by Montana Fish, Wildlife and Parks from 2003-2008 to describe the attractants and human impacts of incidents, and develop a model that predicts the spatial probability of incidents. We combined the locations of black bear sightings ($n = 307$), other incidents, e.g., bear seen feeding on garbage ($n = 549$), and sites where proactive management actions were carried out ($n = 108$), and compared them to 5000 random locations using logistic regression. Based on literature, we used distance to forested patches, distance to water, and housing density as variables in our model. Garbage (38%), fruit trees (10%), and bird feeders (7%) were the most common attractants at incident sites, and some incidents resulted in threats to human safety (9%) and property damage (7%). All variables were significant in the predictive model, and the model performed well at discriminating the relative spatial probability of incidents ($r_s = 0.782$; $P < 0.01$). The probability of incidents increased when residents lived close to forested patches, close to water, and in intermediate housing densities (~ 6.6 houses/ha). Our results suggest that spatial patterns in human-black bear interactions are predictable and these patterns can be used to understand the potential for conflict in developing areas and to identify areas where preventative management is necessary.

A METHOD TO ESTABLISH TREND AREAS THAT PREDICT PRONGHORN POPULATIONS TO GUIDE MANAGEMENT ACTIONS

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Trend area flights offer substantial cost and time-savings over total population counts, but trend area data need to be calibrated to total count data before they can be used with confidence in wildlife management decisions. To develop trend areas for pronghorn (*Antelopcapra americana*) in FWP Administrative Region 5, group location data from total surveys, for the period 1984-2009, were combined with classification information by hunting district (HD) into a GIS. Number of total counts conducted per HD varied from a low of six to a high of 13 and involved classification of between 364 and 8088 antelope. Grids, 5 mi x 5 mi to 12 mi x 12 mi (increasing by 1-mi² intervals) in size were overlain on the pronghorn locations as potential trend areas. Number of yearling, adult and total bucks, does, fawns and total number by year, were calculated for each grid and cross-referenced with HD census data. The predictive ability of each candidate trend area was estimated and internally validated. We selected grids with the highest internally validated predictive ability to be used as trend areas for each HD in Region 5. Correlation coefficients between trend count data and total count data varied from a low of 0.88 to a high of 0.98. Newly established trend areas varied in size from 64.3 mi² to 216.6 mi². The time-savings and reduction in survey costs will allow biologists to fly surveys in each HD annually without sacrificing the ability to predict pronghorn populations accurately.

WINTER ELK DISTRIBUTION AND THE RISK OF BRUCELLOSIS TRANSMISSION FROM ELK TO LIVESTOCK IN THE NORTHERN GREATER YELLOWSTONE ECOSYSTEM

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Predicting spatio-temporal variations in elk (*Cervus elaphus*) distributions is necessary to forecast the risk of brucellosis transmission from elk to livestock within the Greater Yellowstone Ecosystem (GYE). Using Global Positioning System (GPS) data collected from 49 telemetry-collared female elk during 2005-2006, we developed predictive resource selection function models for the brucellosis transmission risk period. To determine applicability of predictive models across the larger GYE landscape, we validated predictive models internally, as well as externally at two additional elk ranges within the GYE using 63 telemetry-collared cow elk during 2002-2009. Finally, we integrated extrapolated resource selection function maps and domestic livestock distributions to forecast elk to domestic livestock brucellosis transmission risk. We found elk distributions varied spatially and temporally during the risk period and predictive accuracy was highest in the study area where the model was developed. Predictive accuracy of extrapolated resource selection function maps was lower in other study areas indicating that risk models developed in one portion of

the GYE are not as accurate in other portions of the GYE. Relative to the other areas included in this study, the Madison Valley and northern Paradise Valley areas were predicted to have the highest risk of elk to livestock transmission risk. Predictions regarding spatio-temporal variations in transmission risk may be used to prioritize management actions aimed at reducing the potential for brucellosis transmission risk, for example hazing to reduce elk-livestock commingling or producer management of livestock distribution.

