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

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

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

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

Acceptance

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

Rejection

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

Reviewer Anonymity

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

Manuscripts Submitted by Editors

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

Abstracts

Only abstracts from the annual meetings of the sponsoring organizations will be published in IJS. Other submissions of abstracts shall be considered on a case-by-case basis by the Editorial Board. Sponsoring organizations shall collect abstracts, review them for subject accuracy, format them in Microsoft Word and email them to 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)

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First Report of Freshwater Jellyfish in Montana

Grant G. Grisak, Montana Fish, Wildlife and Parks, Great Falls, Montana 59405

The first known sample of freshwater jellyfish [(*Craspedacusta sowerbyi*) Lankester, 1880 (Cnidaria: Limnomedusae: Olindiidae)] in Montana came from an artificial pond on an abandoned golf course in Cascade County near the town of Great Falls in 2009 (Fig. 1). The pond is located ~600 m from the Missouri River and is part of a four pond network connected by a dry artificial stream.

C. sowerbyi originated in the Yangtze River area of China. Distribution of this species is widespread throughout Europe (Didžiulis 2008) and believed to be caused by transporting ornamental pond plants containing eggs or polyps. The first reported case outside of China was in London England in 1880. As of 2009, freshwater jellyfish have been reported in all of the continental 48 states except Montana, North Dakota, South Dakota, and Wyoming (T. Peard, Indiana University of Pennsylvania, personal communication, 2010). Most populations are found in lakes and ponds and only about 8 percent in flowing water (Beckett and Turanchik 1980).

The initial collection occurred on 25 August 2009. Hydromedusa were observed swimming near the surface, collected with a dip net, and then preserved in 10-percent

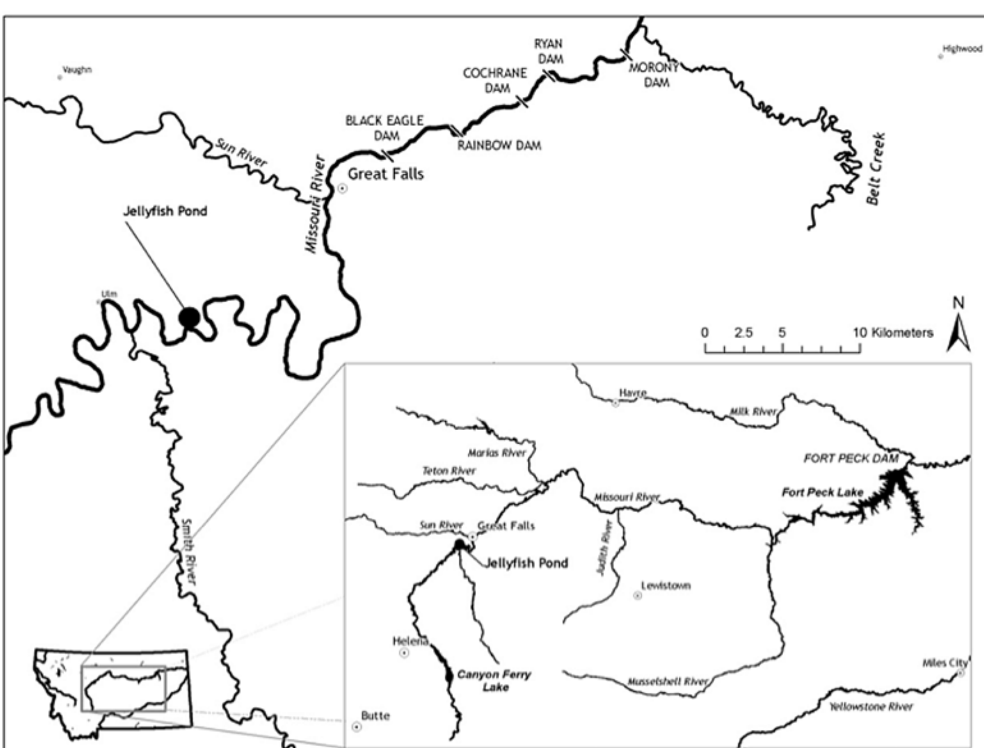

Figure 1. Location of freshwater jellyfish pond in Montana and six downstream reservoirs on the Missouri River.

ethanol for photographs and examination. Mean diameter of the jellyfish measured 29 mm (17-34; Fig. 2). A second visit occurred on 3 September 2009 to make museum collections and record habitat conditions. The pond surface area was 1.09 ha, maximum depth was 2.04 m and mean depth was 1.25 m (Fig 3). Secchi reading was 31 cm. Surface water temperature was 18.1 oC. The substrate of the pond was primarily coarse sand with a few piles of rock 12-25 cm in diameter. No vegetation was present in the water or along the shoreline. Two plankton tows were made from a small raft with a 30-cm diameter 80-micron Wisconsin net at the deepest part of the pond. Plankton collected were *Bosmina* spp., *Cyclops* spp., Nauplii of Cyclops and trace amounts of rotifers *Kellicotia* spp., *Conochilius* spp., and *Asplanchna* spp. One yellow perch (*Perca flavescens*) measuring 49 mm long and several water boatmen (Corixidae) were collected.

The life history, distribution and feeding habits of this species have been adequately described by Stefani et al. (2010) and Smith and Alexander (2008). Field and laboratory studies show when population levels are abundant, C. *sowerbyi* can have significant reductions in plankton abundance (Pérez-Bote et al. 2006, Jankowski et al. 2005) as well as selectivity for plankton species and size (Smith and Alexander 2008, Pérez-Bote et al. 2006).

The location of this population raises concern about possible expansion into the Missouri River. Six hydroelectric dams (Black Eagle, Rainbow, Cochrane, Ryan, Morony) that impound reservoirs on the Missouri River downstream of this pond would provide adequate habitat for this organism to survive (Fig.1). The reservoir effect of the closest dam begins 33 river-km downstream of this pond. Fort Peck Reservoir, the largest earthen dam in the United States, is located on the Missouri River 386 river-km downstream of the

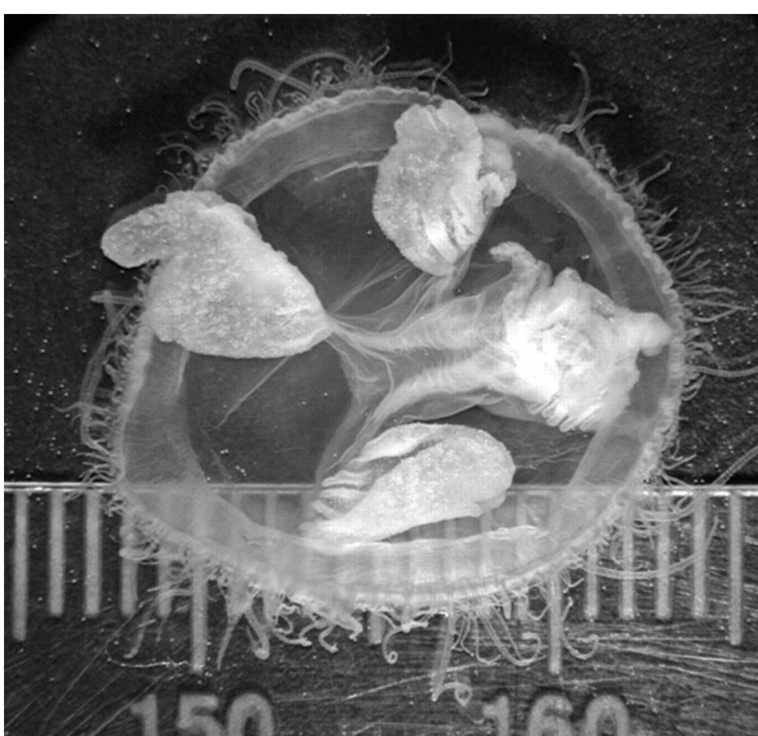

Figure 2. Freshwater jellyfish (*Craspedacusta sowerbyi*) sampled from a pond in Montana, 2009.

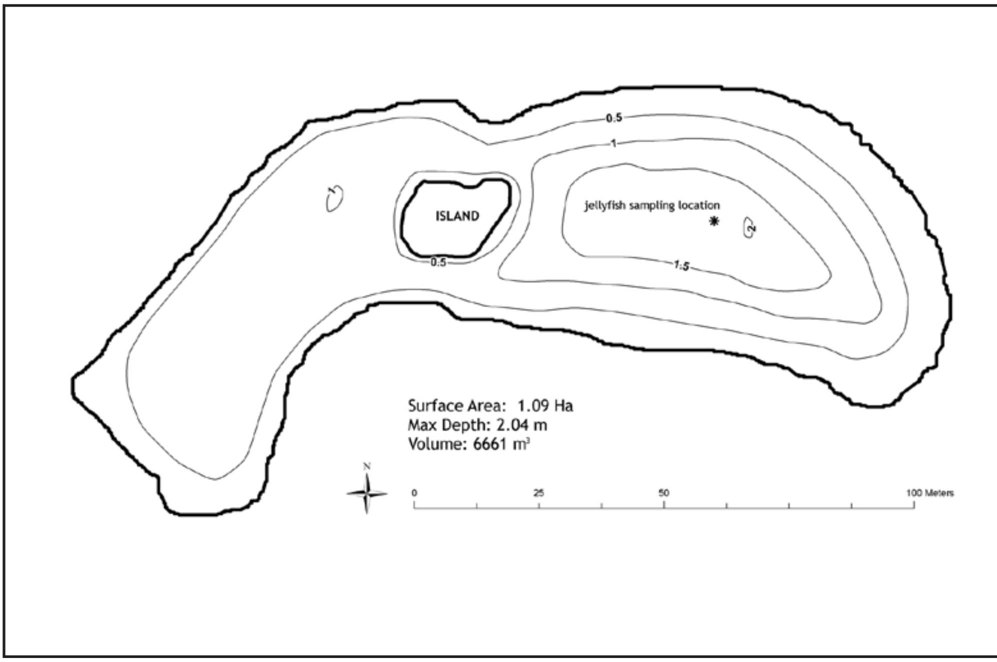

Figure 3. Bathymetric map of freshwater jellyfish pond in Montana with plankton sampling location. Map contours are 0.5-m increments.

pond. This 206-km long reservoir is vital habitat for the last self sustaining population of paddlefish (*Polyodon spathula*) in the United States, and for Cisco (*Coregonus artedi*), which is an important forage fish for the Fort Peck Reservoir sport fishery. Both of these fish species feed almost exclusively on plankton during all life stages. Given the ability of this organism to select for specific plankton and affect their reduction, the ecological impacts of this species could be far reaching if it becomes established in the Missouri River reservoirs.

Literature Cited

Beckett, D.C. and E. J. Turanchik. 1980. Occurrence of the freshwater jellyfish *Craspedacusta sowerbyi* Lankester in the Ohio River. Ohio Journal of Science 80: 95.

Didžiulis, V. 2008. Invasive Alien Species Fact Sheet – *Craspedacusta sowerbyi*. – From: Online Database of the North European and Baltic Network on Invasive Alien Species – NOBANIS. www.nobanis.org.

Jankowski, T, T Strauss, and H. Ratte. 2005. Trophic interactions of the freshwater jellyfish *Craspedacusta sowerbii*. Journal of Plankton Research 27:811-823.

Pérez-Bote, J.L., A. Muñoz, R. Morán, R. Roso, and A. J. Romero. 2006. First record of *Craspedacusta sowerbyi* Lankester, 1880 (Cnidaria: Limnomedusae: Olindiidae) *in* the Proserpina Reservoir (Extremadura, SW Spain) with notes on their feeding habits. Belgian Journal of Zoology 136:163-166.

Smith, A. S. and J.E. Alexander. 2008. Potential effects of the freshwater jellyfish *Craspedacusta sowerbii* on zooplankton community abundance. Journal of Plankton research 30:1323–1327.

Stefani, F. B. Leoni, A. Marieni, and L. Garibaldi. 2010. A new record of *Craspedacusta sowerbii*, Lankester 1880 (Cnidaria, Limnomedusae) in Northern Italy. Journal of Limnology 69:1-4.

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Fish Entrainment Investigations at the Fort Shaw Diversion 2003-2004, Sun River, Montana

Juddson D. Sechrist, USDI Bureau of Reclamation, PO Box 25007 (86-68290),Denver, CO 80225-0007, 303-445-2198, jsechrist@usbr.gov
Katherine Potak Zehfuss, USDI Bureau of Reclamation, PO Box 25007 (86-68290), Denver, CO 80225-0007, 303-445-2240, kzehfuss@usbr.gov

Abstract

Fish entrainment associated with irrigation has had long-term consequences for many species in the western United States. Investigation of entrainment and attempts at its prevention through physical or behavioral barrier installation are common management practices. However, the factors affecting entrainment are rarely quantified. The purpose of this study was to quantify fish entrained from the Sun River mainstem into the Fort Shaw diversion canal by species using an entrainment monitoring system; and second, to analyze the factors that contributed to this fish entrainment. These factors included: year, photoperiod, Sun River flow, Fort Shaw Canal diverted flow, Fort Shaw lag flow, ratio of diverted flow to Sun River flow, temperature, and moon phase. There were 6536 fish captured in 2003 and 2004 comprising 13 species and unknowns. We found significant differences in entrainment rates associated with Sun River flow, ratio of diverted flow to Sun River flow, and photoperiod. Our data indicated that at this site, fish entrainment is directly related to volume of water diverted, especially when diverted flows exceed mainstem river flows, and that fish entrainment at this site was highest during dark periods. The fish entrainment netting system used at the Fort Shaw Diversion was considered to be both economical and effective for documenting occurrence and determining the composition and number of fish entrained.

Key words: Fish Entrainment, Fish Entrainment Quantification, Fish Entrainment Netting System, Sun River, Fort Shaw Diversion, Factors Affecting Fish Entrainment

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Introduction

The practice of irrigation has been practiced in Montana for over 160 yrs. A complete census regarding the number of irrigation diversions in Montana is not currently available; however, historical information regarding increases in irrigated acreage would indicate that the number of irrigation diversions has increased concurrently (Howard 1992). Many of these irrigation diversions lead to unintentional fish entrainment, which can cause long-term detrimental effects on fish populations in Montana (Reiland 1997, Gale et al. 2008) and in the western United States (Prince 1922, Hallock and Van Woert 1959, Cook and Buffaloe 1998, Zydlewski and Johnson 2002, Nobriga et al. 2004, Schrank and Rahel 2004, Moyle and Israel 2005).

Entrainment is defined as the fluvial transport of fish out of their in-stream environment in waters that are passed through a conduit, penstock, or diversion at power generation facilities, dams and / or irrigation canals (Zydlewski and Johnson 2002). Large losses of fish to irrigation canals in Montana have been documented by Thoreson (1952), Clothier (1954), Spindler (1955), Reiland (1997), Mogen and Kaeding (2002), and Sechrist et al. (2005). In addition, Bakes et al. (1998) examined the effects of diversion location on fish movement. Also, quantitative estimates of entrainment at diversions have been determined by Hiebert et al. (2000) and Gale et al (2008).

The effects of irrigation diversions on fish population demographics and connectivity can be cumulative (Helfrich et al. 1999). Several diversions may be located in a specific river basin and, although individual irrigation diversions may not significantly affect fish populations, collectively they may entrain considerable numbers of fish (Hallock and Van Woert 1959).

Most research pertaining to fish entrainment caused by diverted flows has been conducted in accordance with physical fish screen installation and efficiency testing at diversions (Neitzel et al. 1991, McMichael et al. 2001). These research studies therefore have focused on issues such as approach velocities for fish encountering a screened diversion (Pearce and Lee 1991), and physical characteristics at diversion sites that influence entrainment (Spindler 1955).

Many factors contributing to fish entrainment have been assessed in varying degree. These include: placement of irrigation withdrawal structures within a river channel or the channel morphology associated with the structures (Spindler 1955, Hiebert et al. 2000), river discharge as a catalyst for movement (Young 1994, Reiland 1997), temperature effects (Clothier 1954), turbidity effects (Bakes et al. 1998), habitat complementation (for example, spawn to post-spawn movements, e.g. Shrank and Rahel 2004), fish movement based on diel patterns (Nobriga et al. 2004), and ambient light (Gale et al. 2008). It has been assumed qualitatively that the number of fish entrained is positively correlated to the volume of diverted flow and concurrent density of fish in the water being diverted (Hiebert et al. 2000, Hanson 2001, and Post et al. 2006). However, the quantitative relationship between diverted flow and fish entrainment remains poorly understood (Moyle and Israel 2005).

The purpose of our research was to focus on this relationship between entrainment and flow by installing and implementing an entrainment monitoring system. The objectives were to first quantify fish entrained from the Sun River mainstem into the Fort Shaw diversion canal by species; and second, to analyze the factors that contributed to this fish entrainment. Factors included year, photoperiod, Sun River flow, Fort Shaw Canal diverted flow, Fort Shaw lag flow, ratio of diverted flow to Sun River flow, temperature, and moon phase.

Study Area

The Sun River is a tributary to the Missouri River in north-central Montana, with a watershed of ~ 5700-km2 (Fig. 1).

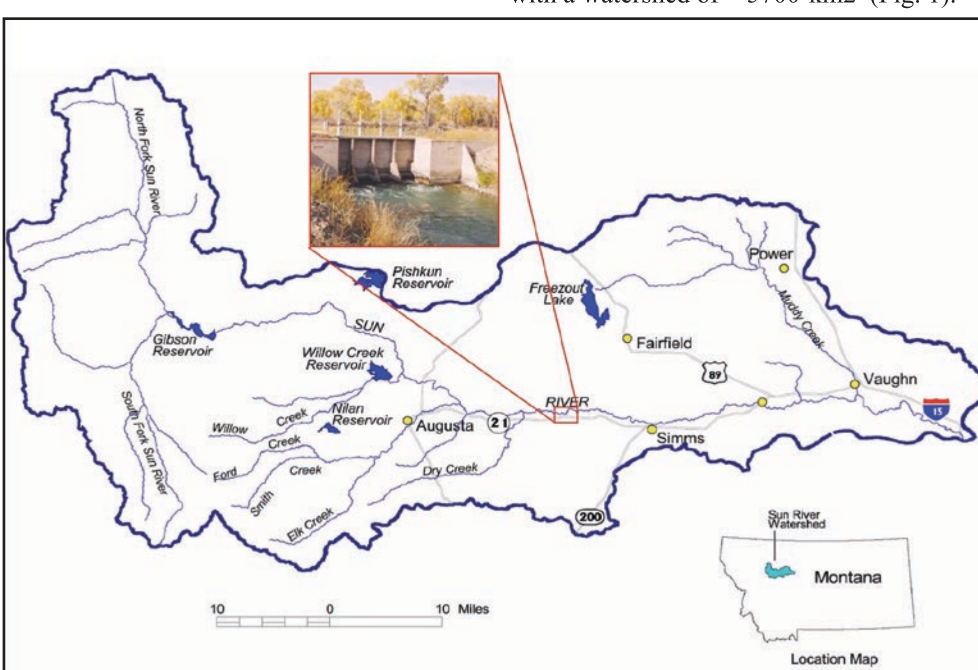

Figure 1. The Sun River watershed with inset of Fort Shaw Diversion Canal.

The Sun River drains from the continental divide via north and south forks to the Missouri River confluence, decreasing in elevation from 2743 m to 914 m along the Rocky Mountain front range for 177 km. Primary water storage on the mainstem Sun River occurs in Gibson Reservoir with a capacity of 122,238,050 m3. Mean annual discharge from Gibson Reservoir in 2003 and 2004 was 15.8 and 14.9 cubic meters/second (m3/s), respectively. The Sun River hydrograph from Gibson Dam to its confluence with the Missouri River is influenced by numerous irrigation diversions. The middle Sun River (from the Sun River Diversion Dam to Fort Shaw, Montana) has three major irrigation diversions and associated districts: Greenfield Irrigation District, Broken 'O' Ranch, and the Fort Shaw Irrigation District.

The Fort Shaw Diversion Dam and Canal is located ~ 8 km upstream from Simms, Montana (Fig. 1). The Fort Shaw Canal inlet is on the main channel of the Sun River immediately upstream from, or south of, the Fort Shaw Diversion Dam. A concrete headworks operates with four gates to regulate the flow into the canal. The canal has an approximate capacity of 6.3 m3/s. The canal is 19.5 km long and supplies water to the Fort Shaw Irrigation District through ~ 85 laterals. Fort Shaw Irrigation District water irrigated ~ 4573 ha during the course of this study (Bill Bohmker, Fort Shaw Irrigation District Irrigation Manager- pers. comm.).