PNEUMONIA OUTBREAK IN BIGHORN SHEEP IN THE EAST FORK OF THE BITTERROOT: A SUMMARY OF PATHOLOGY AND LABORATORY FINDINGS

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A bighorn sheep (*Ovis Canadensis*) pneumonia outbreak began in the East Fork of the Bitterroot River drainage in late November 2009. The decision to cull apparently sick animals provided the unique opportunity to collect fresh, high quality biological samples for diagnostic testing. It is our hope that information gained from this outbreak will contribute to an understanding of bighorn sheep pneumonia outbreaks in western states. The Montana Fish, Wildlife, and Parks wildlife laboratory performed full necropsies on many of the bighorn sheep that died or were culled during this outbreak. Body condition score and severity of lung lesions was noted. A fresh blood sample and fecal sample was collected, and the pharynx and ear canal were swabbed. Lung, tracheobronchial lymph node, and liver samples were also collected. Field personnel collected fresh tissue samples from culled sheep that could not be removed from the field for necropsy. Tissues and swabs were submitted to Washington Animal Disease Diagnostic Laboratory (WADDL) for aerobic and *Mycoplasma* culture. Serum and fecal samples were submitted to the Montana Department of Livestock laboratory in Bozeman. In this presentation we will describe the gross pathology of the pneumonia outbreak, summarize all laboratory findings, and describe similarities and differences when compared to other bighorn sheep pneumonia outbreaks within Montana and in other western states.

COMBINING HUNTER SURVEYS AND TERRITORIAL DYNAMICS TO MONITOR WOLF PACK ABUNDANCE AND DISTRIBUTION IN MONTANA

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Carnivores are difficult to monitor on large spatial scales. We developed a patch occupancy model (POM) using hunter surveys to monitor gray wolves (*Canis lupus*) in Montana, and evaluated the ability of these models to provide wildlife managers with a time-and cost-efficient monitoring technique. We used hunter's sightings of wolves as our index of occupancy and explored how classifying a patch as occupied based on different minimum number of wolves sighted (1,2,3,4, or 5) or different minimum number of hunters sighting wolves (1,2,3,4, or 5) affected results. We also evaluated how our definition of a "patch" influenced the occupancy estimates by creating POMs with 3 different patch sizes that corresponded to the variation in wolf territory sizes in Montana. We ran multiple models with different patch sizes predicting occupancy classified according to different levels of minimum wolf sightings and minimum hunters seeing wolves. We assessed model accuracy by comparing POM estimates to the Montana Fish, Wildlife, and Parks (FWP) minimum wolf pack count. Our preliminary results showed that patch size did not strongly influence occupancy estimates and that a patch should only be identified as occupied if ≥ 2 to ≥ 4 hunters each observed ≥ 2 to ≥ 4 wolves in that patch. Within this range, FWP's minimum wolf pack count fell within the 95-percent confidence interval of POM estimates for 33 percent of the models.

MEASURES OF SUCCESS: A SNAPSHOT OF THE MONTANA WOLF PROGRAM IN 2009

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Montana's gray wolf (*Canis lupus*) population continues to be secure, while the political and legal environments remain dynamic. Wolf delisting is a two-step process. Biological recovery criteria must be met and clearly demonstrated, along with an adequate regulatory framework. Secondly, the delisting decision must be upheld during inevitable legal challenges. The northern Rockies wolf population has met or exceeded numeric and connectivity requirements for many years. The northern Rockies gray wolf population was initially delisted in 2008, but a legal challenge reinstated federal legal protections under the Endangered Species Act mid-summer. By the end of 2008, Montana Fish, Wildlife and Parks

estimated a minimum of 497 wolves in 84 verified packs, 34 of which met the definition of breeding pair. Federal delisting efforts resumed early in 2009 and took effect throughout Montana on 4 May. The second delisting decision was challenged again in Federal Court, although a preliminary injunction request to reinstate federal protections was denied in September. With delisting in Montana, the wolf was automatically reclassified as a species in need of management. Montana's laws, administrative rules, and management plan also took effect. Montana Tribes lead wolf management activities on their respective reservations. The first fair chase wolf hunting season in Montana occurred in 2009. Seventy-two wolves were harvested through a quota-based framework. Wolves and their management continue to be controversial to a diversity of publics for a wide variety of reasons. Nonetheless, Montana's wolf program has a solid regulatory foundation and the population is biologically sound. This presentation will provide an update on a variety of topics.

PROTECTION, CONSERVATION, AND RESTORATION OF THE FORT PECK TRIBES' MANNING LAKE WETLAND COMPLEX ON THE FORT PECK INDIAN RESERVATION

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The Manning Lake Wetland Complex (MLWC), located on the Fort Peck Indian Reservation, is an incredible and unique landscape providing vital breeding and rearing habitat for a diversity of waterfowl, migratory birds, songbirds and other species, including at least 10 of conservation concern. The Fort Peck Assiniboine and Sioux Tribes and their partners have been working toward the protection, conservation, and restoration of the 22,000-ac wetland complex since 2004, when nine natural resource professionals from tribal, state, and federal agencies and programs formed a working group. Since then, thanks in part to grants from USDI Fish and Wildlife Service, Environmental Protection Agency, and Montana Audubon, great progress has been made toward reaching this goal. This presentation will introduce the Manning Lake Wetlands Tribal Wildlife Refuge and share our methods and accomplishments to date which include 1) designation of the Complex by Montana Audubon as An Important Bird Area; 2) Tribal establishment and management of 4000 ac as a Tribal Wildlife Refuge with plans to include additional acres in the future through purchase or long term conservation leases; 3) development of a habitat management plan and a wetland monitoring and assessment plan; 4) creation of a reservation specific wetland rapid assessment method; 5) creation of a baseline macroinvertebrate, bird, and amphibian species list; 6) development of water quality references; and 7) creation of habitat, vegetation associations, and land usage maps.