Methods

Fish Sampling Techniques

We designed the entrainment monitoring system implemented at the Fort Shaw Diversion to sample 100 percent of the diverted flow through the diversion's four gates. It consisted of a steel construction frame-work that enabled fyke-type nets to be raised and lowered at the diversion (Figs. 2 and 3). The system utilized eight – 6.4 m steel net frame guides (SAE measurements: 3/16-in non-radiused stock channel, 3.5-in by 2.5-in inside diameter) to guide four 2.3 m2 net frames (2-in by 2-in square tube) into

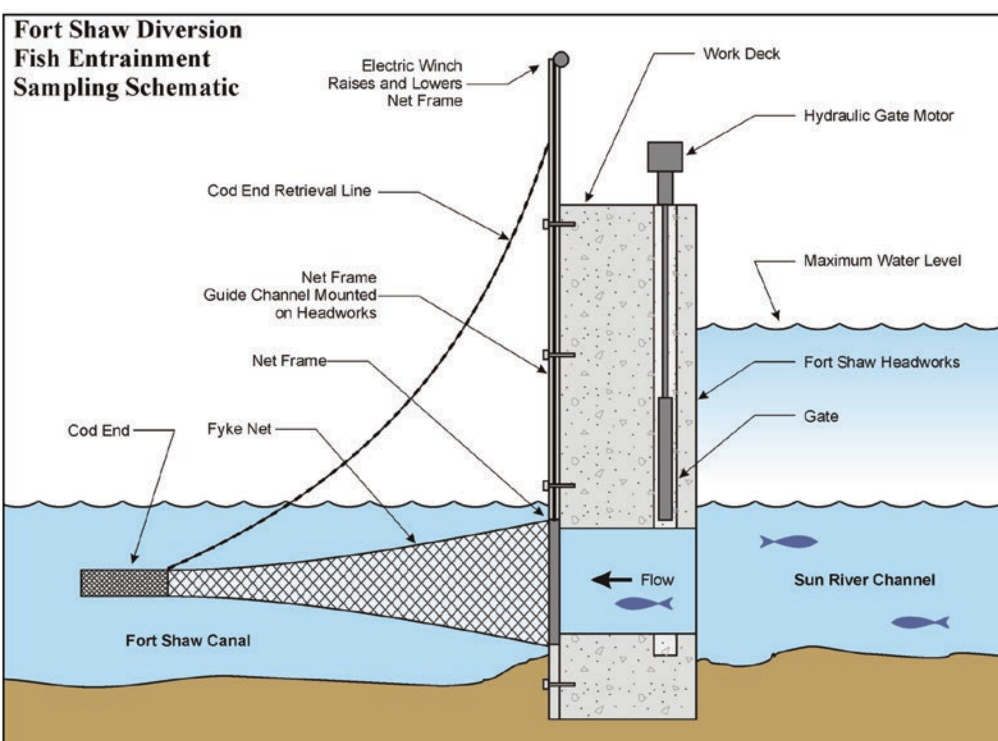

Figure 2. Side-view schematic of the Fort Shaw Diversion entrainment netting system.

Figure 3. Photograph of the deployed Fort Shaw Diversion entrainment netting system. Aspect is from the canal side.

position behind each of the diversion's four gates. Two pieces of 7.6-m channel were welded into place to form a top-bar (2-in radiused bar channel) over the net frame guides. This allowed four 115 V AC electric winches, each with a 454 kg capacity, to be placed above each gate on a mounting bracket to raise and lower the net frames while sampling. Concrete sleeve anchors (1.3 and 1.6 cm or 1/2 and 5/8 in) were used to anchor all un-welded steel to the diversion. Steel installation occurred prior to water-up in the canal in April 2003.

The nets for the entrainment monitoring system consisted of four fyke-type nets from Research Nets (Bothell, WA) used on the net frames. The nets were 6.7 m long and were constructed of 1.3-cm (½-in) knotted mesh running to a 4.8-mm (3/16-in) double-bagged cod-end with a heavy duty zipper to allow contents to be emptied. The nets also had 2.5-cm (1-in) steel rings sewn in to accommodate a 1.6-cm (5/8-in) choker line. The choker line prevented fish and debris from escaping the net during retrieval (Figs. 2 and 3). Ultra-violet resistant industrial zip-ties were used to affix the nets to their respective frames, through grommets near the net mouth. Net installation occurred in May 2003.

In both 2003 and 2004, the four nets were operated for 12-hr "Overall" sampling periods, generally starting at 1500 hrs until 0400 hrs the following day. Nets were pulled every 2 hrs and catch was sorted, measured, and recorded for each sampling period. Sampling periods were further defined as "light" for fish caught before 21:00, and "dark" for fish caught after 21:00. Extended net sets with a 24-hr operational period were also implemented in both years. In 2003, netting occurred on 33 days between 3 June and 25 September. In 2004, netting occurred on 30 days between 25 May and 29 July. Netting coincided with the peak hydrograph for each year. All fish captured in both years were returned to the canal.

Fish Entrainment Rate Calculation

We obtained diverted flow data from the gauge operated by the Fort Shaw Irrigation District (ARC050 V1.4F 09-Dec-1997: Report For Water Year 2003 and Report For Water Year 2004). The gauging station, with Station Identity "FSDM Fort Shaw Diversion Dam near Simms, Montana," is directly downstream of the canal gates (Fig. 1) and generates Daily Mean Canal Discharge (ft3/s). Flows for Sun River were obtained from USGS Real-Time Water Data for Montana using gauging station "USGS 06085800 Sun River at Simms Montana" (http://waterdata.usgs.gov/mt/nwis/uv). Although this gauging station is roughly 15 km downstream of the Fort Shaw diversion dam, it provided an approximation of the magnitude of Sun River flow at the dam. These flow data were converted to cubic meters /second (m3/s), and further converted to cubic meters/sampling period using hours sampled/sampling period.

Because sampling periods generally covered two subsequent dates, an average of these two dates' Daily Mean Discharge were used for volume calculations for overall sampling periods. The first date's Daily Mean Discharge was used for the day sampling period, and the second date's Daily Mean Discharge was used for the night sampling period. This generated a volume for diverted flow per each sampling period. Two types of fish entrainment rates were calculated during this study. For the purposes of comparisons of variables related to flow (Q), the first entrainment rate was calculated and presented as fish per hr. Comparisons of other variables not related to flow are reported are fish per m3.

We divided the number of fish captured per sample period by the diverted flow per sampling period. This yielded an entrainment rate for each overall, day, and night sampling period. Composition metrics and entrainment rates were calculated for all fish species combined, and for individual species in both years.

To obtain an estimate of total fish entrainment occurring at the Fort Shaw diversion during periods outside of the standardized collection period, and to estimate fish entrainment occurring at this diversion during the course of the June-September irrigation season, 24-hr continuous sampling periods were implemented. These data were collected in conjunction with the standardized 12-hr sample periods. The two 24-hr entrainment rates were derived from one 60-hr (14-17 Jul 2003) and one 72-hr (26-29 Jul 2004) continuous sampling effort.

Statistical Analyses

The 2003, 2004, and combined 2003/2004 number of fish entrained and entrainment rates at Fort Shaw were statistically analyzed to determine if they were independent of certain factors. These factors were: year, photoperiod, Sun River flow, Fort Shaw Canal diverted flow, Fort Shaw lag flow, ratio of diverted flow to Sun River flow, temperature, and moon phase. Nonparametric statistical procedures were used, which did not require assuming normality or equal variance. For all significance testing, the alpha level was 0.05 using two-tailed tests.

Flow and Temperature Parameters.— Diverted canal flows were the same data as used for the entrainment rate calculations. The flow being diverted into the Fort Shaw canal in comparison to the concurrent flow in Sun River, or Ratio Flow, was calculated as:

$$\text{FS/SR Ratio Flow} = \text{Fort Shaw canal flow} / \text{Sun River flow}$$

The change in flow being diverted into the canal before each overall sampling period and the preceding day was calculated as:

$$\text{Fort Shaw Lag Flow} = (\text{Fort Shaw canal flow})_{\text{time 2}} - (\text{Fort Shaw canal flow})_{\text{time 1}}$$

Where: Time 2 is current study day and Time 1 is prior calendar day

Temperature data were obtained from Montana Fish Wildlife and Parks (MFWP) thermograph array at Lowry Bridge, which is approximately 5.5 km downstream of the Fort Shaw Diversion (Fig 1).

The Spearman Rank Order Correlation was used to measure the strength of association, or correlation, between pairs of variables (Sokal and Rohlf 1995). The Spearman Rank Order Correlation coefficient is computed by ranking all values of each variable, then computing the Pearson Product Moment Correlation coefficient of the ranks. This Pearson Product Moment Correlation Coefficient, R, was then used to test study hypotheses regarding a correlation between numbers of fish entrained per hour and flow and temperature factors. It is a dimensionless index that ranges from -1.0 to 1.0 inclusive, and reflected the extent of correlation between entrainment (overall sampling period fish entrainment results) and a factor, e.g., Sun River flow, Fort Shaw flow, Fort Shaw lag flow, ratio flow, and temperature.

Year, Photoperiod, and Moon Phase Parameters.— The Mann-Whitney Rank Sum Test was used to test for differences between sample groups that were greater than what could be attributed to random sampling variation (Sokal and Rohlf 1995). The null hypothesis was that the two samples, such as light and dark period entrainment rates, were not drawn from populations with different medians.

Entrainment rates from 2003 and 2004 were compared to assess a difference between years. Within each year, light sampling period entrainment rates were compared to dark sampling period entrainment rates to assess differences in entrainment rates due to photoperiod. We preferred within year day and night entrainment comparisons to pooled comparisons (by year) because of the uncertainty associated with annual run-off timing, etc. Also, for each dark sampling period, moon phase was recorded and verified using a lunar calendar. Entrainment rates for sampling periods with either full moon or new moon phases using both years' data were compared to assess lunar effects.

Results

2003 Entrainment Results

Sampling occurred for 33 days during 3 June 2003 to 25 September 2003 for a total of 395 hours of sampling. There were a total of 2585 fish entrained during this period, comprised of 10 species (Table 1, Fig. 4) with 247 fish of unknown species. Unknown species were attributed to field situations where netting system maintenance required immediate attention so fish identification was hampered or in cases of incomplete specimens. Additionally, 2799 crawfish (Orconectes virilis) were entrained during the netting operations. Mean overall entrainment rates and lengths are given in Table 2.

Twenty-Four Hour Entrainment Rates.— On 14 - 17 July 2003, a 60-hr continuous netting effort was performed to obtain the 24-hr entrainment rates. These 24 hr entrainment rates for all pooled species were 0.000134 fish / m3 14 July-15 July, and 0.000124 fish / m3 on 15 July-16 July. These were lower than the average overall entrainment rates given in Table 2. Although diverted flows into the canal peaked on 16 July and 17 July at approximately 7 m3/s, entrainment rates (qualitatively) appeared to not be affected by the peak (Fig. 4).

By summing seasonal flow data, there were approximately 25,573,828 m3 (ARC050 V1.4F 09-Dec-1997 Report For Water Year 2003) of water diverted from the Sun River into the Fort Shaw Diversion June 2003 – September 2003. We estimated total fish entrainment occurring at this diversion during the course of the June-September irrigation season using the 24-hr entrainment rate and this total diverted flow. Using the 14 July-16 July 24 hour entrainment rate of 0.000134 and 0.000124 fish/m3, multiplied by total flow, we estimate between 3171-3427 fish were entrained June through September 2003.

Table 1. Summary of number of fish captured during the three sampling periods in 2003 and 2004 in Fort Shaw Diversion Canal, Sun River, Montana.

Year	2003			2004			
Sampling Period Species	Light	Dark	Overall	Light	Dark	Overall	Total
Brown Trout *Salmo trutta*	28	76	104	24	51	75	**179**
Fathead Minnow *Pimephales promelas*	0	0	0	0	49	49	**49**
Lake Chub *Couesius plumbeus*	1	9	10	0	27	27	**37**
Longnose Dace *Rhinichthys cataractae*	58	1310	1368	63	2565	2628	**3996**
Longnose Sucker *Catostomus catostomus*	14	198	212	65	218	283	**495**
Mottled Sculpin *Cottus bairdi*	7	109	116	8	207	215	**331**
Mountain Sucker *Catostomus platyrhynchus*	6	17	23	0	23	23	**46**
Mountain Whitefish *Prosopium williamsoni*	95	171	266	181	136	317	**583**
North. Redbelly Dace *Phoxinus eos*	0	9	9	0	2	2	**11**
Rainbow Trout *Oncorhynchus mykiss*	22	165	187	6	146	152	**339**
Silvery or Brassy Minnow *Hybognathus sp.*	0	0	0	0	25	25	**25**
White Sucker *Catostomus commersoni*	5	38	43	30	113	143	**186**
Yellow Perch *Perca flavescens*	0	0	0	0	1	1	**1**
Unk/Unmeas.	8	239	247	0	11	11	**258**
Total	**244**	**2341**	**2585**	**377**	**3574**	**3951**	**6536**

2004 Entrainment Results

Sampling occurred for 30 days during 25 May 2004 to 29 July 2004 for a total of 358 hours of sampling. There were a total of 3951 fish entrained during our sampling effort, comprised of 13 species (Table 1, Fig. 5) with 11 fish of unknown species. Additionally, 2630 crawfish were entrained during the netting operations. Again, longnose dace were the most common species captured (see 2003 vs. 2004, Table 1). Mean overall entrainment rates and lengths are given in Table 2.

Entrainment rates in 2004 appeared to increase as the amount of water being diverted at Fort Shaw approached or became greater than the downstream river flow below the diversion in the summer (Fig. 5).

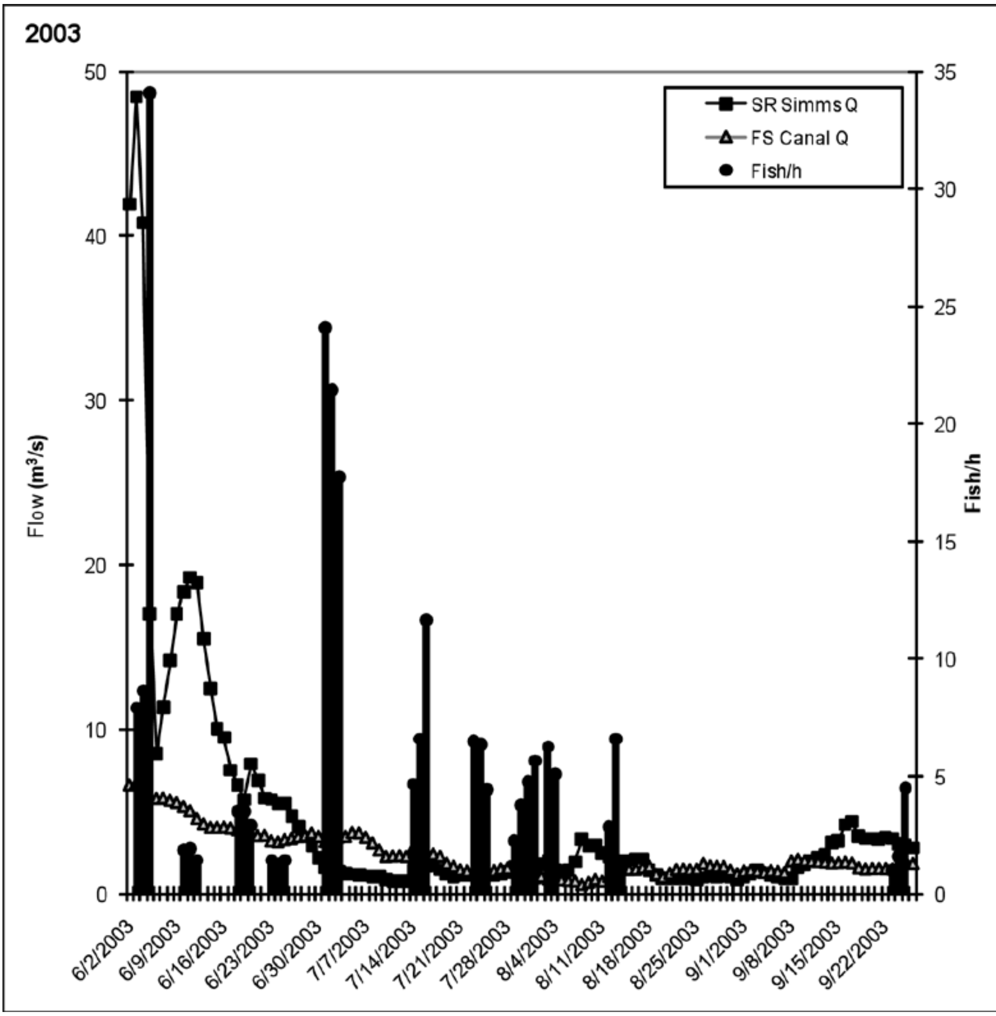

Figure 4. Fish entrained per study hour in 2003 overall sampling period in Fort Shaw Canal with Fort Shaw Canal diverted flow and Sun River flow at Simms, MT.

These inflection points in June and July represented the highest entrainment rates for the sample period.

Twenty-Four Hour Entrainment Rates.— On 26 - 29 July 2004, a 72-hr continuous netting effort was performed to obtain the 24-hr entrainment rates. These 24-hr entrainment rates, 0.000088 (27 Jul) and 0.00012 fish / m3 (28 Jul), were lower than the average overall entrainment rates as shown in Table 2. There were ~ 46,169,269 m3 (ARC050 V1.4F 09-Dec-1997 Report For Water Year 2004) of water diverted from the Sun River into the Fort Shaw Diversion June 2004-September 2004. May flow estimates were not included so that flow during irrigation seasons could be compared between years. Using the 27-28 July 24-hr entrainment rates, multiplied by total flow, we estimate between 4063-5540 fish were entrained June-September 2004.

Flow and Temperature Effects on Entrainment Results

During the 2003 study period, diverted flow into the Fort Shaw Canal was highest during June, ranging 3.1-6.7 m3/s, and was lower during July-September staying 0.6 - 3.7 m3/s (Fig. 4, also Table 1 in Appendix A). During the 2004 study period, diverted

Table 2. Summary of lengths of fish entrained during all sampling periods and mean entrainment rates for Overall sampling period during 2003 and 2004 in Fort Shaw Diversion Canal, Sun River, Montana. ER is the entrainment rate of fish per 1000 m3 of flow.

Species	Mean Study Year	Min. Length (mm)	Max. Mean Length (mm)	Length (mm)	Overall ER
Brown Trout	2003	157	39	565	0.0252
	2004	148	42	385	0.0145
Fathead Minnow	2003	.	.	.	0
	2004	43	25	77	0.0084
Lake Chub	2003	77	57	108	0.0031
	2004	44	26	75	0.0035
Longnose Dace	2003	71	25	225	0.4670
	2004	61	22	109	0.4762
Longnose Sucker	2003	145	33	457	0.0821
	2004	120	23	372	0.0493
Mottled Sculpin	2003	79	32	111	0.0510
	2004	63	26	90	0.0381
Mountain Sucker	2003	125	52	184	0.0069
	2004	68	40	173	0.0042
Mountain Whitefish	2003	142	27	372	0.0727
	2004	142	36	370	0.0626
North. Redbelly Dace	2003	53	32	67	0.0013
	2004	49	45	52	0.0003
Rainbow Trout	2003	129	41	456	0.0400
	2004	92	30	300	0.0246
Silvery or Brassy Minnow	2003	.	.	.	0
	2004	38	30	60	0.0040
White Sucker	2003	197	48	449	0.0116
	2004	110	46	280	0.0302
Yellow Perch	2003	.	.	.	0
	2004	66	.	.	0.0002
All Species	2003				0.7959
	2004				0.7181

flow was highest in late July with flows reaching 7.4 m3/s with slightly lower flows earlier in the season (Fig. 5, also Table 2 in Appendix A). In both years, Sun River flows peaked above 39 m3/s early in the season, and then quickly dropped to ~ 1.5 m3/s the remainder of the season.

In assessing effects of flow variables on fish entrained/hour, only the effects of Sun River flow and the FS:SR Ratio Flow appeared significant (Table 3, Fig. 6). Fish entrained/hour was negatively correlated with Sun River flow, with more fish entrained as less flow was discharged in the river. Fish entrainment was positively correlated with the ratio of Fort Shaw Canal flow to Sun River flow, indicating that more fish were entrained as Fort Shaw Canal flow exceeded that of the Sun River. The Sun River temperature was not significantly

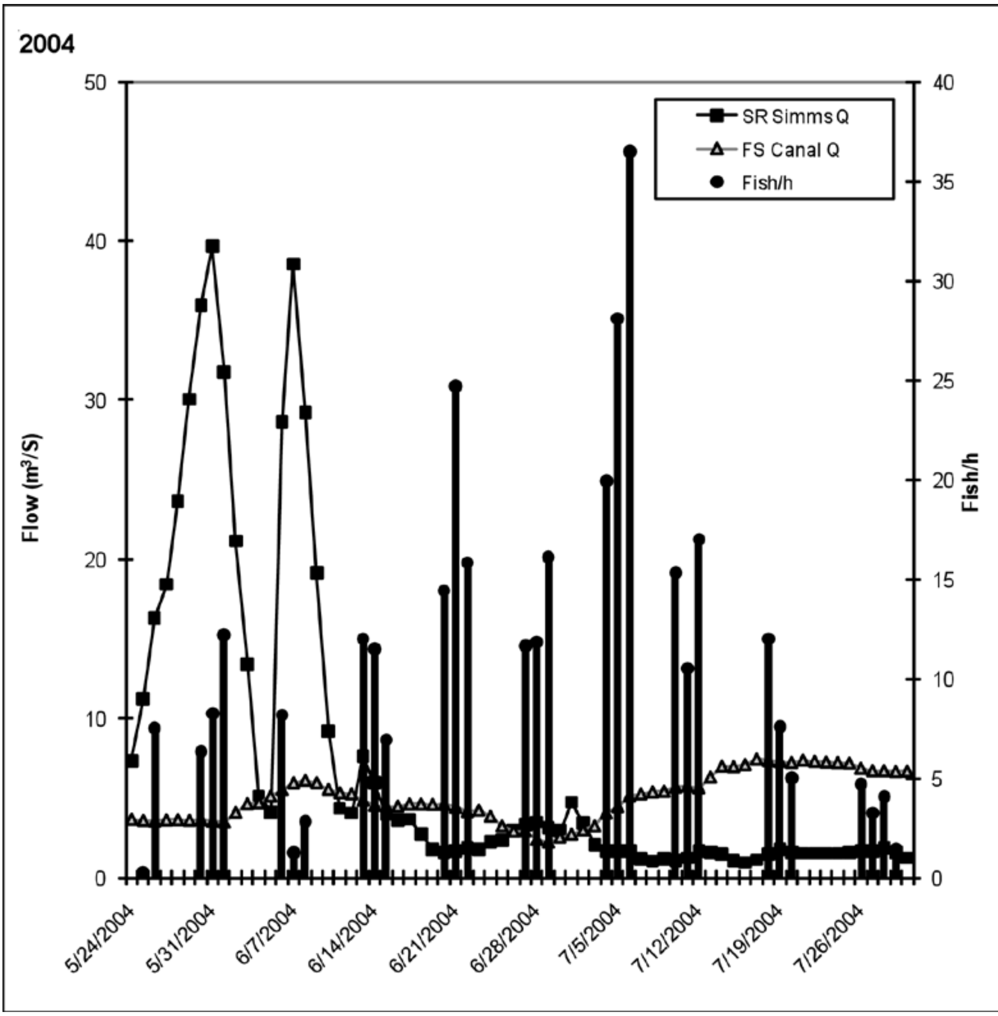

Figure 5. Fish entrained per study hour in 2004 overall sampling period in Fort Shaw Canal with Fort Shaw Canal diverted flow and Sun River flow at Simms, MT.

Table 3. Statistical results for variables correlated with Number of Fish Entrained per Hour in both years for Overall Sampling Period using Spearman Rank Order Correlation. Asterisk indicates significance.

Correlation to Fish Entrained per Hour			
Variable	N	Correlation Coefficient	P Value
Sun River Q	63	-0.254	0.0444*
Fort Shaw Canal Q	63	0.180	1.1570
Ratio FSQ:SRQ	63	0.370	0.0029*
Lag Sun River Q	63	-0.121	0.3430
Lag Fort Shaw Canal	63	0.101	0.4290
Temperature	57	0.071	0.5990

correlated with fish entrainment (Table 3, also Tables 1 and 2 in Appendix B).

Year, Photoperiod, and Moon Phase Effects on Entrainment Results

A graphical comparison of median entrainment rates is given in Figure 7. There was not a significant difference (Mann -Whitney U Statistic = 517.0 P = 0.767) in median overall entrainment rates for all species between 2003 and 2004.

We detected a significant difference both years (2003: Mann-Whitney U Statistic = 997.0 P ≤ 0.001, 2004: Mann-Whitney U Statistic= 835.0 P ≤ 0.001) when comparing

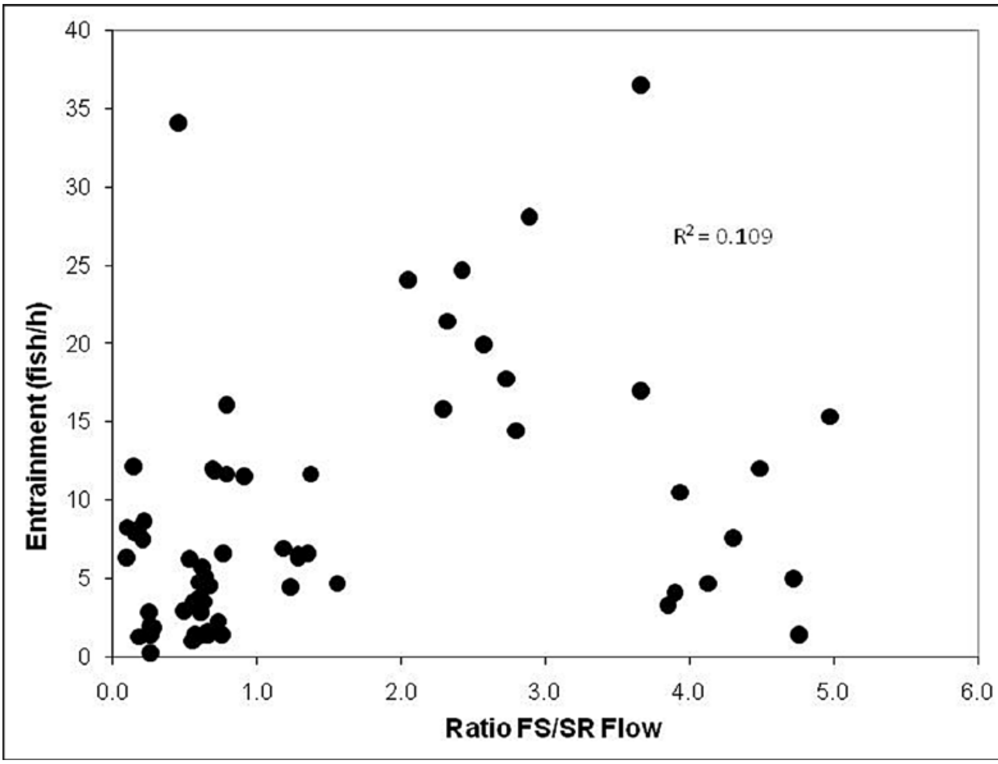

Figure 6. Scatter Plot depicting correlation between fish entrained per study hour in Fort Shaw Canal during overall sampling periods and ratio of Fort Shaw Canal diverted flow to Sun River flow at Simms, MT.

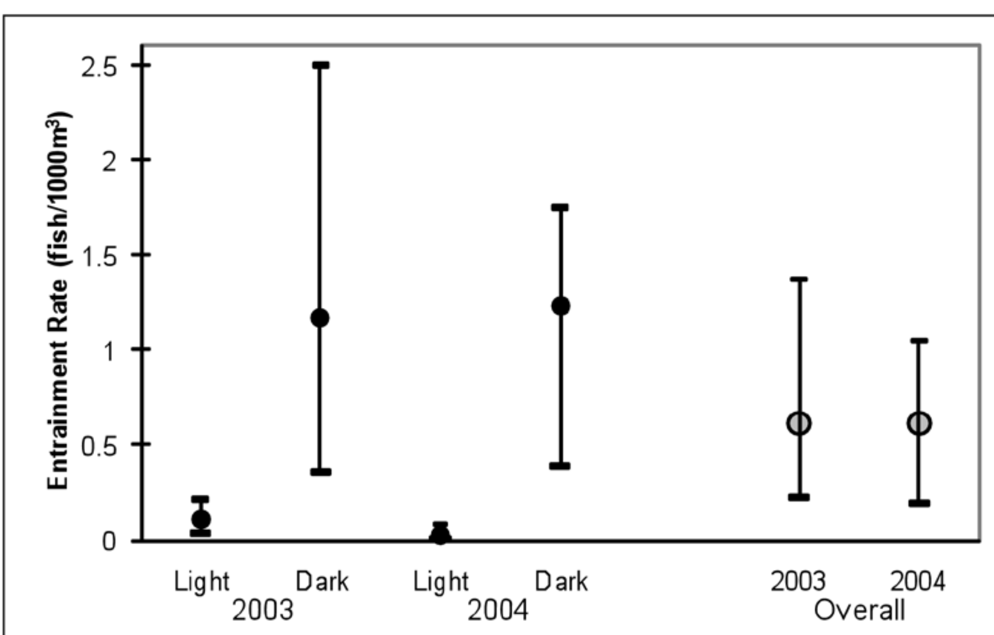

Figure 7. Comparison of Entrainment Rates between years and sampling periods, depicting median Entrainment Rate with 25% and 75% quartiles.

median values for light and dark sampling period entrainment rates.

There was not a significant difference (Mann-Whitney U Statistic = 272.0 P = 0.420, Tables 1 and 2 in Appendix B) when comparing the difference in median dark entrainment rates for all species between new moon and full moon periods for both years.

Discussion

The Fort Shaw nets captured 10 species previously identified to occur within the Sun River, but 3 species [northern redbelly dace (*Phoxinus eos*), fathead minnow (*Pimephales promelas*), and yellow perch (*Perca flavescens*)] were captured but were previously unrecorded within the Sun River Mainstem (based on Horton et al. 2006). Brook trout (*Salvelinus fontinalis*), burbot (*Lota lota*), carp (*Cyprinus carpio*), and northern pike (*Esox lucius*) have all been sampled in low numbers in the Sun River, and of these, burbot were the only species sampled in the vicinity of the Fort Shaw Diversion by Horton et al. (2006) that was not captured. Entrainment rates and percentage of larger trout as defined by Horton et al. (2006) > 200 mm total length were similar in both years, i.e., 14.4 of brown trout and 4.3 percent of rainbow trout in 2003, and 16.0 percent of brown trout and 2.6 percent of rainbow trout in 2004). Trout population density estimates obtained from MFWP indicated Sun River densities near the Fort Shaw Diversion were low in comparison to other trout population densities in North-Central Montana. Mean trout densities of fish > 200 mm near the Fort Shaw Diversion were the lowest of all reaches sampled by Horton et al. (2006). This could be a result of irrigation withdrawals since our net capture data supports that trout are being entrained. We do not, however, know whether trout of all sizes were entrained disproportionately to their abundance since we did not simultaneously obtain an abundance estimate. Also, the relationship between abundance in Sun River and entrainment rate for all species remains unclear. For example, our estimates for longnose dace entrainment at the Fort Shaw Diversion indicated a potential for very high losses of this species. However, electrofishing-based population estimates for small, non-game species such as longnose dace are not particularly effective (Horton et al. 2006). Thus, application of the hypothesis that entrainment rates are related to main stem population density is one of probability, supported only by evidence that some small-bodied fishes have been found to have swimming performances inversely proportionate to water velocity (Warren and Pardew 1998), and have preferences for shallower shoreline habitat (Gryska et al. 1998), likely making them susceptible to entrainment due to diversion canal structure and velocities.

Although the 2003 sampling period encompassed a longer period of the irrigation season than 2004, the total number of fish entrained during 2004 was higher than 2003 by 1366 fish, which consisted mostly of the species longnose dace. There was a lower volume of water diverted in 2003 than in 2004 (20,595,441 fewer m3/s in 2003). This qualitatively seems to support common assumptions that fish entrainment is directly related to volume of water diverted (Hiebert et al. 2000, Hanson 2001, Post et al. 2006).

In both years there was a significant relationship between diverted flow and entrainment. The significance of the ratio of mainstem flow to diverted flow on fish entrained per hour indicates that fish may follow the cue of the larger flow. The numbers of fish entrained increased as the ratio (FS/SR) became > 1, indicating that the fish were following the larger diverted flow cue.

The 2004 Sun River hydrograph experienced a double peak in early June, yet this did not seem to affect entrainment. We would have expected to see higher entrainments in response to this second peak if Sun River flow was positively instead of negatively affecting entrainment. With one exception (4 June 2003), entrainment in both years appears to be the highest directly after an event where the diverted flow into the canal exceeded the Sun River flow (Figs. 4 and 5). In addition, there was a statistically significant effect of this ratio between the two flows and entrainment. This would indicate that entrainment is probably affected by the change in flow with fish following the magnitude of the flow, whether it is down river or into the diversion. Our data indicate that when diverted flows exceed mainstem Sun River flows, fish are at greater risk for entrainment.

Many species such as salmon (Salmonidae), sturgeon (Ascipensceridae), paddlefish (*Polydon spathula*), and blue suckers (*Cycleptus elongates*) have been shown to initiate large scale spawning movements within rivers experiencing discharge peaks (Russell 1986, Young 1994, Holton and Johnson 1996). Movement into the canal could be falsely cued by diversion discharges, which could increase entrainment probabilities for fish species in the Sun River.

In both years, entrainments rates were significantly higher during dark than during light sampling periods. Fish were more prone to entrainment during dark periods because they were likely more active during the dark periods, (e.g., Beers and Culp 1990, Schmetterling and Adams 2004). The 12-hr sample period used in our study appeared to be effective at capturing fish entrained into the canal because it likely incorporates this period of highest activity, which yielded higher capture efficiencies. For example, two 24-hour sampling periods from 2003 are compared in Figure 8. The hours of 2130-0330 appeared to be periods of highest entrainment. Future research studies at this site could consider doing only dark net sets if resources are limited.

There are examples in the literature that both support and refute a corollary for the effect of lunar periodicity. For example, Rooker and Dennis (1991) found that

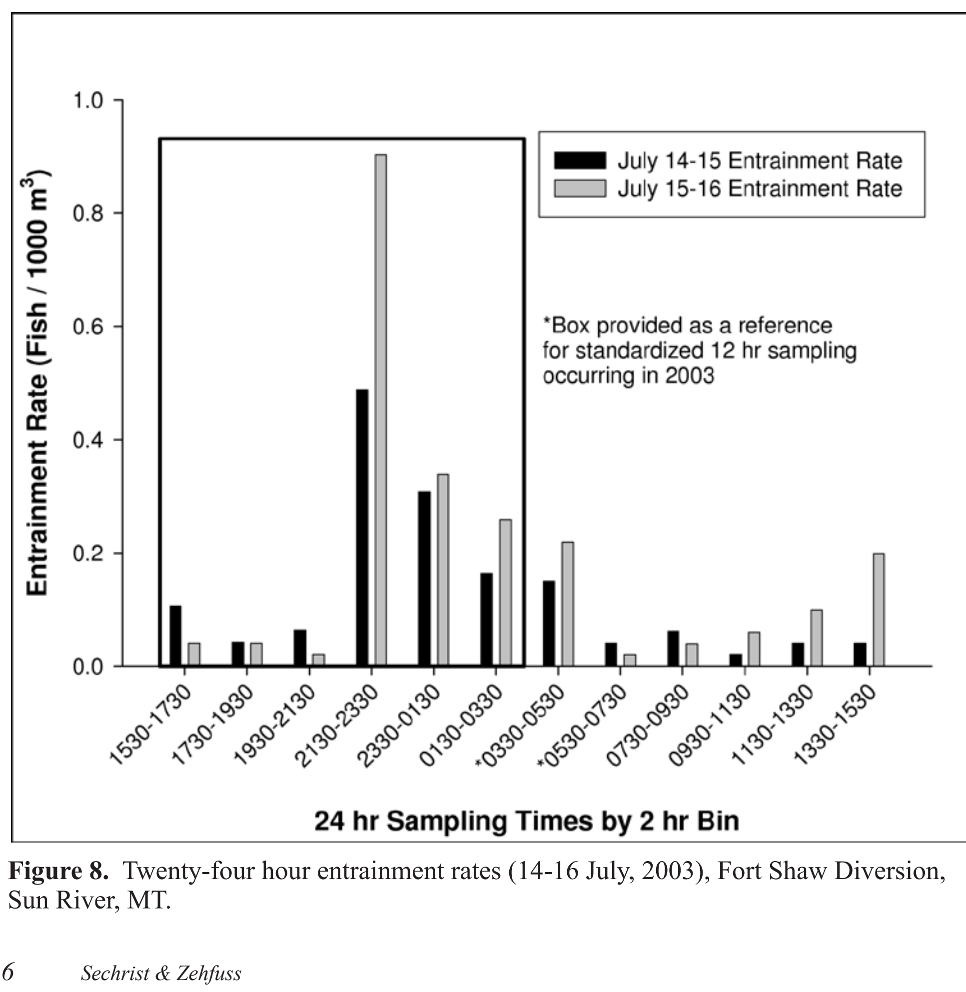

Figure 8. Twenty-four hour entrainment rates (14-16 July, 2003), Fort Shaw Diversion, Sun River, MT.

lunar periodicity had no obvious effect on abundance of migratory fish assemblages in a tidal system, whereas Gale (2005) found lunar cycles may have influenced downstream movement young cutthroat trout; however, it did not appear to have an effect on fish entrainment at this diversion. We did not find that in-stream temperature had an effect on entrainment at the Fort Shaw Diversion although increasing stream temperatures likely initiate movement of cool or cold-water fishes (Lessard and Hayes 2003); and this movement presumably would increasing the chance of entrainment as fish encounter diversions while seeking thermal refugia.

We considered the fish entrainment netting system used at the Fort Shaw Diversion to be both economical and effective. This general design has been used on several Bureau of Reclamation entrainment studies in Montana but has not been formally published. For example, the Huntley (Best et al. 2004) and Intake Diversions (Hiebert et al. 2000) on the Yellowstone River, the St. Mary Diversion on the St. Mary River (Mogen and Kaeding 2002), the Frenchtown Diversion on the Clark Fork River (Sechrist et al. 2005), and in other river systems in the Western United States. Larger netting systems of this type have also been used to monitor entrainment from large reservoir turbine outfalls at Shasta and Blue Mesa Reservoirs (California and Colorado respectively, USDI Bureau of Reclamation, Unpub. data). These systems allow for quantification of entrainment timing (diurnal, seasonal) and species composition, yielding daily, seasonal, and species-specific entrainment rates. However, fyke-type netting systems of this design are monitoring intensive because they require frequent checks to clear debris and to prevent fish impingement at the back of the cod-end. The system is not robust to high water volume or velocity because the working ratio of frame opening to net length is assumed to be roughly 1:3/m2 of frame opening (the net must be 3 times longer) to dissipate flow energy through our chosen mesh size. Thus in some diversion locations, net lengths could become unmanageable. Also, capture efficiency for larval or large, strong swimming fish have not been measured at any of the locations where these systems have been installed.

Conclusions and Management Implications

Losses of Sun River fishes to irrigation diversions have been documented since 1952 (Thoreson 1952). Our study further revealed that many of these fish are entrained when the majority of the instream flow is diverted into irrigation canals. It is apparent that effective screening techniques would decrease entrainment at the Fort Shaw Diversion, and by extension, other large diversions within the Sun River.

In addition to potential screening, other proactive management techniques merit consideration. For example, in 2004, a limited salvage operation at the Fort Shaw canal did return some fish to the Sun River after irrigation deliveries had ceased. Further, in some years, an informal downstream flow agreement has existed to maintain limited flow below the Sun River Diversion Dam. To be effective, and because there are many diversions on the Sun River, any proactive water management that is likely to succeed will rely on consensus and cooperation between suppliers (government) and water users (stakeholders).

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Literature Cited

Bakes, K. M., V. Riggs, and D. Peters. 1998. Tongue river entrainment study on the T&Y Canal, May 29 to October 10, 1997. Montana Fish, Wildlife, and Parks, Region 7, Miles City. 16 pp.

Beers, C. E. and J. M. Culp. 1990. Plasticity in foraging behavior of a lotic minnow (Rhinichthys cataractae) in response to different light intensities. Canadian Journal of Zoology 68:101-105.

Best, E. L., J. D. Sechrist, and S. D. Hiebert. 2004. Fish entrainment investigations at the Huntley Diversion Dam, Yellowstone River, Montana. USDI Bureau of Reclamation, Denver, CO.

Cook, L. and L. D. Buffaloe. 1998. Delta agricultural diversion evaluation summary report, 1993-1995. Interagency Ecological Program for the San Francisco Bay / Delta Estuary Technical Report 61. Sacramento, CA.

Clothier, W. D. 1954. Fish loss and movement in irrigation diversions from the West Gallatin River, Montana. Journal of Wildlife Management 17: 144-158.

Gale, S. B. , A. V. Zale, and C. G. Clancy. 2008. Effectiveness of fish screens to prevent entrainment of westslope cutthroat trout into irrigation canals. North American Journal of Fisheries Management 28: 15441-1553.

Gryska, A. D., W. A. Hubert, and K. G. Gerow. 1998. Relative abundance and lengths of Kendall Warm Springs dace captured from different habitats in a specially designed trap. Transactions of the American Fisheries Society 127:309-315.

Hallock, R. J., and W. F. Van Woert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. California Fish and Game 45:227-293.

Hanson, C. H. 2001. Are juvenile chinook salmon entrained at unscreened diversions in direct proportion to the volume of water diverted? Pp. 331-341 *in* R. L. Brown ed., Contributions to biology of Central Valley salmonids, Volume 2. California Department of Fish and Game Fish Bulletin 179.

Helfrich, L. A., C. Liston, S. Hiebert, M. Albers, and K. Frazer. 1999. Influence of low-head diversion dams on fish passage, community composition, and abundance in the Yellowstone River, Montana. Rivers 7(1):21-32.

Hiebert, S., R. Wydowski, and T. Parks. 2000. Fish entrainment at the LowerYellowstone Diversion Dam, Intake Canal, Montana 1996-1998. USDI Bureau of Reclamation, Denver, CO.

Holton, G. D. and H. E. Johnson. 1996. A field guide to Montana fishes, 2nd edition. Montana Fish, Wildlife, and Parks, Helena, MT.

Howard, S. W. 1992. Green fields of Montana. Sunflower University Press, Manhattan, KS. 153 pp.

Horton, T. B., G. A. Liknes, and P. D. Hamlin. 2006. Montana Statewide Fisheries Management Federal Aid Job Progress Report, F 113 R5 and F 113 R6. Great Falls Management Area Fisheries Progress Report, 2005 Annual Report. Montana Fish, Wildlife, and Parks. Fisheries Division, Helena.

Lessard, J. L. and D. B. Hayes. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19:721–732.

McMichael, G. A., J. A. Carter, and M. A. Chamness. 2001. Walla Walla River Basin fish screen evaluations, 2001; Burlingame and Little Walla Walla sites. Prepared by the Pacific Northwest Laboratory, Richland, Washington, for the U. S. Department of Energy, Bonneville Power Administration, Portland, OR.

Mogen, J. T. and L .R. Kaeding. 2002. Fish entrainment investigations at the St. Mary

Diversion Dam, St. Mary, Montana. USDI Fish and Wildlife Service. Bozeman, MT.

Moyle, P. B. and J. A. Israel. 2005. Untested assumptions: effectiveness of screening diversions for conservation of fish populations. Fisheries(30)5:20-29.

Neitzel, D. A., C. S. Abernathy, and E. W. Lusty. 1991. Evaluation of drum screen facilities in the Yakima River Basin, south-central Washington State. American Fisheries Society Symposium 10:325-334.

Nobriga, M. L., Z. Matica, and Z. P. Hymanson. 2004. Evaluating entrainment vulnerability to agricultural irrigation diversions: A comparison among open-water fishes. American Fisheries Society Symposium 39:281-295.

Pearce, R. O. and R. T. Lee. 1991. Some design considerations for approach velocities at juvenile salmonid screening facilities. American Fisheries Society Symposium10:237-248.

Post, J. R., B. T. van Poorten, T. Rhodes, P. Askey, and A. J. Paul. 2006. Fish entrainment into irrigation canals: an analytical approach and application to the Bow River, Alberta, Canada. North American Journal of Fisheries Management 26:875-887.