PASSIVE ACOUSTIC MONITORING FOR BATS IN SUPPORT OF THE COYOTE WIND PROJECT, SWEET GRASS COUNTY, MONTANA

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Wind energy development in the United States has been increasing rapidly and is expected to continue to do so. There are many benefits to producing wind energy; however

it is also important to understand potential negative effects and ways these impacts could be mitigated. Impacts to bats, and how to predict and mitigate impacts, are less well known than wind project impacts to birds. We conducted passive acoustic monitoring from 29 August to 6 November 2008 in Sweet Grass County, Montana, as part of pre-construction surveys for Enerfin Energy Company's proposed Coyote Wind Project. We deployed four Anabat acoustic detectors on two portable towers at 1.5- and 20-m heights, and recorded data nightly. We used these data to evaluate bat activity over the study period; within each night; relative to wind speed; relative to temperature; and relative to instrument heights. We recorded 668 echolocation files in 3 phonic groups. Bat activity was highest between 29 August and 1 October, and within 3 hrs of sunset. Bat activity peaked at wind speeds of 2-3 m/s and dropped off with increasing wind speeds to about 8 m/s. Bats were most active at air temperatures between 5 and 20 °C. Instrument height and bat phonic group were significantly correlated. These results are generally consistent with those found by Arnett et al. (2006) in Pennsylvania. Increasing our understanding of environmental parameters and bat activity in Montana will contribute to appropriate wind project siting and mitigation.

EVALUATION OF BEAR RUB SURVEYS TO MONITOR GRIZZLY BEAR POPULATION TRENDS

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Wildlife managers need reliable estimates of population size, trend, and distribution to make informed decisions about how to recover at-risk populations, yet obtaining these estimates is costly and often imprecise. The grizzly bear (*Ursus arctos*) population in northwestern Montana has been managed for recovery since being listed under the U.S. Endangered Species Act in 1975, yet no rigorous data were available to evaluate the program's success. We used encounter data from 379 grizzly bears identified through bear rub surveys to parameterize a series of Pradel model simulations in program MARK to assess the ability of noninvasive genetic sampling to estimate population growth rates. We evaluated model performance in terms of: 1) power to detect gender-specific and population-wide declines in population abundance, 2) precision and relative bias of growth rate estimates, and 3) sampling effort required to achieve 80-percent power to detect a decline within 10 yrs. Simulations indicated that ecosystem-wide, annual bear rub surveys would exceed 80-percent power to detect a 3-percent annual decline within 6 yrs. Robust design models with two simulated surveys per year provided precise and unbiased annual estimates of trend, abundance, and apparent survival. Designs incorporating one survey/year require less sampling effort but only yield trend and apparent survival estimates. Our results suggested that systematic, annual bear rub surveys may provide a viable complement or alternative to telemetry-based methods for monitoring trends in grizzly bear populations.

MONTANA'S FIRST NRCS COOPERATIVE CONSERVATION PARTNERSHIP INITIATIVE: RESTORING RANGLANDS FOR PRIORITY BIRDS IN EASTERN MONTANA

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The 2008 Farm Bill introduced the cooperative conservation partnership initiative (CCPI), a new initiative designed to leverage resources from outside the USDA to assist agricultural producers in coordinated efforts to address environmental challenges in their region. Proposed by the Environmental Defense Fund, locally-based Ranchers Stewardship Alliance, The Nature Conservancy and the World Wildlife Fund, "Restoring Rangelands for Priority Birds in Eastern Montana" is the first CCPI supported by the Natural Resource Conservation Service in Montana. With Montana Fish Wildlife and Parks as a new partner this CCPI is dedicated to preserving one of the few remaining strongholds of untilled native grass and shrub lands in the plains of eastern Montana with the long-term goal of reversing the trend of declines among grassland birds. The CCPI covers over 300,000 acres of private lands within the 1.5 million ac landscape in South Phillips County, Montana. Private landowners will play a crucial role in conserving grassland birds by supporting the initiative's goal to increase habitat structural diversity over space and time on each participant's ranch. This will be accomplished through a combination of grazing and burning strategies and practices applied to promote structural heterogeneity in vegetation at varying scales. The CCPI will provide the technical and financial resources private landowners need to continue the kind of stewardship that sustains healthy habitat for priority grassland birds, and a healthy bottom line for their ranching operations.