Prince, E. E. 1922. Irrigation canals as an aid to fisheries development in the West. Transactions of the American Fisheries Society 52:157-165.

Reiland, E. W. 1997. Fish loss to irrigation canals and methods to reduce these losses on the West Gallatin River, Montana. Master's Thesis, Montana State University. Bozeman.

Rooker, J. R. and G. D. Dennis. 1991. Diel, lunar, and seasonal changes in a mangrove fish assemblage off southwestern Puerto Rico. Bulletin of Marine Sciences 49: 684-698.

Russell, T. R. 1986. Biology and life history of the paddlefish – a review. Pp 2-20 *in* J.G. Dillard, L. K. Graham, and T. R. Russell, eds., Paddlefish – a threatened resource? Proc. of a symposium. St. Louis, MO.

Schmetterling, D. A. and S. B. Adams. 2004. Summer movements within the fish community of a small montane stream. North American Journal of Fisheries Management 24: 1163-1172.

Schrank, A. J. and F. J. Rahel. 2004. Movement patterns in inland cutthroat trout (*Oncorhynchus clarki utah*): management and conservation implications. Canadian Journal of Fisheries and Aquatic Sciences 61:1528-1537.

Sechrist, J. D., E. L. Best, and S. D. Hiebert. 2005. Fisheries entrainment investigations at Frenchtown Diversion Canal, Frenchtown, Montana: Report of findings 2003-2004. USDI Bureau of Reclamation, Denver, CO.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. 3rd edition. W. H. Freeman and Co.: New York. 887 pp. ISBN: 0-7167-2411-1.

Spindler, J. C. 1955. Loss of game fish in relation to physical characteristics of irrigation-canal intakes. Journal of Wildlife Management 19:375-382.

Thoreson, N. A. 1952. Central Montana fisheries study: fish losses in the Pishkun Irrigation Canal and development of census techniques. Montana Fish, Wildlife, and Parks Job Completion Report, Project F-5-R-1, Helena.

Warren, M. L. and M. G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society. 127: 637-644.

Young, M. K. 1994. Mobility of brown trout in south-central Wyoming streams. Canadian Journal of Zoology 72: 2078-2083.

Zydlewski, G. B. and J. R. Johnson. Response of bull trout fry to four types of water diversions screens. North American Journal of Fisheries Management 22:1276-1282.

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Appendix A.

Table 1. USGS and Hydromet stream flow gage data for Sun River at Simms and Fort Shaw Canal during 2003. Lag proportional flow is percentage change in flow from previous day. Entrainment (Fish/h) is based on 12 h sample periods.

Date	SR Simms Q (m3/s)	FS Canal Q (m3/s)	Ratio FS/SR Q	Lag Prop. SR Flow	Lag Prop. FS Flow	Overall Study Fish/h
6/2/2003	41.9136	6.6000	0.1575	.	.	
6/3/2003	48.4272	6.7124	0.1386	0.155	0.017	7.91
6/4/2003	40.7808	6.5586	0.1608	-0.158	-0.023	8.64
6/5/2003	16.9920	5.8336	0.3433	-0.583	-0.111	34.09
6/6/2003	8.4960	5.7937	0.6819	-0.500	-0.007	
6/7/2003	11.3280	5.8149	0.5133	0.333	0.004	
6/8/2003	14.1600	5.6773	0.4009	0.250	-0.024	
6/9/2003	16.9920	5.5485	0.3265	0.200	-0.023	
6/10/2003	18.3514	5.3083	0.2893	0.080	-0.043	1.83
6/11/2003	19.2293	5.0500	0.2626	0.048	-0.049	1.92
6/12/2003	18.9178	4.5742	0.2418	-0.016	-0.094	1.42
6/13/2003	15.5194	4.2534	0.2741	-0.180	-0.070	
6/14/2003	12.4608	4.0387	0.3241	-0.197	-0.050	
6/15/2003	9.9970	4.0381	0.4039	-0.198	0.000	
6/16/2003	9.4872	4.0577	0.4277	-0.051	0.005	
6/17/2003	7.5048	4.0047	0.5336	-0.209	-0.013	
6/18/2003	6.6269	3.9031	0.5890	-0.117	-0.025	3.50
6/19/2003	5.7206	3.8793	0.6781	-0.137	-0.006	3.50
6/20/2003	7.9013	3.7238	0.4713	0.381	-0.040	2.92
6/21/2003	6.9101	3.5341	0.5114	-0.125	-0.051	
6/22/2003	5.8056	3.5522	0.6119	-0.160	0.005	
6/23/2003	5.7206	3.2262	0.5640	-0.015	-0.092	1.42
6/24/2003	5.4941	3.1684	0.5767	-0.040	-0.018	1.25
6/25/2003	5.4658	3.2967	0.6032	-0.005	0.040	1.42
6/26/2003	4.7294	3.3783	0.7143	-0.135	0.025	
6/27/2003	4.0498	3.4808	0.8595	-0.144	0.030	
6/28/2003	3.4550	3.5434	1.0256	-0.147	0.018	
6/29/2003	2.9170	3.7026	1.2693	-0.156	0.045	
6/30/2003	2.1806	3.4910	1.6009	-0.252	-0.057	
7/1/2003	1.5859	3.1902	2.0116	-0.273	-0.086	24.08
7/2/2003	1.5576	3.2429	2.0820	-0.018	0.017	21.42
7/3/2003	1.3310	3.4590	2.5987	-0.145	0.067	17.75
7/4/2003	1.2178	3.4938	2.8691	-0.085	0.010	
7/5/2003	1.1894	3.7300	3.1360	-0.023	0.068	
7/6/2003	1.1611	3.7068	3.1924	-0.024	-0.006	
7/7/2003	1.0762	3.4420	3.1984	-0.073	-0.071	
7/8/2003	1.0478	3.1036	2.9619	-0.026	-0.098	
7/9/2003	1.0478	2.6765	2.5543	0.000	-0.138	
7/10/2003	0.8213	2.2783	2.7741	-0.216	-0.149	
7/11/2003	0.7646	2.3103	3.0215	-0.069	0.014	
7/12/2003	0.7363	2.3302	3.1646	-0.037	0.009	
7/13/2003	0.7646	2.2775	2.9785	0.038	-0.023	

Appendix A, Table 1 (cont).

Date	SR Simms Q (m3/s)	FS Canal Q (m3/s)	Ratio FS/SR Q	Lag Prop. SR Flow	Lag Prop. FS Flow	Overall Study Fish/h
7/14/2003	1.4443	2.7725	1.9196	0.889	0.217	4.67
7/15/2003	1.9258	2.4687	1.2819	0.333	-0.110	6.58
7/16/2003	1.6426	2.3503	1.4309	-0.147	-0.048	11.67
7/17/2003	1.8408	2.4282	1.3191	0.121	0.033	
7/18/2003	1.4726	2.2914	1.5560	-0.200	-0.056	
7/19/2003	1.2461	1.8708	1.5014	-0.154	-0.184	
7/20/2003	1.0478	1.6825	1.6057	-0.159	-0.101	
7/21/2003	1.0762	1.4721	1.3679	0.027	-0.125	
7/22/2003	1.1611	1.4021	1.2076	0.079	-0.048	
7/23/2003	1.0762	1.2954	1.2037	-0.073	-0.076	6.50
7/24/2003	1.0478	1.4282	1.3630	-0.026	0.103	6.33
7/25/2003	1.1328	1.3684	1.2080	0.081	-0.042	4.43
7/26/2003	1.1328	1.4225	1.2558	0.000	0.040	
7/27/2003	1.1894	1.5313	1.2874	0.050	0.076	
7/28/2003	1.3310	1.5703	1.1798	0.119	0.026	
7/29/2003	1.5859	1.3285	0.8377	0.191	-0.154	2.25
7/30/2003	1.6426	1.0311	0.6278	0.036	-0.224	3.75
7/31/2003	1.5576	0.8873	0.5696	-0.052	-0.140	4.75
8/1/2003	1.5576	0.9858	0.6329	0.000	0.111	5.67
8/2/2003	1.7842	1.0815	0.6062	0.145	0.097	
8/3/2003	1.9541	0.9314	0.4767	0.095	-0.139	6.25
8/4/2003	1.4726	0.8952	0.6079	-0.246	-0.039	5.08
8/5/2003	1.2744	0.8592	0.6742	-0.135	-0.040	
8/6/2003	1.4160	0.8252	0.5828	0.111	-0.040	
8/7/2003	1.9258	0.7952	0.4129	0.360	-0.036	
8/8/2003	3.3134	0.5797	0.1750	0.721	-0.271	
8/9/2003	2.9170	0.7241	0.2483	-0.120	0.249	
8/10/2003	2.9170	0.8932	0.3062	0.000	0.233	
8/11/2003	2.4638	0.7881	0.3199	-0.155	-0.118	
8/12/2003	2.2656	1.0725	0.4734	-0.080	0.361	2.83
8/13/2003	1.9541	1.4922	0.7636	-0.138	0.391	6.58
8/14/2003	1.9824	1.5140	0.7637	0.014	0.015	1.42
8/15/2003	2.0390	1.5089	0.7400	0.029	-0.003	
8/16/2003	2.1240	1.5171	0.7143	0.042	0.005	
8/17/2003	2.1240	1.6165	0.7611	0.000	0.066	
8/18/2003	1.4443	1.6848	1.1665	-0.320	0.042	
8/19/2003	1.1045	1.1960	1.0828	-0.235	-0.290	
8/20/2003	0.9629	1.0529	1.0935	-0.128	-0.120	
8/21/2003	0.9346	1.2625	1.3509	-0.029	0.199	
8/22/2003	0.9346	1.4973	1.6021	0.000	0.186	
8/23/2003	0.9629	1.5211	1.5797	0.030	0.016	
8/24/2003	0.9346	1.4817	1.5855	-0.029	-0.026	
8/25/2003	0.8496	1.5086	1.7757	-0.091	0.018	
8/26/2003	0.9912	1.8618	1.8783	0.167	0.234	
8/27/2003	1.1045	1.7083	1.5467	0.114	-0.082	

Appendix A, Table 1 (cont).

Date	SR Simms Q (m3/s)	FS Canal Q (m3/s)	Ratio FS/SR Q	Lag Prop. SR Flow	Lag Prop. FS Flow	Overall Study Fish/h
8/28/2003	1.0478	1.6822	1.6054	-0.051	-0.015	
8/29/2003	1.0762	1.6729	1.5545	0.027	-0.006	
8/30/2003	1.0195	1.4508	1.4231	-0.053	-0.133	
8/31/2003	0.8496	1.2305	1.4483	-0.167	-0.152	
9/1/2003	0.9912	1.4007	1.4131	0.167	0.138	
9/2/2003	1.2178	1.4330	1.1767	0.229	0.023	
9/3/2003	1.4443	1.4021	0.9708	0.186	-0.022	
9/4/2003	1.2744	1.3214	1.0369	-0.118	-0.058	
9/5/2003	1.1045	1.4149	1.2810	-0.133	0.071	
9/6/2003	0.9912	1.3704	1.3826	-0.103	-0.031	
9/7/2003	0.9346	1.3087	1.4003	-0.057	-0.045	
9/8/2003	0.9629	2.0073	2.0847	0.030	0.534	
9/9/2003	1.5859	2.1070	1.3286	0.647	0.050	
9/10/2003	1.7842	2.0218	1.1332	0.125	-0.040	
9/11/2003	1.9541	1.9920	1.0194	0.095	-0.015	
9/12/2003	2.1523	1.9600	0.9107	0.101	-0.016	
9/13/2003	2.3506	1.9317	0.8218	0.092	-0.014	
9/14/2003	3.1152	1.8841	0.6048	0.325	-0.025	
9/15/2003	3.2002	1.9059	0.5956	0.027	0.012	
9/16/2003	4.1914	1.9314	0.4608	0.310	0.013	
9/17/2003	4.3896	1.8872	0.4299	0.047	-0.023	
9/18/2003	3.5117	1.5941	0.4540	-0.200	-0.155	
9/19/2003	3.3418	1.5364	0.4597	-0.048	-0.036	
9/20/2003	3.3418	1.5556	0.4655	0.000	0.013	
9/21/2003	3.3134	1.5616	0.4713	-0.008	0.004	
9/22/2003	3.4550	1.5502	0.4487	0.043	-0.007	
9/23/2003	3.3418	1.5310	0.4581	-0.033	-0.012	1.00
9/24/2003	3.0019	1.9422	0.6470	-0.102	0.269	1.58
9/25/2003	2.9170	1.9442	0.6665	-0.028	0.001	4.50
9/26/2003	2.8037	1.8589	0.6630	-0.039	-0.044	

Appendix A.

Table 2. USGS and Hydromet stream flow gage data for Sun River at Simms and Fort Shaw Canal during 2004. Lag proportional flow is percentage change in flow from previous day. Entrainment (Fish/h) is based on 12 h sample periods.

Date	SR Simms Q (m3/s)	FS Canal Q (m3/s)	Ratio FS/SR Q	Lag Prop. SR Flow	Lag Prop. FS Flow	Overall Study Fish/h
5/24/2004	7.3349	3.6655	0.4997	.		
5/25/2004	11.2430	3.5975	0.3200	0.533	-0.019	0.25
5/26/2004	16.2840	3.5397	0.2174	0.448	-0.016	7.50
5/27/2004	18.4080	3.6241	0.1969	0.130	0.024	
5/28/2004	23.6472	3.6388	0.1539	0.285	0.004	
5/29/2004	30.0192	3.6017	0.1200	0.269	-0.010	
5/30/2004	35.9664	3.6383	0.1012	0.198	0.010	6.33
5/31/2004	39.6480	3.5309	0.0891	0.102	-0.030	8.25
6/1/2004	31.7184	3.4848	0.1099	-0.200	-0.013	12.17
6/2/2004	21.1550	4.0905	0.1934	-0.333	0.174	
6/3/2004	13.3670	4.6300	0.3464	-0.368	0.132	
6/4/2004	5.1259	4.6867	0.9143	-0.617	0.012	
6/5/2004	4.1064	5.1067	1.2436	-0.199	0.090	
6/6/2004	28.6032	5.5269	0.1932	5.966	0.082	8.17
6/7/2004	38.5152	5.9469	0.1544	0.347	0.076	1.25
6/8/2004	29.1696	6.1069	0.2094	-0.243	0.027	2.83
6/9/2004	19.1160	5.9523	0.3114	-0.345	-0.025	
6/10/2004	9.2040	5.5334	0.6012	-0.519	-0.070	
6/11/2004	4.3330	5.3182	1.2274	-0.529	-0.039	
6/12/2004	4.0498	5.2485	1.2960	-0.065	-0.013	
6/13/2004	7.6181	4.8572	0.6376	0.881	-0.075	12.00
6/14/2004	5.9472	4.5326	0.7621	-0.219	-0.067	11.50
6/15/2004	3.9648	4.4782	1.1295	-0.333	-0.012	6.92
6/16/2004	3.6250	4.4828	1.2366	-0.086	0.001	¬
6/17/2004	3.6533	4.6125	1.2626	0.008	0.029	
6/18/2004	2.7470	4.6139	1.6796	-0.248	0.000	
6/19/2004	1.7558	4.5870	2.6124	-0.361	-0.006	
6/20/2004	1.5576	4.5969	2.9513	-0.113	0.002	14.42
6/21/2004	1.6709	4.4174	2.6437	0.073	-0.039	24.67
6/22/2004	1.8691	4.1460	2.2182	0.119	-0.061	15.83
6/23/2004	1.7842	4.2293	2.3705	-0.045	0.020	
6/24/2004	2.2656	3.8498	1.6993	0.270	-0.090	
6/25/2004	2.3506	3.2432	1.3798	0.038	-0.158	
6/26/2004	2.9736	2.9175	0.9811	0.265	-0.100	
6/27/2004	3.3134	2.9257	0.8830	0.114	0.003	11.67
6/28/2004	3.4550	2.4027	0.6954	0.043	-0.179	11.83
6/29/2004	3.1435	2.2384	0.7121	-0.090	-0.068	16.08
6/30/2004	2.9170	2.5380	0.8701	-0.072	0.134	
7/1/2004	4.7294	2.7292	0.5771	0.621	0.075	
7/2/2004	3.4267	2.9872	0.8717	-0.275	0.095	
7/3/2004	2.0674	3.2327	1.5637	-0.397	0.082	
7/4/2004	1.6709	4.0560	2.4275	-0.192	0.255	19.92

Appendix A, Table 2 (cont).

Date	SR Simms Q (m3/s)	FS Canal Q (m3/s)	Ratio FS/SR Q	Lag Prop. SR Flow	Lag Prop. FS Flow	Overall Study Fish/h
7/5/2004	1.6426	4.4562	2.7129	-0.017	0.099	28.08
7/6/2004	1.6709	5.1146	3.0610	0.017	0.148	36.50
7/7/2004	1.1611	5.2437	4.5161	-0.305	0.025	
7/8/2004	1.0195	5.3740	5.2711	-0.122	0.025	
7/9/2004	1.1611	5.4145	4.6632	0.139	0.008	
7/10/2004	1.0762	5.6657	5.2647	-0.073	0.046	15.33
7/11/2004	1.2178	5.7368	4.7109	0.132	0.013	10.50
7/12/2004	1.6709	5.6221	3.3647	0.372	-0.020	17.00
7/13/2004	1.5859	6.2972	3.9707	-0.051	0.120	
7/14/2004	1.4726	6.9888	4.7458	-0.071	0.110	
7/15/2004	1.0762	6.9554	6.4632	-0.269	-0.005	
7/16/2004	0.9346	7.0803	7.5761	-0.132	0.018	
7/17/2004	1.1328	7.4247	6.5543	0.212	0.049	
7/18/2004	1.4726	7.3315	4.9785	0.300	-0.013	12.00
7/19/2004	1.7842	7.2799	4.0803	0.212	-0.007	7.58
7/20/2004	1.5859	7.2083	4.5452	-0.111	-0.010	5.00
7/21/2004	1.5010	7.3652	4.9070	-0.054	0.022	
7/22/2004	1.5293	7.2913	4.7678	0.019	-0.010	
7/23/2004	1.5010	7.2434	4.8258	-0.019	-0.007	
7/24/2004	1.5010	7.2029	4.7989	0.000	-0.006	
7/25/2004	1.5576	7.1686	4.6024	0.038	-0.005	
7/26/2004	1.6426	6.8520	4.1716	0.055	-0.044	4.67
7/27/2004	1.6426	6.7042	4.0816	0.000	-0.022	3.25
7/28/2004	1.8408	6.7056	3.6428	0.121	0.000	4.08
7/29/2004	1.5859	6.6527	4.1948	-0.138	-0.008	1.39
7/30/2004	1.2178	6.6790	5.4847	-0.232	0.004	
7/31/2004	1.0762	6.6849	6.2118	-0.116	0.001	
8/1/2004	1.2744	6.7960	5.3327	0.184	0.017	

Appendix B.

Table 1. Temperature gage and moon phase data for Fort Shaw Canal at diversion during 2003.

Date	Moon phase	Mean Temp. at Canal °C	Hours netted	Sum Fish Entrained
6/3/2003	New		11	87
6/4/2003	New	.	11	95
6/5/2003	New	.	11	375
6/10/2003	Full	.	12	22
6/11/2003	Full	.	12	23
6/12/2003	Full	.	12	17
6/18/2003	Last Quarter	21.15	12	42
6/19/2003	Last Quarter	18.65	12	42
6/20/2003	Last Quarter	16.87	12	35
6/23/2003	New	14.10	12	17
6/24/2003	New	13.65	12	15
6/25/2003	New	13.60	12	17
7/1/2003	New	21.20	12	289
7/2/2003	New	20.42	12	257
7/3/2003	New	18.20	12	213
7/14/2003	Full	19.37	12	56
7/15/2003	Full	20.48	12	79
7/16/2003	Full	21.87	12	140
7/23/2003	Last Quarter	22.64	12	78
7/24/2003	Last Quarter	20.20	12	76
7/25/2003	Last Quarter	19.26	14	62
7/29/2003	New	21.98	12	27
7/30/2003	New	22.14	12	45
7/31/2003	New	21.42	12	57
8/1/2003	New	21.37	12	68
8/3/2003	First Quarter	22.03	12	75
8/4/2003	First Quarter	20.70	12	61
8/12/2003	Full	19.81	12	34
8/13/2003	Full	21.15	12	79
8/14/2003	Full	21.48	12	17
9/23/2003	New	10.99	12	12
9/24/2003	New	11.66	12	19
9/25/2003	New	13.76	12	54

Appendix B.

Table 2: Temperature gage and moon phase data for Fort Shaw Canal at diversion during 2004.

Date	Moon phase	Mean Temp. at Canal °C	Hours netted	Sum Fish Entrained
5/25/2004	First Quarter	11.27	12	3
5/26/2004	First Quarter	11.93	12	90
5/30/2004	Full	10.77	12	76
5/31/2004	Full	11.60	12	99
6/1/2004	Full	12.71	12	146
6/6/2004	Last Quarter	13.54	12	98
6/7/2004	Last Quarter	9.38	12	15
6/8/2004	Last Quarter	8.88	12	34
6/13/2004	New	14.65	12	144
6/14/2004	New	15.10	12	138
6/15/2004	New	13.99	12	83
6/20/2004	New	12.54	12	173
6/21/2004	New	15.60	12	296
6/22/2004	New	17.15	12	190
6/27/2004	First Quarter	17.15	12	140
6/28/2004	First Quarter	19.04	12	142
6/29/2004	Full	20.54	12	193
7/4/2004	Full	16.59	12	239
7/5/2004	Full	17.37	12	337
7/6/2004	Full	18.65	10	365
7/10/2004	Last Quarter	18.81	12	184
7/11/2004	Last Quarter	18.76	12	126
7/12/2004	Last Quarter	18.70	12	204
7/18/2004	New	21.09	12	144
7/19/2004	New	21.20	12	91
7/20/2004	New	20.81	12	60
7/26/2004	First Quarter	21.53	6	28
7/27/2004	Full	19.48	12	39
7/28/2004	Full	19.65	12	49
7/29/2004	Full	19.98	18	25

Distribution of Gray Wolves in Response to Habitat and Human Presence in the Absaroka-Beartooth Wilderness, Montana

Gidske Houge[1], Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Post Box 5003, NO-1432 Ås, Norway
Daniel B. Tyers[2], USDA Forest Service, GardinerDistrict, Gardiner, Montana 59030-005
Jon E. Swenson, Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences, Post Box 5003, NO-1432 Ås, Norway and Norwegian Institute for Nature Research, NO-7485 Trondheim, Norway

Abstract

Since wolves (*Canis lupus*) were reintroduced into Yellowstone National Park (YNP) in 1995 and 1996, the population has increased and expanded into adjacent areas. In this study, we documented the distribution of wolves in relation to habitat and human presence in the Absaroka-Beartooth Wilderness (ABW) in Montana during the summers of 2005 and 2006, prior to the onset of wolf hunting in 2009, by observing tracks and scat along USDA Forest Service (USFS) trails. Our results indicated that wolves in the ABW 1) were primarily located near the boundary of YNP, 2) did not prefer forested habitats when traveling on trails, 3) did not avoid USFS cabins or outfitter camps, and 4) did not differentiate between permanent cabins and temporary camps.

Key words: Absaroka-Beartooth Wilderness, *Canis lupus*, gray wolf, human-wolf interactions, Montana, sign survey.

Introduction

Historically, the gray wolf (*Canis lupus*) was persecuted intensively by European settlers in North America (Bangs and Fritts 1996). In 1884, the Territorial Government of Montana initiated wolf bounties as part of an official eradication effort (USDI Fish and Wildlife Service et al. 2006). The last known wolf in Yellowstone National Park (YNP) was shot in 1926 (Smith 2005), and by the 1930s wolf populations had disappeared from Montana, Idaho, and Wyoming (Bangs and Fritts 1996). It was protected by law in 1974 under the federal Endangered Species Act of 1973 (Smith 2005, USDI Fish and Wildlife Service et al. 2006).

Wolves were reintroduced into YNP in 1995 as a nonessential experimental population, i.e., not essential for the survival of the species, so it could be managed with more flexibility (USDI Fish and Wildlife Service et al. 2006). A total of 31 wolves were captured in Alberta and British Columbia, Canada, and released into YNP in 1995 and 1996 (Smith 2005). At the end of 2006, an estimated 390 wolves were in the Greater Yellowstone Recovery Area (USDI Fish and Wildlife Service et al. 2007). This population of wolves in Montana was removed from the protection of the Endangered Species Act on 4 May 2009, and the State of Montana began a quota-regulated hunting season in the fall of 2009. With the August 5, 2010 federal court decision that reinstated Endangerd Species Act protection for wolves in the Northern Rocky Mountains, federal law again guides Montana's managment of the state's wolf population.

Key components of wolf habitat include access to sufficient prey throughout the year, suitable and somewhat secluded denning and rendezvous sites, and sufficient space with minimal exposure to humans (USDI Fish and Wildlife Service 1987). Wolves use many different types of habitat,

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[1] Stømsbuveien 7j, NO-4835 Arendal, Norway
[2] USDA Forest Service, Interagency Grizzly Bear Study Team, Northern Rockies Science Center, 2327 University Way Ste.2, Bozeman, MT 59715

including nonforested areas such as deserts, prairies, swamps and tundra (Fuller et al. 2003). They are still found in open habitats, for instance in Spain (Fritts et al. 2003, Blanco et al. 2005), but studies from Poland (Jedrzejewski et al. 2004, Jedrzejewski et al. 2005), Italy (Ciucci et al. 1997, Massolo and Meriggi 1998) and North America (Mladenoff et al. 1995, Johnson et al. 2005, Oakleaf et al. 2006) have shown that they prefer forests.

Early studies on the effects of human presence on wolves have shown that they avoid areas where road densities are above a particular threshold value, such as 0.45 (Mladenoff et al. 1995, Mladenoff et al. 1999), 0.58 (Thiel 1985, Jensen et al. 1986, Mech et al. 1988) or 0.70 km/km^2 (Fuller et al. 1992). Roads serve as an indicator of human presence, and because humans are a major contributor to wolf mortality (Mech 1977, Forbes and Theberge 1992, Wydeven et al. 1992, Boyd and Pletscher 1999), wolves risk being killed by trappers, hunters, or vehicles when they are near roads (Jensen et al. 1986, Mech et al. 1988). More recent studies have moderated this conclusion by indicating that roads with relatively low levels of use can benefit wolves by creating easy paths of travel (Thurber et al. 1994, James and Stuart-Smith 2000, Pedersen et al. 2003, Whittington et al. 2005). Merrill (2000) reported successful wolf reproductions at road densities of 1.42 km/km^2 and Thiel et al. (1998) found that wolves denned close to areas with high degrees of human activity. These two cases illustrate that the main concern is the attitudes of local people, not the roads themselves (Carroll et al. 2003). Wolves avoid human settlements and buildings in some areas (Theuerkauf et al. 2003a, Jedrzejewski et al. 2004, Jedrzejewski et al. 2005, Kaartinen et al. 2005), but are not affected by them (Pedersen et al. 2003), or may actively seek them out in search of food, in other areas (Fritts et al. 2003). To our knowledge, researchers have not investigated whether wolves differentiate between permanent and temporary structures.

The goal of this study was to document the distribution of wolves in the Absaroka-Beartooth Wilderness (ABW), immediately north of YNP, as indicated by their scats and tracks along USFS trails to test the following hypotheses: 1) Because several studies from North America have found that wolves preferred forested habitat, we predicted that there would be sign on trails more often in forested areas than in areas without forest cover; 2) If wolves actively avoid humans and their activities, we would expect sign less often on trails near outfitter camps and USFS cabins than on trails far from these structures; 3) If wolves habituate more easily to permanent structures, we predicted that wolves would avoid temporary outfitter camps more than permanent USFS cabins.

Study Area

The study was conducted in the ABW, which is located in south-central Montana adjacent to the northern boundary of YNP (Fig. 1). The USFS manages this area, which encompasses portions of three National Forests (Gallatin, Shoshone and Custer) and five Ranger Districts (Gardiner, Beartooth, Big Timber, Clark's Fork, and Livingston). The ABW has a total area of 3819 km^2, primarily in Montana but with a small portion in Wyoming. The area was officially designated in 1978 as a Wilderness Area under the U. S. Wilderness Act of 1964. Regulations prohibit use or possession of motorized and mechanized equipment, which was intended to minimize disturbance to wildlife and to preserve the wilderness character.

Our effort centered primarily in the Gardiner Ranger District (GRD), which borders YNP and comprises about one-third of the ABW. The GRD has the highest ungulate/prey density in the ABW, is adjacent to YNP, and wolf packs occurred within its boundaries. We also conducted field work in other ABW Ranger Districts, but not as intensively as in the GRD.

The terrain is remote, rugged, mountainous, and consists of deeply incised glacial valleys and high plateaus. Vegetation includes montane forests

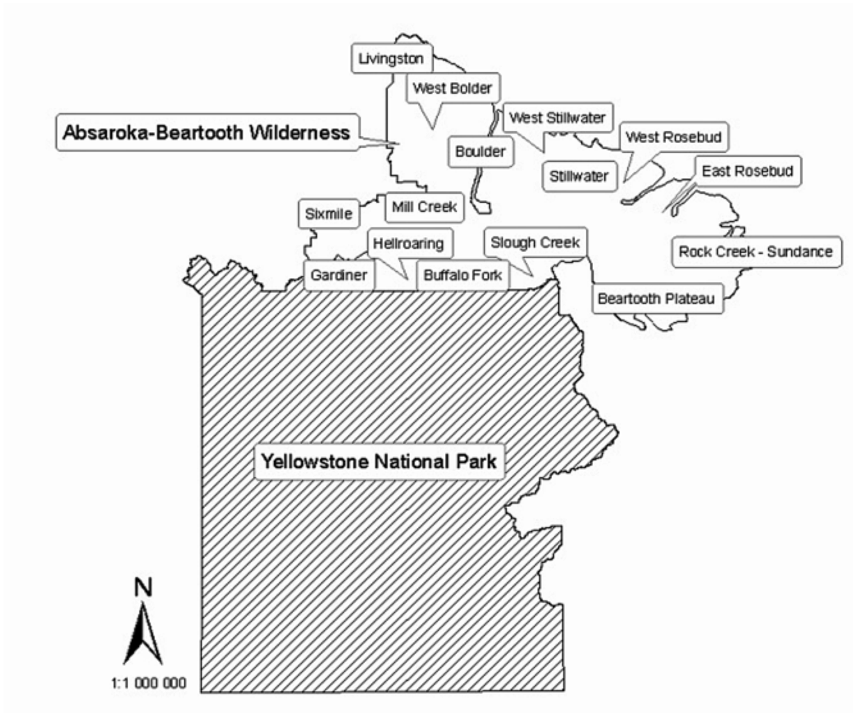

Figure 1. Yellowstone National Park and the Absaroka-Beartooth Wilderness Montana and Wyoming, showing the major drainages within the wilderness area.

dominated by Douglas-fir (*Pseudotsuga menziesii*), quaking aspen (*Populus tremuloides*), Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), and limber pine (*P. flexilis*), and subalpine forests dominated by subalpine fir (*Abies lasiocarpa*) and whitebark pine (*P. albicaulis*) (Alden et al. 1999, DeBlander 2001). The vegetation at high elevations includes tundra and perennial snowfields. Riparian areas are comparatively limited, but are ecologically important. Carnivorous mammals occurring in this study area include grizzly bears (*Ursus arctos*), black bears (*U. americanus*), mountain lions (*Felis concolor*), lynx (*Lynx canadensis*), wolverine (*Gulo gulo*), wolves, coyotes (*Canis latran*s), and red foxes (*Vulpes vulpes*). Ungulate species include elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), and mountain goats (*Oreamnos americanus*).

The varied topography of the Rocky Mountains creates a wide range of weather conditions and unique local climates (Alden et al. 1999). At high elevations, there is snow from early October to early July, and at lower elevations, from late October to late May (Despain 1990). The annual rainfall in the Rocky Mountains ranges from 18 to 109 cm (Despain 1990) .

Methods

The ABW has about 1437 km of trails, which we delineated into 379 labeled and easily defined segments, generally from one trail junction to another. The trail segments varied between 0.2 to 13.4 km in length and were used by the GRD Forest Service backcountry crew, hikers, etc. between 15 May and 1 November each year. Tasks of the backcountry crew were many, and sampling for wolf sign was done while hiking the trails. The backcountry crew used 278 trail segments in 2005 and 216 in 2006. The backcountry crew recorded the number of wolf scats and tracks representing individual wolves for each segment on each trip. Multiple tracks scattered over a distance were thought to have originated from one individual if the tracks were going in the same direction within the same trail segment. The crew was trained to identify wolf scats and tracks by Jim Halfpenny, director of "A Naturalist's World" in Gardiner.

Common ways to differentiate between wolf and dog (*Canis familiaris*) sign, e.g., difference in paw size, movement behavior, amount of hair and bone in scats, are not always reliable (Aronson and Eriksson 1992, Landa 1999). To minimize uncertainty, we considered the frequency by which trail segments were used by hikers with dogs. If the crew encountered hikers with dogs, or the trail was known to be a popular recreation area for people with dogs, we considered the probability of a large canine track belonging to a dog to be high and disregarded all observed sign. However, YNP has a ban on dogs, so we classified sign found on ABW trails originating from YNP as wolf sign.

We distinguished coyote tracks from wolf tracks based on the fact that wolves have larger paws than coyotes (Murray and Lariviere 2002). To differentiate between coyote and wolf scat, we used Halfpenny's (1986) cutoff diameter and classified all canine scat ≥ 23 mm as wolf scat. The large overlap in diameter (Weaver 1979, Reed et al. 2004, Prugh and Ritland 2005) caused some bias because some of the collected scats could be from coyotes, and small wolf scats would be classified as coyote and not included in the sample.

Sign of wolves was recorded as a binary variable, observed or not. We then created maps using ArcGIS 9.1 and analyzed data using a combination of tools in ArcGIS 9.1, Hawth's Analysis Tools 3.26 and ET Geo Wizards 9.6. We classified trail segments as forested or nonforested by using vegetation maps provided by the Gallatin National Forest. Permanent structures included three USFS cabins located on Slough Creek, Buffalo Fork and Hellroaring creeks, as well as the Silver Tip Ranch in Slough Creek. Temporary structures included 13 outfitter camps. Outfitter camps were present in the ABW from 2 wks to 4 mos. The USFS cabins were used between May and November.

We tested the hypotheses with a binary logistic regression (Agresti 2002) using MINITAB 14 Statistical Software (Minitab Inc). When testing hypothesis No. 3 (wolves should be found farther from permanent than temporary structures), we measured the distance from each trail to the nearest structure. When testing hypothesis No. 1 (wolves should prefer forested habitats), we classified the habitat type for each trail according to the dominant vegetation type along its length. To test for other variables, we included the distance to the YNP boundary in the model, using the shortest distance from the center of each trail segment to the boundary of the YNP. We corrected for sampling effort by including the average number of times a trail had been sampled in the model. We used only trail segments within the GRD for this test. Hypotheses were tested using a significance threshold of $P < 0.05$.

Results

The monitoring frequency for trail segments decreased from 2005 to 2006 (Table 1) with sampling efforts of 1050 km and 709 km, respectively, but the average number of times a trail was sampled increased from 2005 to 2006. The unadjusted total amount of sign in 2005 was 115; 74 tracks and 41 scats. In 2006, this doubled to 241; 137 tracks and 104 scats. A significantly greater frequency of trail segments (all segments) showed wolf presence in 2006 than 2005 ($\chi^2 = 22.28$, d.f. = 1, $P < 0.001$). In 2005, the majority of sign was located from the eastern part of the Gardiner Basin, eastwards through the Hellroaring, Buffalo Fork and Slough Creek drainages, to the southern part of the Stillwater Drainage and was also high in the southern part of the Beartooth Plateau and the western part of the Boulder Drainage, close to the Mill Creek Drainage. Single cases of wolf sign were registered on four different trail segments on the north-eastern boundary of the ABW. In 2006, the areas with the highest amount of sign shifted

Table 1. Summary statistics for the gray wolf sign survey in the Absaroka-Beartooth Wilderness, south-central Montana, USA (2005-2006).

	2005	2006
No. trail segments	278	216
No. times a trail was traveled		
$\bar{X}$	3.08	6.24
SD	2.85	6.70
Range	1-22	1-52
Scats/trail segment		
$\bar{X}$	0.15	0.48
SD	0.47	1.14
Range	0-3	0-6
Tracks/trail segment		
$\bar{X}$	0.27	0.63
SD	0.64	1.22
Range	0-4	0-6

slightly. Sign was greater along the southern boundary of the ABW, i.e., from the middle of the Gardiner Basin, eastwards through the Hellroaring, Buffalo Fork and Slough Creek drainages. There was, however, a gap in the presence of sign between the Gardiner Basin and Hellroaring/Buffalo Fork/Slough Creek drainages. There still was sign in the southern part of the Beartooth Plateau, but the sign in the western part of the Boulder Drainage continued over into the Mill Creek Drainage in 2006. In addition to wolf sign, wolves were observed once and wolves were heard howling four times during 2006 by the backcountry crew.

According to the binary logistic model we used to explain wolf presence in the GRD, wolves did not avoid temporary camps or permanent cabins or differentiate between them, nor did they use forested and nonforested trail segments differently (Table 2). Wolf presence was significantly and negatively correlated with distance to YNP. According to the logistic model, 50 percent probability of finding wolf sign occurred when the trail segment was 21.5 km from the YNP boundary. The variable "average number of times a trail segment was traveled" was added to the model to correct for effort and naturally showed that there was a higher probability of encountering wolf sign if the trail had been traveled often. By including this variable, we corrected for the bias that it otherwise would have caused in the analysis of the effects of the other variables. The interaction term showed that the field crew traveled less on trail segments located far from camps and cabins. The fit of the model was not high, however. A Pearson goodness-of-fit was 0.35, which indicated that the model did not explain much variation in wolf distribution.

Discussion

Track surveys and other noninvasive methods are becoming more popular in wildlife and conservation research, because of few negative effects, such as immobilizing and handling the animals, in addition to being less time-consuming and expensive (Kendall et al. 1992, Smallwood and Fitzhugh 1995, Alexander et al. 2005).

Distribution of wolves

As expected from our hypothesis, a logistic regression analysis corrected for effort indicated that the probability of finding wolf sign in the ABW was higher in the vicinity

Table 2. Logistic regression model explaining gray wolf presence in the Gardiner Ranger District, Absaroka-Beartooth Wilderness, south-central Montana, in 2005 and 2006.

Predictor	Coefficient	P-value
Constant	1.962	0.125
Distance to camps/cabins (km)	0.029	0.374
Distance to Yellowstone National Park (km)	-0.091	0.013
Camp type (categorical)	0.239	0.687
Forest (categorical)	-1.260	0.304
Average number of times a trail segment was traveled	0.301	0.005
Distance camps/cabins (km) * Average number of times a trail segment was traveled	-0.039	0.002

of YNP. Given the dispersal capabilities of wolves, it is surprising that wolves had not traveled further into the wilderness area. Wolves have been recorded dispersing long distances, such as 670 (Van Camp and Gluckie 1979), 732 (Ballard et al. 1983), 840 (Boyd and Pletscher 1999) and 886 (Fritts 1983) km. Even though wolves have a great capacity for dispersal, they maximize their chance of breeding rather than maximizing resources (Mech and Boitani 2003). Studies have shown that territorial species are attracted to areas that already are inhabited (Stamps 1988, Smith and Peacock 1990, Ray et al. 1991), presumably because areas that are occupied by conspecifics offer mates and an assurance of good habitat ("cuing") (Stamps 1988). The colonization rate for wolves in the GYA averages 9.78 km/year, which is considerably lower than would be expected from the high reproductive rate and long distance dispersal of wolves (Hurford et al. 2006) and was consistent with our results. In addition to the drainages located close to YNP, sign also was detected on the southern slope of the Beartooth Plateau and in the Boulder/Mill Creek drainages, perhaps due to the occurrence of reproducing packs in these areas. Single tracks and scats were observed on separate trail segments in 2005. These trail segments were located on the wilderness boundary from the north to the east.

Use of forested and nonforested habitat

Contrary to our hypothesis, we detected no difference in use of forested and nonforested habitats by wolves. This may have been an error due to definitions used in the study because the vegetation maps used in the analysis divided vegetation into only four categories; aspen (forest), conifer (forest), sagebrush grassland (nonforested) and willow (nonforested), which may have been too coarse to allow any patterns of selection to be manifested. Also, trail segments often crossed several vegetation types, but only the dominant vegetation type was recorded for each trail. The dominant vegetation type was usually forest, so the number of trail segments with nonforested habitat was low compared to the number of trail segments with forest. Although the results did not support our hypothesis and assuming that they were not a statistical error, they did fit well with the fact that wolves are habitat generalists (Fuller et al. 2003) and are limited only by access to a sufficient prey base when not hunted by humans (USDI Fish and Wildlife Service 1987). The method we used possibly did not allow documentation of the true preference for forested and nonforested areas but only showed if wolves used trails more or less in these habitats. Because the trails represent easy paths of travel (Thurber et al. 1994, James and Stuart-Smith 2000, Whittington et al. 2005, Shepherd and Whittington 2006), there is no reason why wolves should leave the trails once they enter a different habitat.

Avoidance of humans

Also contrary to our hypothesis, we found no evidence that wolves either differentiated between temporary outfitter camps and permanent USFS cabins, or avoided camps or cabins. The outfitter camps and USFS cabins in the ABW differed in two main aspects. The cabins are permanent structures, whereas the camps are temporary. Also, the camps are always occupied by one or more people who look after the camp, whereas the cabins are occasionally vacant of people. Our results suggested that wolves view these structures equally.

In a study conducted in the Canadian central Arctic, Johnson et al. (2005) found that wolves selected mineral exploration sites and outfitter camps, probably because of the availability of food rewards. However, with the "leave no trace" policies in the ABW, i.e. packing out all trash, leftover food, and litter, there is little or no food around camps and cabins to attract wolves. Generally, wolves are believed to avoid human contact spatially in areas with low human density, and temporally in areas with high human density (Vilà et al. 1992, Ciucci et al. 1997, Pedersen et al. 2003, Theuerkauf et al. 2003a). In Poland, where human density is high, wolves avoid being in the same place at the same time as humans (Theuerkauf et al. 2003a, Theuerkauf et al. 2003b). Wam (2003) studied wolf behavior towards humans in densely populated parts of Norway and found that, when approached, wolves ran away with a mean tolerance distance of 257 m. Because our data only included sign to indicate wolf presence, we were unable to determine whether wolves in the ABW avoided humans temporally. In areas with no legal or illegal hunting, however, wolves are thought to be less wary of humans (Thiel et al. 1998, Merrill 2000, McNay 2002, Whittington et al. 2005), and wolves are currently colonizing a wide range of habitats that previously were not thought to be suitable wolf habitat (Mech 1995). A study investigating carnivore responses to big-game hunting on the boundary between ABW and YNP found that wolves did not change their movement patterns during the pre-hunt and hunting periods (Ruth et al. 2003). Because wolves in the ABW and YNP were not hunted by humans during our study, it is reasonable to conclude that wolves do not avoid humans in this area.