BIOLOGISTS AND BIOLOGY IN MONTANAGONIA: PARTNERS IN CONSERVATION AT THE END OF THE WORLD

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The Montana-Patagonia Chapter of the Partners of the Americas in both Argentina and Montana was established during the 1980s. Rick Douglass, Department Head and Biology Professor at Montana Tech, has been largely responsible for keeping this volunteer organization active and viable for the last 20 yrs. The Partners of the Americas program was initiated nationally during the Kennedy administration. Each State in the U.S. is paired with a Central or South American Country. During the last 20 yrs a host of wildlife and fisheries biologists have volunteered to travel back and forth from Patagonia to Montana. Culture and education exchanges have focused on biology and have been completed in the areas of fisheries management, electro-shocking, wildlife survey and inventory, grazing systems, hunting systems, puma conflicts, environmental education and more. Patagonia biologists in Argentina have implemented groundbreaking research and management programs that have promoted the conservation of endemic species at the southern tip of the South American continent. Participation in the Partners of the Americas Program has enriched the careers and lives of professional biologists in both hemispheres.

FROM THE TEMPERATE ZONE TO THE TROPIC—SUN BEAR RESEARCH AND CONSERVATION FROM MONTANA TO BORNEO

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Originally found throughout Southeast Asia, sun bears (*Helarctos malayanus*) are the least known bear and remain poorly studied. We initiated one of the first ecological studies of the sun bear in Sabah, Malaysian Borneo starting in 1998. This research has continued since then and has expanded to include conservation actions that respond to key findings. Our research documented the life history and ecology of the sun bear in the tropical rainforest and highlighted serious conservation concerns for the species. Sun bear numbers are decreasing in Borneo and the rest of Southeast Asia from habitat loss and illegal hunting for food and medicine. Poaching sun bears for body parts and capturing sun bear cubs for the pet trade has resulted in many orphaned sun bears. In addition to these direct human pressures, we documented the impact of environmental variability on sun bears in Malaysia when we observed an unusual famine event in Borneo in 1999-2000. Studied sun bears suffered from severe emaciation and even death. The famine event was related to abnormal climatic events of El Nino and La Nina Southern Oscillation that disrupted the mast fruiting activities in the forest. In response to the many conservation issues facing sun bears in Malaysia, Siew Te Wong founded the Borneo Sun Bear Conservation Centre (BSBCC) in 2008. The BSBCC aims to conserve sun bears by rehabilitating orphaned bears, providing long-term care for captive bears, conducting education and outreach activities, and serving as a base for sun bear research.

SUBSPECIFIC IDENTIFICATION OF SHARP-TAILED GROUSE SAMPLES FROM MONTANA

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Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) historically occupied much of the shrub-steppe habitat of the intermountain west, ranging from interior British Columbia south to California and Colorado. The subspecies has been extirpated from most of its range and currently exists in only scattered isolated populations. The last remnant populations in western Montana were located in the Tobacco Valley near Eureka and the Blackfoot Valley near Helmville. However, those populations were extirpated during the previous decade and the subspecies can no longer be confirmed in the state. A rangewide genetic analysis of sharp-tailed grouse in 2006 documented restricted gene flow based on an analysis of 45 tissue samples taken from Montana birds east of the continental divide. We extended that earlier analysis with a total of 133 tissue samples, including samples from western Montana birds extracted from museum skins collected in 1897, and compared these

samples to other genetic profiles reported from across the species range. We compared these samples to test for genetic differences in an area where the reported distribution of the Columbian subspecies is geographically near populations from the plains subspecies (*T. p. jamesi*). We were able to assign subspecies classification to 126 of the 133 Montana samples, including all samples from west of the Continental Divide. All Montana samples conclusively typed out to the Plains subspecies. Our analysis identified 3 similar genetic clusters across sharptail populations: (1) Alberta, Colorado, Montana, North Dakota, South Dakota and Nebraska, (2) Washington, British Columbia and western Idaho, and (3) Utah and southern Idaho. Both microsatellite and control region sequence data indicate that sharp-tailed grouse from all localities in Montana are molecularly most similar to populations from the plains regions of Alberta to Nebraska, indicating that Montana birds share a relatively recent molecular history. It does not appear that the Continental Divide is a current or historical barrier to gene flow in sharp-tailed grouse.

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