Conclusions and Management Implications

We found no evidence that wolves in the ABW selected between forested and nonforested habitats, differentiated between temporary outfitter camps and permanent USFS cabins, or avoided these centers of human activity. The latter may suggest that little illegal hunting of wolves was taking place in the ABW. However, the model gave a relatively poor fit, which suggested that important factors explaining wolf presence were not included in the model. Possible additional factors that are important for the distribution of wolves are location of prey and reproducing wolf packs. Therefore, the model may have been improved by incorporating seasonal distribution of ungulates, locations of active wolf dens, and by including more seasons of data. Our results suggest that, at present, no special precautions are needed to ensure survival of wolves in the ABW. We recommend that this study be continued to document whether the behavior of wolves in the ABW changes after the advent of hunting in 2009.

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Literature Cited

Agresti, A. 2002. Categorical data analysis. John Wiley & Sons, Hoboken, New Jersey.

Alden, P., B. Cassie, J. Grassy, J. D. W. Kahl, A. Leventer, D. Mathews, and W. B. Zomlefer. 1999. National Audubon Society field guide to the Rocky Mountain states. Alfred A. Knopf, New York.

Alexander, S. M., P. C. Paquet, T. B. Logan, and D. J. Saher. 2005. Snow-tracking versus radio telemetry for predicting wolf-environment relationships in the Rocky Mountains of Canada. Wildlife Society Bulletin 33:1216-1224.

Aronson, Å. and P. Eriksson. 1992. Dyrespor og kunsten å spore. (In Norwegian). J. W. Cappelens Forlag, Oslo, Norway.

Ballard, W. B., R. Farnell, and R. O. Stephenson. 1983. Long-distance movement by gray wolves, Canis lupus. Canadian Field-Naturalist 97:333-333.

Bangs, E. E. and S. H. Fritts. 1996. Reintroducing the gray wolf to central Idaho and Yellowstone National Park. Wildlife Society Bulletin 24:402-413.

Blanco, J. C., Y. Cortes, and E. Virgos. 2005. Wolf response to two kinds of barriers in an agricultural habitat in Spain. Canadian Journal of Zoology 83:312-323.

Boyd, D. K. and D. H. Pletscher. 1999. Characteristics of dispersal in a colonizing wolf population in the central Rocky Mountains. Journal of Wildlife Management 63:1094-1108.

Carroll, C., M. K. Phillips, N. H. Schumaker, and D. W. Smith. 2003. Impacts of landscape change on wolf restoration success: Planning a reintroduction program based on static and dynamic spatial models. Conservation Biology 17:536-548.

Ciucci, P., L. Boitani, F. Francisci, and G. Andreoli. 1997. Home range, activity and movements of a wolf pack in central Italy. Journal of Zoology 243:803-819.

DeBlander, L. T. 2001. Forest Resources of the Custer National Forest. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Despain, D. G. 1990. Yellowstone vegetation. Consequences of environment and history in a natural setting. Roberts Rinehart Publishers, Boulder, Santa Barbara, West Cork.

Forbes, G. J. and J. B. Theberge. 1992. Influences of a migratory deer herd on wolf movement and mortality in and near Algonquin Park, Ontario. Pp. 303-314 in L. N. Carbyn, S. H. Fritts, and D. R. Seip, editors. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Alberta, Canada.

Fritts, S. H. 1983. Record dispersal by a wolf from Minnesota. Journal of Mammalogy 64:166-167.

Fritts, S. H., R. O. Stephenson, R. D. Hayes, and L. Boitani. 2003. Wolves and humans. Pp. 289-316 in L. D. Mech, and L. Boitani, editors. Wolves. Behavior, ecology, and conservation. The University of Chicago Press, Chicago and London.

Fuller, T. K., W. E. Berg, G. L. Radde, M. S. Lenarz, and G. B. Joselyn. 1992. A history and current estimate of wolf distribution and numbers in Minnesota. Wildlife Society Bulletin 20:42-55.

Fuller, T. K., L. D. Mech, and J. F. Cochrane. 2003. Wolf population dynamics. Pp. 161-191 *in* L. D. Mech, and L. Boitani, editors. Wolves. Behavior, ecology, and conservation. The University of Chicago Press, Chicago and London.

Halfpenny, J. 1986. A field guide to mammal tracking in North America. Johnson Books, Boulder, Colorado.

Hurford, A., M. Hebblewhite, and M. A. Lewis. 2006. A spatially explicit model for an Allee effect: Why wolves recolonize so slowly in Greater Yellowstone. Theoretical Population Biology 70:244-254.

James, A. R. C. and A. K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154-159.

Jedrzejewski, W., M. Niedzialkowska, R. W. Mysiajek, S. Nowak, and B. Jedrzejewska. 2005. Habitat selection by wolves Canis lupus in the uplands and mountains of southern Poland. Acta Theriologica 50:417-428.

Jedrzejewski, W., M. Niedzialkowska, S. Nowak, and B. Jedrzejewska. 2004. Habitat variables associated with wolf (Canis lupus) distribution and abundance in northern Poland. Diversity and Distributions 10:225-233.

Jensen, W. F., T. K. Fuller, and W. L. Robinson. 1986. Wolf, Canis lupus, distribution on the Ontario Michigan border near Sault-Ste-Marie. Canadian Field-Naturalist 100:363-366.

Johnson, C. J., M. S. Boyce, R. L. Case, H. D. Cluff, R. J. Gau, A. Gunn, and R. Mulders. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monographs:1-36.

Kaartinen, S., I. Kojola, and A. Colpaert. 2005. Finnish wolves avoid roads and settlements. Annales Zoologici Fennici 42:523-532.

Kendall, K. C., L. H. Metzgar, D. A. Patterson, and B. M. Steele. 1992. Power of sign surveys to monitor population trends. Ecological Applications 2:422-430.

Kunkel, K. and D. H. Pletscher. 2001. Winter hunting patterns of wolves in and near Glacier National Park, Montana. Journal of Wildlife Management 65:520-530.

Landa, A. 1999. Spor og tegn. Et hefte i bestemmelse av store rovdyr. (In Norwegian). Norwegian Institute for Nature Research (NINA) Norwegian Institute for Cultural Heritage Research (NIKU), Trondheim, Norway.

Massolo, A. and A. Meriggi. 1998. Factors affecting habitat occupancy by wolves in northern Apennines (northern Italy): a model of habitat suitability. Ecography 21:97-107.

McNay, M. E. 2002. Wolf-human interactions in Alaska and Canada: a review of the case history. Wildlife Society Bulletin 30:831-843.

Mech, L. D. 1977. Productivity, mortality, and population trends of wolves in northeastern Minnesota. Journal of Mammalogy 58:559-574.

Mech, L. D. 1995. The challenge and opportunity of recovering wolf populations. Conservation Biology 9:270-278.

Mech, L. D. and L. Boitani. 2003. Wolf social ecology. Pp. 1-34 in L. D. Mech, and L. Boitani, editors. Wolves. Behavior, ecology, and conservation. The University of Chicago Press, Chicago and London.

Mech, L. D., S. H. Fritts, G. L. Radde, and W. J. Paul. 1988. Wolf distribution and road density in Minnesota. Wildlife Society Bulletin 16:85-87.

Merrill, S. B. 2000. Road densities and gray wolf, Canis lupus, habitat suitability: an exception. Canadian Field-Naturalist 114:312-313.

Mladenoff, D. J., T. A. Sickley, R. G. Haight, and A. P. Wydeven. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern Great-Lakes region. Conservation Biology 9:279-294.

Mladenoff, D. J., T. A. Sickley, and A. P. Wydeven. 1999. Predicting gray wolf landscape recolonization: Logistic regression models vs. new field data. Ecological Applications 9:37-44.

Murray, D. L. and S. Lariviere. 2002. The relationship between foot size of wild canids and regional snow conditions: evidence for selection against a high footload? Journal of Zoology 256:289-299.

Oakleaf, J. K., D. L. Murray, J. R. Oakleaf, E. E. Bangs, C. M. Mack, D. W. Smith, J. A. Fontaine, M. D. Jimenez, T. J. Meier, and C. C. Niemeyer. 2006. Habitat selection by recolonizing wolves in the Northern Rocky Mountains of the United States. Journal of Wildlife Management 70:554-563.

Pedersen, H. C., S. M. Brainerd, O. Liberg, H. Sand, and P. Wabakken. 2003. Utredninger i forbindelse med ny rovviltmelding. Ulv - Bestandsdynamikk, levedyktighet og effekter av uttak. (Wolf - population dynamics, viability and effects of alpha-individual loss. Abstract in English). Norwegian Institute for Nature Research (NINA). Report 61.

Prugh, L. R. and C. E. Ritland. 2005. Molecular testing of observer identification of carnivore feces in the field. Wildlife Society Bulletin 33:189-194.

Ray, C., M. Gilpin, and A. T. Smith. 1991. The effect of conspecific attraction on metapopulation dynamics. Biological Journal of the Linnean Society 42:123-134.

Reed, J. E., R. J. Baker, W. B. Ballard, and B. T. Kelly. 2004. Differentiating Mexican gray wolf and coyote seats using DNA analysis. Wildlife Society Bulletin 32:685-692.

Ruth, T. K., D. W. Smith, M. A. Haroldson, P. C. Buotte, C. C. Schwartz, H. B. Quigley, S. Cherry, K. M. Murphy, D. Tyers, and K. Frey. 2003. Large-carnivore response to recreational big-game hunting along the Yellowstone

National Park and Absaroka-Beartooth Wilderness boundary. Wildlife Society Bulletin 31:1150-1161.

Shepherd, B. and J. Whittington. 2006. Response of wolves to corridor restoration and human use management. Ecology and Society 11:1.

Smallwood, K. S. and E. L. Fitzhugh. 1995. A track count for estimating mountain lion Felis concolor californica population trend. Biological Conservation 71:251-259.

Smith, A. T. and M. M. Peacock. 1990. Conspecific attraction and the determination of metapopulation colonization rates. Conservation Biology 4:320-323.

Smith, D. W. 2005. Ten years of Yellowstone wolves, 1995-2005. Yellowstone Science 13:7-33.

Stamps, J. A. 1988. Conspecific attraction and aggregation in territorial species. American Naturalist 131:329-347.

Theuerkauf, J., W. Jedrzejewski, K. Schmidt, and R. Gula. 2003a. Spatio-temporal segregation of wolves from humans in the Bialowieza Forest (Poland). Journal of Wildlife Management 67:706-716.

Theuerkauf, J., W. Jedrzejewski, K. Schmidt, H. Okarma, I. Ruczynski, S. Sniezko, and R. Gula. 2003b. Daily patterns and duration of wolf activity in the Bialowieza Forest, Poland. Journal of Mammalogy 84:243-253.

Thiel, R. P. 1985. Relationship between road densities and wolf habitat suitability in Wisconsin. American Midland Naturalist 113:404-407.

Thiel, R. P., S. Merrill, and L. D. Mech. 1998. Tolerance by denning wolves, Canis lupus, to human disturbance. Canadian Field-Naturalist 112:340-342.

Thurber, J. M., R. O. Peterson, T. D. Drummer, and S. A. Thomasma. 1994. Gray wolf response to refuge boundaries and roads in Alaska. Wildlife Society Bulletin 22:61-68.

USDI Fish and Wildlife Service. 1987. Northern Rocky Mountain Wolf Recovery Plan. United States Fish and Wildlife Service.

USDI Fish and Wildlife Service, Nez Perce Tribe, National Park Service, Montana Fish Wildlife and Parks, Idaho Fish and Game, and USDA Wildlife Services. 2006. Rocky Mountain Wolf Recovery 2005 Annual Report. C.A. Sime and E. E. Bangs, eds. United States Fish and Wildlife Service. 130 pp.

USDI Fish and Wildlife Service. 2007. Rocky Mountain Wolf Recovery 2006 Annual Report. C.A. Sime and E. E. Bangs, eds. United States Fish and Wildlife Service. 235 pp.

Van Camp, J. and R. Gluckie. 1979. Record long-distance move by a wolf (Canis lupus). Journal of Mammalogy 60:236-237.

Vilà, C., V. Urios, and J. Castroviejo. 1992. Observations on the daily activity patterns in the Iberian wolf. Pp 335-340 in L. N. Carbyn, S. H. Fritts, and D. R. Seip, editors. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Alberta, Canada.

Wam, H. K. 2003. Wolf behaviour towards people - the outcome of 125 monitored encounters. Master's Thesis Agricultural University of Norway, Ås, Norway.

Weaver, J. L. 1979. Comparison of coyote and wolf scat diameters. Journal of Wildlife Management 43:786-788.

Whittington, J., C. C. St Clair, and G. Mercer. 2005. Spatial responses of wolves to roads and trails in mountain valleys. Ecological Applications 15:543-553.

Wydeven, A. P., R. N. Schultz, and R. P. Thiel. 1992. Monitoring of a recovering gray wolf population in Wisconsin, 1979-1991. Pp. 147-156 *in* L. N. Carbyn, S. H. Fritts, and D. R. Seip, editors. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Alberta, Canada.

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An Approach to Determine the Effect of El Nino on Extreme Daily Weather Occurrence

Joseph M. Caprio, Professor Emeritus, Department of Land Resources and Environmental Sciences, 334 Leon Johnson Hall, Montana State University, Bozeman, Montana, 59717-3120
Perry R. Miller, Department of Land Resources and Environmental Sciences, 334 Leon Johnson Hall, Montana State University, Bozeman, Montana, 59717-3120
Jon M. Wraith[1], Department of Land Resources and Environmental Sciences, 334 Leon Johnson Hall, Montana State University, Bozeman, Montana, 59717-3120

Abstract

We developed a procedure using the chi-square statistic to determine the effect of El Nino-Southern Oscillation on the frequency of extreme daily weather occurrence. Its application is demonstrated for a site in southwestern Montana, located east of the Continental Divide 970 km from the Pacific Ocean. The study used daily weather data focused on a 29-wk period from 3 Dec to 23 Jun in a 100-yr weather record at Montana State University (Bozeman) and compared this weather in relation to November-March sea-surface temperature anomalies in an area of the eastern tropical Pacific Ocean. Daily weather extremes were compared between 25 El Nino years and 50 'normal' years. During El Nino years, December-June weather at Bozeman was characterized by more days of extreme high maximum temperatures, fewer days of extreme low minimum temperatures, fewer days of high precipitation amounts, and fewer days with small diurnal temperature ranges. For the 29-wk period, we determined the difference between El Nino years and normal years to be about 20 percent for each of these four extreme daily weather conditions. An increase or decrease of extreme daily weather occurrences can impact natural resources and a wide range of human activities including agriculture, forestry, recreation, construction, and other businesses.

Keywords: El Nino, extreme daily weather, Northwestern United States, iterative Chi-square

Introduction

The variability of the El Nino-Southard Oscillation (ENSO) sea-surface temperature anomalies affect extremes of climate over much of the world with important consequences for natural resources and a wide range of human activities (McPhaden et al. 2006). Since El Nino sea surface temperature anomalies tend to persist for many months and have predictable climatic associations, it is prudent to undertake research to understand how El Nino affects extremes of weather for individual locations in order to provide useful information for decision makers.

Numerous studies of the El Nino effect have compared the monthly mean temperatures and/or precipitation at given locations during El Nino years with so-called 'normal' years (Shabbar et al. 1997, Wang and Fir 2000, Twine et al. 2005). Researchers have also studied extremes of daily weather events associated with the El Nino in which given values of extreme daily weather occurrences are selected for analysis or the daily extremes are determined as percentages of occurrences, such as being beyond the 95-percent probability level (Gershunov et al. 1998, Cayan et al. 1999).

Caprio (1966) first described the conceptual basis and details of the statistical procedure used in this study, known as the iterative chi-square method. Caprio and Quamme (2002) applied this methodology in previous research to determine daily weather effects on grape production, and to determine climate change of daily maximum and minimum temperature and precipitation

[1] Associate Dean of Agriculture and Associate Director of New Hampshire Agricultural Experiment Station, College of Life Sciences and Agriculture, G15 Rudman Hall, 46 College Road, Durham, New Hampshire 03824

over a 56-yr period in the Okanagan Valley of British Columbia, Canada. It has also been applied in research to determine the impact of daily weather on growth of tree rings in Arizona (Caprio et al. 2003) and to determine recent climate change of extreme daily temperatures at two locations in northwestern North America (Caprio et al. 2009). Our research objective was to develop a procedure to determine the effect of El Nino on frequency of extreme daily occurrence of several climatic elements. This was achieved by applying the iterative chi-square approach that considered climate differences between El Nino years and 'normal years.' We demonstrated the technique by using daily weather data for a 100-yr period at the Montana State University Weather Station, Bozeman, Montana, which is located in the Rocky Mountain foothills east of the Continental Divide 970 km from the Pacific Ocean.

Methods

Year Characterization

The ENSO Index chosen for use in this study is based on the Japanese Meteorological Agency (JMA) estimate of sea-surface temperature (SST) anomalies, known as the JMA ENSO Index (Sittel 1994, Green 1995). The Index is based on SST anomalies in the tropical Pacific Ocean in an area bounded by 4o S to 4o N latitude and 150o W to 90o W longitude. When we initiated this study the JMA ENSO Index was the only century-long El Nino index available. The National Oceanic and Atmospheric Administration (NOAA) identified several El Nino areas in the eastern Pacific Ocean. The JMA ENSO Index is based on ocean temperatures in a rectangle area that is the same as NOAA NCEP/NCAB El Nino Region 3 Index area except the NOAA Index extends 5 degrees north and south of the equator rather than 4 degrees. (Trenberth 1997, Trenberth and Stepaniak 2001).

The JMA mean normal SST for the period 1961-1990 is as follows: Jan (25.4 °C), Feb (26.2 °C), Mar (26.9 °C), Apr (27.1 °C), May (26.6 °C), Jun (26.1 °C), July (25.2 °C), Aug (24.6 °C), Sep (24.6 °C), Oct (24.6 °C), Nov (24.6 °C), and Dec (24.9 °C). We determined the JMA Index for each month by computing a 5-mo running mean (labeled as the central month) of the monthly SST anomalies (Sittel 1994, Green 1995). Thus, a given monthly JMA Index includes information for each of the five monthly SST anomaly values in order to smooth out possible intra-seasonal variations. The annual values used in this analysis to identify an El Nino year were chosen to be the mean of the five JMA Index values for the 5-mo period, Nov-Mar, which includes weather data from Sep-May. The year of the El Nino is identified here as the year of the Jan-Mar period. The 100 annual values of the JMA Index were ordered from low to high and divided into quartiles. The highest quartile years were considered the El Nino years and the lowest quartile years were considered the La Nina years. The central two quartiles constituted the 'normal years'.

According to this classification, all those years where the mean Nov-Mar JMA Index was ≥ +0.46 °C were considered El Nino years. For the La Nina years, the mean Nov-Mar JMA index was ≤ -0.50 °C. This study considers only the relation between the 25 El Nino yr, sometimes referred to as the 'Warm Phase' and the two central quartile, i.e., 50 yrs, 'normal' years. According to this classification the 25 El Nino years were: 1903, 1905, 1906, 1912, 1914, 1919, 1920, 1926, 1928, 1930, 1931, 1941, 1952, 1958, 1966, 1969, 1970, 1973, 1977, 1983, 1987, 1988, 1992, 1995, and 1998. The 25 La Nina years were: 1904, 1909-11, 1917, 1918, 1923, 1939, 1943, 1945, 1946, 1950, 1955, 1956, 1965, 1968, 1971, 1974-76, 1985, 1989, 1996, 1999, and 2000. This classification method was highly consistent with a report spanning from 1951 to 2008 (National Weather Service 2008). All other years during 1901-2000 not listed as El Nino or La Nina were considered the 50 'normal' years. The average monthly JMA Index SST anomaly for Nov-Mar was +1.01 °C during the 25 El Nino yrs and the two most extreme values were +2.58 °C and

+2.82 °C in 1983 and 1998, respectively. During the 25 La Nina yrs, the average monthly JMA Index SST anomaly for Nov-Mar was -0.93 °C and the two most extreme values were -1.74 °C and -1.34 °C in 1917 and 1971, respectively.

Chi-Square Analyses

Weather data at the Bozeman, Montana, site (45º 40'N, 111º 03'W, elevation 1480 m) were measured and analyzed in Imperial units and the results were converted to metric units. Daily meteorological data were recorded to the nearest whole °F (temperature) or 0.01 in (precipitation) from 26 Nov to 30 Jun each year. For chi-square analyses, we used a sliding window of 3 wks, adding a new week and dropping the first week as the overlapping 3-wk time frame advanced. For example, the first 3-wk period included days 1-21, i.e., 26 Nov-16 Dec, with all associated daily weather values and was labeled as the central or 11th day, i.e., 6 Dec. The second 3-wk period included days 8-28, i.e., 3 -23 Dec, and was labeled as 13 Dec, etc., continuing until 29 successive 3-wk periods, spanning 31 wks, i.e., 26 Nov-30 Jun), were recorded within each 'year.' A 3-wk span of daily weather data was used in this study since previous studies found this smoothing process to provide reasonable conclusions about the occurrence of extreme weather.

Within each 3-wk period, temperature was broken down into classes of 2 °F in order to have an adequate number of observations in most classes and precipitation was broken down into classes of 0.05 in. The climate variables, maximum and minimum temperature, precipitation, and diurnal temperature range, were each sorted from low to high values, separately within the 25 El Nino and 50 'normal' years. The terms maximum and daytime temperature and the terms minimum and nighttime temperature were used interchangeably in this study. For each overlapping 3-wk period for the four climate variables, the chi-square statistic was used to test the significance of the difference from an expected 1:2 ratio of the frequency of days between the 25 El Nino years and the 50 'normal' years in cumulative scans in both increasing and decreasing directions, explained below. For the test of each class of a given climatic variable, the total number of daily occurrences in each 3-wk period was 525 (21 days x 25 yr). The total number of days in the normal category was 1050 (21 days x 50 yr). The chi-square test is made, iteratively, of the total number of days accumulating in each class of the given variable in succession ordered from high to low values (high-low scan) or from low to high values (low-high scan). The first chi-square value in the high to low scan includes data in the highest class only, the second for cumulative data in the first plus the second (next highest) class, the third for cumulative data in the first plus the second plus the third class, etc. The low to high scan is performed identically, but starting with the lowest class.

When the counts for the El Nino years deviate from the expected 1:2 ratio with the 'normal' years the chi-square values in the scan increase to a maximum and then decrease beyond the point in which the relationship no longer exists, i.e., final cumulative data analysis for each 3-wk period must, by definition, contain 525 El Nino counts and 1050 'normal' counts. The maximum chi-square point in the scan identifies the "cardinal value" of the climatic element. The "cardinal value" is that point which defines the beginning of the extreme values above or below, depending on the scan direction. In this way, the iterative chi-square method provides a way to determine whether the number of extreme daily occurrences during ENSO years differs significantly from the expected number of occurrences during normal years.

Chi-square values for temperature were taken as statistically significant at P = 0.01 (df = 1); when the actual value was ≥ 6.63. For efficient data analysis, we considered temperature differences in this study significant when $\chi^2 \geq 7$ (rounded up from the actual valued of 6.63), so the significance was slightly more conservative than P = 0.01. Chi-square values for precipitation were taken as statistically significant at P = 0.05 (df = 1); when χ^2 was ≥ 3.84. Similarly, we rounded 3.84 up to '4' for efficient computation. Previous studies have used this level of significance for precipitation because a large percentage of days are without precipitation and in view of the large spatial variability of precipitation (Caprio and Quamme 2002, Caprio et al. 2003). When the relation is significant, the hypothesis that the extreme climate during El Nino years is the same as during normal years is rejected. The larger the value of chi-square, the higher the probability that there is a real extreme climatic effect of the El Nino. We performed high-low and low-high scans for each of the four climatic elements.

A minus sign is given to the chi-square value when the extreme climatic occurrence in the El Nino years is less than in the normal years (inverse relationship). Positive and negative values in the chi-square values plotted against time of year reveal those periods when the El Nino affects extreme climate. Chi-square probability levels are not strictly applicable when counts of the daily weather elements are small (Snedecor 1946). However, chi-square values based on low counts tend to be insignificant and superseded by larger chi-square values in the classes further up (or down) in the scan.

Data for two examples are presented in Table 1 to show how the χ^2 value is computed considering extreme low daily minimum temperature for El Nino years versus normal years. In Equation 1 below, 'A' and 'E' represent actual and expected number of occurrences, respectively. The letters 'e' and 'n' are for El Nino and normal years, respectively.

Eq. 1

$$\chi^2 = \frac{(Ae - Ee)^2}{Ee} + \frac{(An - En)^2}{En}$$

For the first 3-wk period:

$$\chi^2 = \frac{(43 - 81)^2}{81} + \frac{(200 - 162)^2}{162} = 27$$

For the second 3-wk period:

$$\chi^2 = \frac{(150 - 121)^2}{121} + \frac{(212 - 241)^2}{241} = 10.$$

The total number of extreme low daily minimum temperature in the first sample was 43 + 200 = 243 and in the second sample 150 + 212 = 362 (Table 1). We expected the 243 occurrences in the first sample to be proportional in a ratio of 1:2, or 81 for El Nino years and 162 for normal years. In the first sample, the 43 occurrences during El Nino years was less than the 81 expected occurrences, resulting in the large significant χ^2 value of 27 (deficit). In the second sample, the 150 occurrences during El Nino years were greater than the 121 expected occurrences, resulting in the large significant χ^2 value of 10 (excess). The cardinal temperatures in the two samples were ≤ –19 ºC (-3 ºF) in deficit and ≤ –12 ºC (+11 ºF) in excess, respectively.

For each overlapping 3-wk period and scan, our computer output included the maximum χ^2, the accumulated counts of daily weather occurrences, and associated cardinal values. we assigned the χ^2 value of each 3-wk sliding window to the center week. Section A of Figures 1-4 gives 3-wk running averages of the weekly χ^2 values. The cardinal value of the most statistically significant week within each significant period was entered near the appropriate peak shown in Figures 1 to 4. Reference in the text to an association is usually made only if the association was significant for a period of > 2 consecutive weeks.

Table 1. Counts, cardinal temperatures, and chi-square for El Nino vs. 'normal' years for the 3-wk periods centered on 7 Jan and 7 Mar using the low to high scans of extreme low daily minimum temperature

3-wk center date	Scan direction	El Nino year's count	Normal year's count	Cardinal temperature	Chi-square
7 Jan	Low-high	43	200	≤ -19ºC (-3 ºF)	27 (deficit)
7 Mar	Low-high	150	212	≤ -12ºC (+11 ºF)	10 (excess)

Determination of Size of Departure from Normal

Applying the iterative chi-square method offers a number of advantages. The method requires no limiting assumptions as to linearity. In addition, the method provides measures of significance and gives threshold values ≥ and ≤ when there are significant responses of the climatic elements to the El Nino effect. Also, use of daily weather provides 1-wk resolution to determine the effect of El Nino on occurrence of extreme daily weather elements. Caprio et al. (2003) provide a more detailed description of the iterative chi-square method with examples of the interpretation of computer output in a paper on tree ring weather relations, along with comparisons with some other statistical methods.

For each overlapping 3-wk period during 31 wk from 26 Nov to 30 Jun, i.e., 29, 3-wk periods, we calculated the difference in the number of extreme days in the 25 El Nino yrs compared to one half the number of extreme days in the 50 'normal' yrs. This value divided by 25 (number of yrs) gives the difference in number of days/ year during that 3-wk period. In turn, this value divided by three (number of wks) gives the difference in the mean number of extreme days/week. We calculated 3-wk running averages of these weekly values. Thus, smoothed weekly values of the difference in number of extreme days/ week were then divided by 7 (days/wk) and multiplied by 100 to yield the average daily percent of an extreme daily weather due to the El Nino. These daily percentage values were plotted for each week in the B- sections of Figures 1-4. For example, if each day within a particular week during an El Nino year had an average of one-tenth (or 10%) of a day greater extreme daily occurrence due to the El Nino effect, this was referred to as a 10-percent climate change. Since one day represents 14.3 percent of a week, percentages shown in the B-section of the graphs indicates one day of climatic change/week for each 14 percent. Thus, seven percent on the graph represents 0.5 day of climatic change/week.

Percentages in the tables and in part B of the graphs indicate the increase or decrease in percent of a day within each particular week of an El Nino year having an extreme daily weather occurrence due to the El Nino effect. For example, if the percentage for a particular week is indicated in a table or in the B section of the graph as 10 percent, it indicates that each day within that week of an El Nino year had an extra 0.1 day of an extreme weather event due to the El Nino effect.

Results and Discussion

Chi-Square Test for Extreme High Daily Maximum Temperature (High-Low Scan)

Our data indicated an excess of days of extreme high maximum temperature during 15 of the 29 wks of the study, whereas no weeks had a deficit of days of extreme high maximum temperature (Fig. 1). The excess of extreme high daily maximum temperature was most numerous during two periods (Table 2).

Maximum χ^2 of 23 occurred during weeks 22-23 (27 May-9 Jun) with a CT of

Table 2. Data on two periods that had a significant increase in the number of days of extreme high minimum temperatures due to El Nino.

Weeks	Dates	Max weekly χ^2	Daily average period change*	Dates of Max χ^2 wks	Daily average change of Max χ^2 wks*	Cardinal temp of Max χ^2 wks
3 - 8	14 Jan – 24 Feb	15	+8.6%	28 Jan – 3 Feb	+16%	≥ 1°C (+33°F)
17 - 25	22 Apr – 2 June	23	+5.7%	27 May – 9 June	+8%	≥ 27°C (+81°F)

* Positive signs indicate the average fraction of a day (in percent) increase in extreme high daily minimum temperatures during the two intervals that were attributable to El Nino.

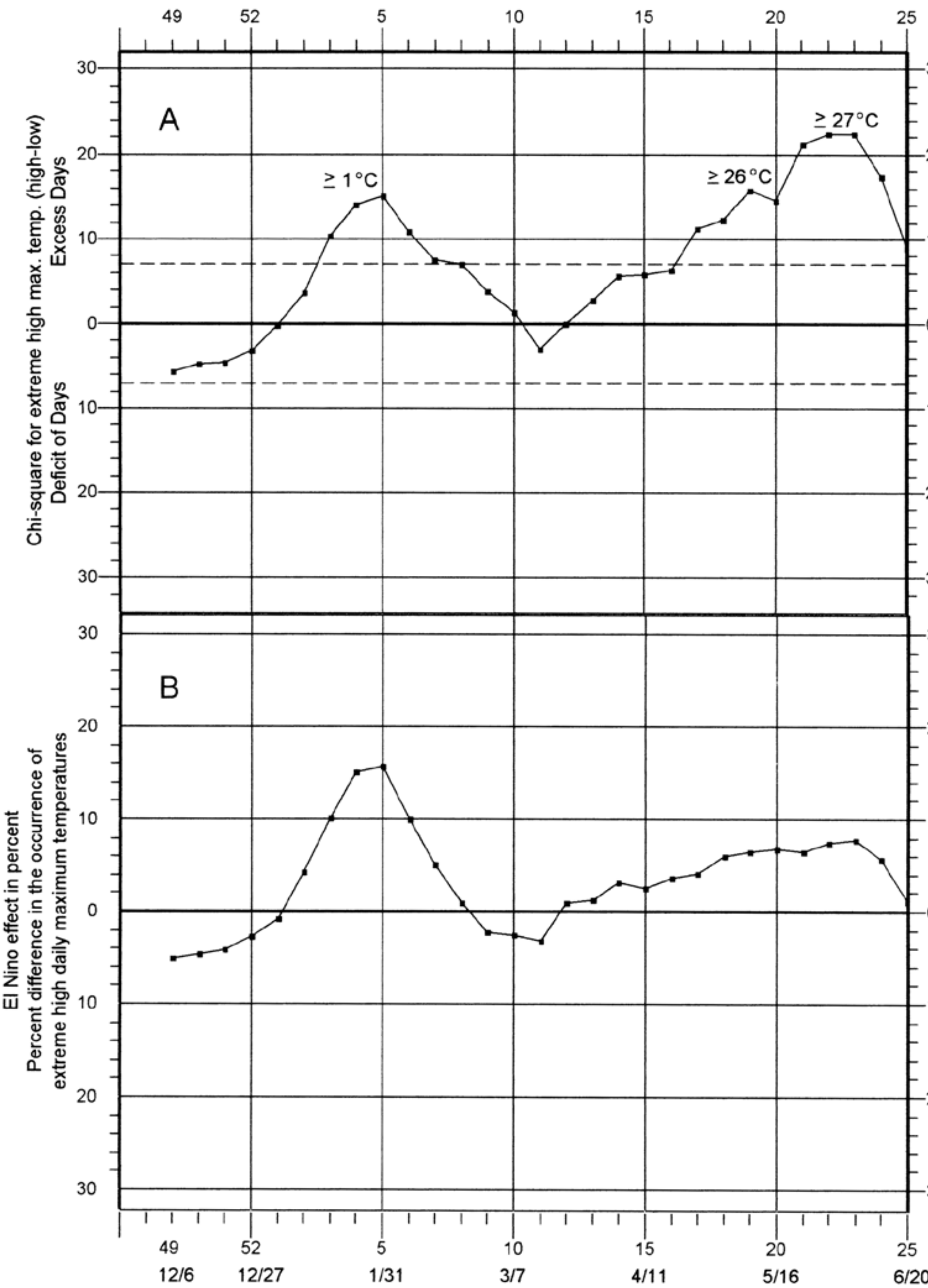

Figure 1. (A) Significance of the difference in the number of extreme high maximum temperature days during the 25 El Nino years compared to the 50 normal years. Cardinal values (the extreme high maximum temperature occurrence during the week of maximum χ^2) are indicated on the graph. Chi-square values =7 (indicated by the dotted lines) are the critical values for significance (P=0.01, 1df).

(B) For each date (plotted weekly) in an El Nino year, the average percent that had an extreme high maximum temperature occurrence due to the El Nino effect.

≥ 27 ºC (81 ºF). Departure from normal during this period was an increase of 8 percent. However, the maximum percentage departure from normal occurred during week 5 (28 Jan-3 Feb) with an increase of 16 percent associated with a χ^2 of 15 and a CT of ≥ 1 ºC (33 ºF). Considering seven percent as the level for 0.5 day/wk as the El Nino effect and 14 percent as the level for 1 day/wk, we can make the following interpretations:

1. For extreme high maximum temperatures there were 8 wks with at ≥ 1 day increase associated with the El Nino and 2 wks that had at ≥ 1 day/wk increase associated with the El Nino.

2. We observed no weeks with low maximum temperature cooling associated with the El Nino.

3. The greatest percentage increase in extreme maximum temperatures occurred during week 5 (28 Jan-3 Feb) when we detected a 16 percent increase. Whereas the biggest departure from normal occurred during winter (14 Jan-24 Feb), a greater number of days of extreme high maximum temperatures occurred during weeks 17-25 (22 Apr-23 Jun), as indicated by the large chi-square values, but with a percentage increase consistently < 8 percent. This was consistent with earlier onset of spring, which has been reported previously for this region (Cutforth et al. 1999, Cayan et al. 2001).

4. During the first significant departure period (14 Jan-24 Feb), peak response occurred during week five (28 Jan-3 Feb) when an excess of extreme daily maximum temperatures ≥ +1 ºC (+33 ºF) occurred. During this 6-wk period, occurrence of extreme maximum daily temperatures averaged 26 percent more frequently, i.e., 249.5 vs. 198, during El Nino years than during normal years.

Additional comparisons can be made for each significant departure period using information from the associated table and text. An example is given below for the significant departure period covering weeks 3-8 (14 Jan-24 Feb) for extreme high daily maximum temperature at Bozeman. Since the 0.086 fraction of extreme days from Table 2 represents a 26-percent increase of the fraction of extreme days compared with 'normal' years, i.e., 249.5/198 x 100 = 26 percent, the fraction of extreme days in normal years equates to 0.331, i.e., 0.086/0.26 = 0.331, and the total fraction of extreme days in El Nino years is 0.331 plus 0.086 which equals 0.417. Given that the percent of extreme days in normal years is 33.1 percent while the percent of extreme days in El Nino years is 41.7 percent, the percent of non-extreme days in normal and El Nino years is 66.9 and 58.3 percent, respectively.

During the second significant period (22 Apr-23 Jun) peak response occurred during weeks 22-23 (27 May-9 Jun) when an excess of daily maximum temperatures ≥ +27 ºC (+81 ºF) occurred. During this 9-wk period the occurrence of extreme maximum daily temperatures averaged 67 percent more frequent during El Nino years than during normal years. We determined for all 29 wks combined that El Nino years averaged 20 percent more days, i.e., 119.9 vs. 100.2, with extreme high maximum temperature than normal years.

Chi-Square Test for Extreme Low Minimum Temperature (Low-High Scan)

We detected a deficit of days of extreme low minimum temperatures during the El Nino years during 7 of the 29 wks of the study (Fig. 2). The deficit of days extended from 7 Jan to 24 Feb. Alternatively, there was an excess of days of extreme low minimum temperatures during only 2 of the 29 wks, from 4 to 17 Mar (Table 3). Maximum χ^2 of 32 occurred during week 5 (28 Jan-3 Feb) with a CT of ≤ -19 ºC (-3 ºF). The percent change during this week was a decrease of 12 percent.

For extreme low minimum temperatures there were 5 wks that had ≥ 0.5 day decrease associated with the El Nino and 2 wks that had nearly 1 day/week decrease associated with the El Nino (Fig. 2). The greatest percentage decrease in extreme low minimum temperature occurred during weeks 4 and 5 (21 Jan-3 Feb) when we

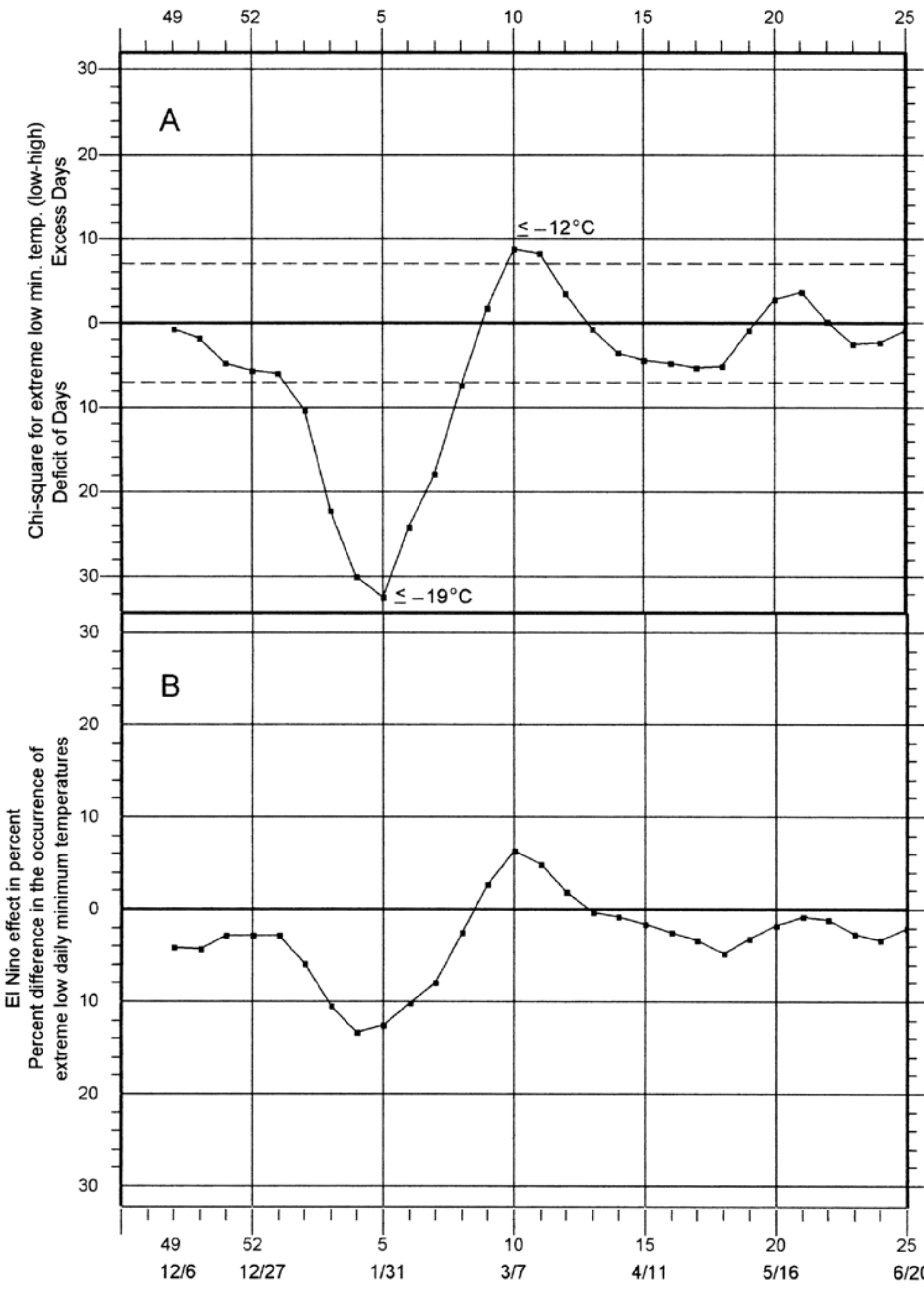

Figure 2. (A) Significance of the difference in the number of extreme low minimum temperature days during the 25 El Nino years compared to the 50 normal years. Cardinal values (the extreme low minimum temperature occurrence during the week of maximum χ^2) are indicated on the graph. Chi-square values =7 (indicated by the dotted lines) are the critical values for significance (P=0.01, 1df).

(B) For each date (plotted weekly) in an El Nino year, the average percent that had an extreme low minimum temperature occurrence due to the El Nino effect.

Table 3. Data on the seven-week period that had a significant decrease in the number of days of extreme low minimum temperatures due to El Nino.

Weeks	Dates	Max weekly χ^2	Daily average period change*	Dates of Max χ^2 wks	Daily average change of Max χ^2 wks*	Cardinal temp of Max χ^2 wks
2 - 8	7 Jan – 24 Feb	32	-9.0%	28 Jan – 3 Feb	-12%	< -19°C (-3°F)

* Negative sign indicates the average fraction of a day (in percent) decrease in extreme low daily minimum temperatures during the interval that was attributable to El Nino.

detected a 13-percent decrease. Peak response during 7 Jan-24 Feb occurred during week 5 (28 Jan-3 Feb) when a deficit of extreme daily minimum temperatures ≤ -19 ºC (-3 ºF) occurred. During this 6-wk period, occurrence of extreme daily minimum temperatures averaged 50 percent less frequent during El Nino years than during normal years. El Nino years averaged 18 percent fewer days, i.e., 71.6 vs. 87.6, for all 29 wks combined with extreme low daily minimum temperature than normal years.

Chi-Square Test for Extreme High Precipitation (High-Low Scan)

We detected a deficit of days of high precipitation during El Nino years during 13 of 29 wks of the study (Fig. 3). Only during weeks 14-15 (1-14 Apr, 21.6 mm) the analysis indicated that high precipitation days were more frequent during the December-June period of the 25 El Nino years. Ten of 12 total days that had precipitation amounts of ≥ 12.7 mm (0.50 in) occurring during weeks 14-15 (1-14 Apr) coincided with unusually warm January SSTA of ≥ +1.00 °C. These 10 days with large precipitation amounts occurred during eight different El Nino years.

The deficit of days with heavy precipitation was significant during two periods (Table 4). Maximum χ^2 of 7 occurred during week 6 (4-10 Feb) and χ^2 of 8 for week 23 (3-9 Jun) both with a CT of 1.3 mm (0.05 in; Table 4). For high precipitation there were only 2 wks that had ≥ 0.5 day of decrease of high precipitation (Fig. 3). The greatest percentage decrease in high precipitation amounts occurred during week 23 (3-6 Jun) when we detected an 8-percent decrease. This study did not compare total accumulated precipitation during El Nino years with that during normal years. However, a previous report by the National Weather Service indicated that the South-central Crop District of Montana received only 74 percent of normal precipitation during El Nino years (National Weather Service 2003).

Peak response during the first significant period (4 Feb-17 Mar) occurred during week 7 (4-10 Feb) when a deficit of high precipitation days ≥ 1.3mm (0.05 in) occurred. During this 6-wk period, high precipitation days averaged 41 percent fewer during El Nino years than during normal years. Peak response during the second significant period occurred during weeks

Table 4. Data on two periods that had a significant decrease in the number of days of extreme high precipitation days due to El Nino.

Weeks	Dates	Max weekly χ^2	Daily average period change*	Dates of Max χ^2 wks	Daily average change of Max χ^2 wks*	Cardinal temp of Max χ^2 wks
5 - 11	4 Feb – 17 Mar	7	-2.1%	28 Jan – 10 Feb	-3%	≥ 1.3 mm (0.05 in)
22 - 23	27 May – 9 June	8	-6.6%	27 May – 9 Jun	-8%	≥ 1.3 mm (0.05 in)

* Negative signs indicate the average fraction of a day (in percent) increase in extreme high daily precipitation during the two intervals that were attributable to El Nino.

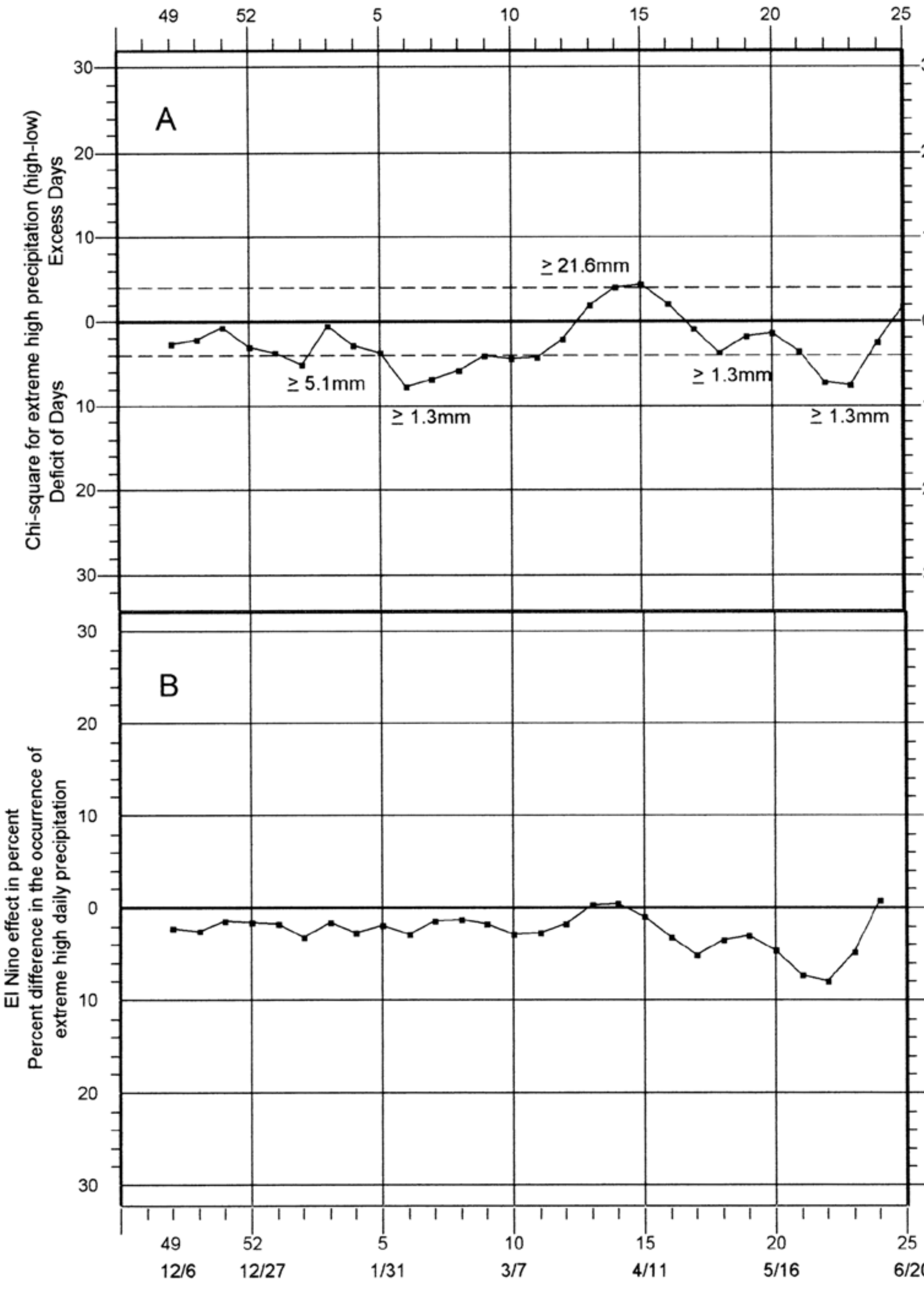

Figure 3. (A) Significance of the difference in the number of high precipitation days during the 25 El Nino years compared to the 50 normal years. Cardinal values (the extreme high precipitation occurrence during the week of maximum χ^2) are indicated on the graph. Chi-square values =7 (indicated by the dotted lines) are the critical values for significance (P=0.05, 1df).

(B) For each date (plotted weekly) in an El Nino year, the average percent that had a high precipitation occurrence due to the El Nino effect.

22-23 (27 May-9 June) when a deficit of high precipitation days > 1.3mm (0.05 in) occurred. During this 2-wk period, high precipitation days averaged 24 percent fewer during El Nino years than during normal years. We determined that for the entire 29-wk study period, El Nino years averaged 21 percent fewer days, i.e., 48.9 vs. 61.7, with high precipitation amounts than normal years.

Chi-Square for Extreme Small Diurnal Temperature Range (Low-High Scan)

There was a deficit of extreme small diurnal temperature ranges during El Nino years during seven of the 29 wks of the study (Fig, 4), with no periods of excess (Table 5).

Maximum χ^2 of 13 occurred during week 22 (27 May-3 Jun) with a CT of 14 ºC (25 ºF), representing a 12-percent decrease during this week. For the deficit of extreme small diurnal temperature ranges there were 4 wks that had ≥ 0.5 day associated with the El Nino and no weeks that had at least one whole day/week decrease associated with the El Nino.

During the first significant period (18 Feb-10 Mar), peak response occurred during weeks 8-10 (18 Feb-10 Mar), when a deficit of small diurnal temperature range days ≤ 8 ºC (15 ºF) occurred (Table 5); this occurrence of extremely small diurnal temperature-range days averaged 29 percent fewer during El Nino years than during normal years. During 13 May-9 Jun, peak response occurred during week 22 (27 May-2 Jun) when a deficit of small diurnal temperature range days ≤ 14 ºC (25 ºF) occurred. During this 4-wk period, occurrence of extreme small diurnal temperature days averaged 26 percent fewer during El Nino years than during normal years. For the entire 29-wk study period, El Nino years averaged 18 percent fewer days, i.e., 86.7 vs. 105.2, with extreme small diurnal temperature ranges than normal years.

Summary and Conclusions

These results were consistent with other studies on the effect of El Nino on temperature and precipitation in Montana (Sittel 1994, Green et al. 1997, Bernhardt 2002, NOAA 2003). This analysis indicated that based on 100 yr of climate record, Bozeman's local climate was significantly impacted by the El Nino conditions. The 29-wk study period from 3 Dec to 23 June was characterized by a greater number of extreme high daytime temperatures, a deficit of extreme low nighttime temperatures, a deficit of high precipitation days, and a deficit of days with extremely small diurnal temperature ranges. We determined the difference between El Nino years and normal years to be about 20 percent for each of these four extreme daily weather conditions.

The influence of El Nino on daytime temperatures was most significant during the period from about mid January to mid February and from about mid April to early June, during which time a greater number of extreme high daytime temperatures occurred. Peak percent increase of extreme high daytime temperatures occurred

Table 5. Data on two periods that had a significant decrease in the number of days of extreme small diurnal temperatures due to El Nino.

Weeks	Dates	Max weekly χ^2	Daily average period change*	Dates of Max χ^2 wks	Daily average change of Max χ^2 wks*	Cardinal temp of Max χ^2 wks
8 - 10	18 Feb – 10 Mar	7	-4.7%	18 Feb – 10 Mar	-5%	< 8°C (15°F)
20 - 23	13 May – 9 June	13	-9.8%	27 May – 2 June	-12%	< 14°C (25°F)

* Negative signs indicate the average fraction of a day (in percent) increase in extreme high daily diurnal temperatures during the two intervals that were attributable to El Nino.

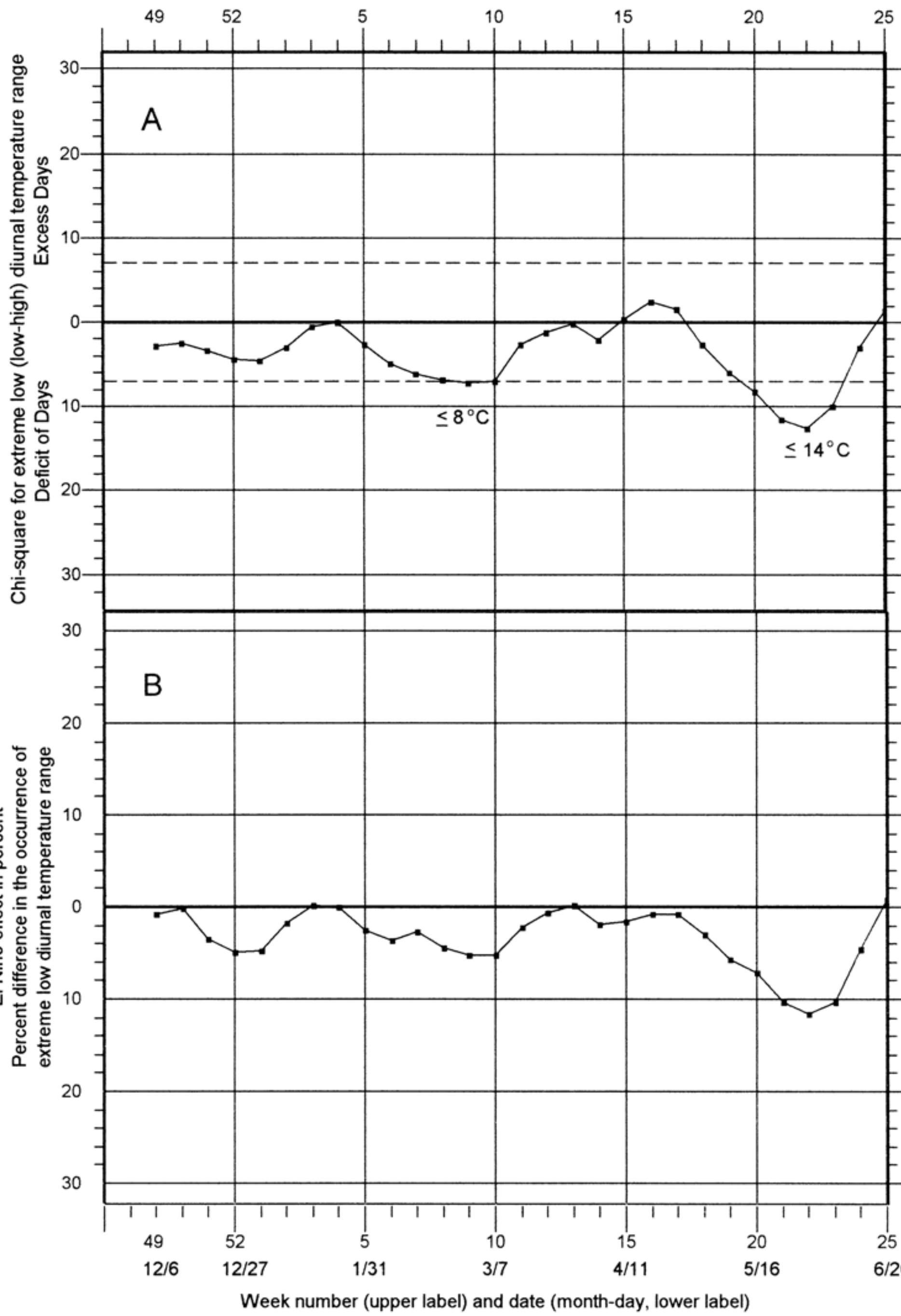

Figure 4. (A) Significance of the difference in the number of low diurnal temperature range days during the 25 El Nino years compared to the 50 normal years. Cardinal values (the extreme low diurnal temperature occurrence during the week of maximum χ^2) are indicated on the graph. Chi-square values =7 (indicated by the dotted lines) are the critical values for significance (P=0.01, 1df).

(B) For each date (plotted weekly) in an El Nino year, the average percent that had a low diurnal temperature range occurrence due to the El Nino effect.

during these two periods at 13 and nine percent, respectively. Extreme high daytime temperatures during the most significant period (22 Apr-23 June) averaged 67 percent more frequent during El Nino years than during normal years.

The influence of El Nino on extreme low nighttime temperatures was most significant during the period from about early January to late February during which time a deficit of extreme low nighttime temperatures was experienced. The greatest decrease in extreme low nighttime temperatures was 12 percent. During the one significant period (7 Jan-24 Feb), extreme low nighttime temperatures averaged 50 percent less frequent during El Nino years than during normal years.

The influence of El Nino on fewer days of high precipitation amounts was most significant during the periods from about early February to mid March and from late May to early June. The greatest percentage decreases of high precipitation amounts observed during these two periods were three and eight percent respectively. High precipitation days during the most extreme precipitation periods, 28 Jan-17 Mar and 20 May-9 Jun, averaged 44 and 24 percent less frequently during El Nino years than during normal years.

The influence of El Nino on the deficit of extreme small diurnal temperature ranges was most significant during the period from about mid February to mid March and from about mid May to early June. Peak percent deficit of extreme small diurnal temperature ranges during these two periods were seven and 13 percent, respectively. Extremely small diurnal temperature range days during the most significant period (13 May-9 Jun) averaged 29 percent less frequently during El Nino years than during normal years.

This approach to determine extreme daily weather associated with the El Nino can be applied at any location for which an uninterrupted long daily weather record is available. The technique provides important information concerning the specific time when El Nino-caused extreme daily weather occurrences may be expected with a time resolution of one week. This procedure revealed extreme high or low thresholds (≥, or ≤) of the most significant climatic elements; thus, the analyst is not required to select arbitrary extreme thresholds for each climate element. Important information is provided on significant levels and percent of extreme daily weather occurrences that can help assess the potential impact of an El Nino event.

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Literature Cited

Bernhardt, D. 2002. Past El Nino effects on Montana weather. National Weather Service, Great Falls, MT, November 6, 2002.

Caprio, J. M. 1966. A statistical procedure for determining the association between weather and non-measurement biological data. Agricultural and Forest Meteorology 3:55-72.

Caprio, J. M. and H. A. Quamme. 2002. Weather conditions associated with grape production in the Okanagan Valley of British Columbia and potential impact of climate change. Canadian Journal of Plant Science 82:755-763.

Caprio J. M., H. C. Fritts, R. L. Holmes, D. M. Meko, and D. L. Hemming. 2003. A chi-square test for the association and timing of tree ring-daily weather relationships: A new technique for dendroclimatology. Tree Ring Research. 59:99-113.

Caprio, J. M., H. A. Quamme, and K. T. Redmond. 2009. A statistical procedure to determine recent climate change of extreme daily meteorological data as applied at two locations in Northwestern North America. Climatic Change 92:65-81.

Cayan, D. R., K. T. Redmond, and L. G. Riddle. 1999. ENSO and hydrologic extremes in Western United States. Journal of Climate 12:2881-2893.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82:399-415.

Cutforth, H. W., B. G. McConkey, R. J. Woodvine, D. G. Smith, P. G. Jefferson, and O. O. Akinremi. 1999. Climate change in the semiarid prairie of southwestern Saskatchewan: Late winter - early spring. Canadian Journal of Plant Science 79:343-350.

Gershunov, A., and T. B. Barnett. 1998. ENSO influence on intraseasonal extreme rainfall and temperature frequencies in the contiguous United States. Journal of Climate 11:1575-1586.

Green, P., D. M. Legler, C. Mirana, and J. J. O'Brien. 1997. The North American patterns associated with El Nino-Southern Oscillation. Center for Ocean-Atmospheric Prediction Studies Technical Report 97-1, 8 pp. Florida State University, Tallahassee.

Green, P. M. 1996. Regional analysis of Canadian, Alaskan and Mexican precipitation and temperature for ENSO impact. Center for Ocean-Atmospheric Prediction Studies Technical Report No.96-6. Florida State University, Tallahassee.

Kalma, J. D., G. P. Laughlin, J. M. Caprio, and P. J. Hammer. 1992. Weather and winterkill of wheat: a case study. Pp. 73-82 *in* Advances in Bioclimatology-2. The Bioclimatology of Frost: Its Occurrence, Impact and Protection, Springer-Verlag, New York.

McPhaden, M. J., S. E. Zebiak, and M. H. Glantz. 2006. ENSO as an integrating concept in Earth Science. Science 314:1740-1745.

Myers, S. D., J. J. O'Brien, and E. Thelin. 1999. Reconstruction of monthly SST in the Tropical Pacific Ocean during 1868-1993 using adaptive climate basis functions. Journal of Climate 16:1249-1258.

National Weather Service. 2003. ENSO Impacts on the U.S., (Montana) http://www.noaanews.noaa.gov/stories/s1112.htm. [verified 10 Feb 2009]

National Weather Service. 2008. Cold and warm episodes by season. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. [verified 10 Feb, 2009]

National Weather Service. 2003. The 1997 El Nino: Potential effects in Montana November 1997 to April 1998. 14 Jan 2003.

Shabbar, A., B. Bonsal, and K. Madhav. 1997. Canadian precipitation patterns associated with the Southern Oscillation. Journal of Climate 10:3016-3027.

Sittel, M. 1994. Differences in the means of ENSO extremes of temperature and precipitation in the United States. Center for Ocean-Atmospheric Prediction Studies Technical Report 94-2. Florida State University, Tallahassee.

Snedecor, G. W. 1946. Statistical Methods. Iowa State University Press, Ames.

Trenberth, K.E. 1997. The definition of El Nino. Bulletin of the American Meteorological Society 78:2771-2777.

Trenberth, K. E. and D. P. Stepaniak. 2001. Indices of El Nino evolution. Journal of Climate 14:1697-1701.

Twine, T. E., C. J. Kucharik, and J. A. Foley. 2005. Effects of El Nino-Southern Oscillation on the climate, water balance and streamflow of the Mississippi river basin. Journal of Climate 18:4840-4861.

Wang, H. and R. Fu. 2000. Winter monthly mean atmospheric anomalies over the North Pacific and North America associated with El Nino SSTs. Journal of Climate 13:3435-3447.

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Training Volume and Methods of Athletes Competing at a Mixed Martial Arts Event

John Amtmann, Applied Health Science, Montana Tech of the University of Montana, Butte, MT 59701

Abstract

This study surveyed 32 athletes competing at a mixed martial arts (MMA) event held in Butte, Montana. The survey attempted to gather information regarding overall training volume, supplement use, volume change and specific exercises used. The survey return rate was 100 percent (32/32). Twenty-five of 32 athletes supplemented their training with strength training. Overall frequency of strength training ranged from one to six sessions/week, and overall frequency of fighting-specific training sessions/week ranged from two to 10. Two of 32 athletes used/had used anabolic-androgenic steroids. Sixteen MMA athletes performed exercises specifically for the neck musculature, and eight used the power clean within their strength-training program. Results suggested that strength and conditioning specialists should educate MMA athletes regarding the importance of, volume variation and periodization, balanced training, effective exercises, and the side effects of anabolic androgenic steroid use.

Key words: mixed martial arts, periodization, strength training, conditioning

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Introduction

The sport of mixed martial arts (MMA) is becoming one of the most popular sports in the world today, and training for the sport must be comprehensive in nature. The sport is a mixture of various combat sports that include stand-up striking, i.e., boxing, kick-boxing, muay thai, stand-up grappling, i.e., judo, greco-roman and freestyle wrestling, and ground grappling, i.e., ju-jitsu, judo and wrestling. The most successful athletes in this arena combine elite level skills with extraordinary strength and conditioning levels. Because MMA combines different sports, high training volumes for MMA athletes have been frequently reported and overtraining is a serious risk, which is probably why there is also serious concern over anabolic androgenic steroid (AAS) use in the sport.

Although strength and conditioning guidelines have been formally established for grappling and striking sports (Cordes 1991, Ebben 1997,Grisaffi 1996, Kovaleski Gurchiek and Pearsall 2001, Lansky 1999, Pulkkinen 2001, Takahashi 1992), an extensive literature search yielded only two results in peer reviewed sources regarding training methods employed by MMA athletes (Amtmann 2002, Amtmann et al. 2008). Neither of these studies, however, revealed insight into training volume changes in the months prior to an MMA event.

Recently, a MMA event was held in Butte, Montana. The Event Director designated time for surveys to be completed just prior the rules meeting. The major purpose of the survey was to add to the existing information about the strength and conditioning practices employed by MMA competitors and how training volume varied as the date of the bout approached.

Methods

Experimental Approach to the Problem

This was an exploratory descriptive study that sought to add to the minimal information in peer-reviewed research journals regarding the strength and conditioning methods MMA athletes employ.

Subjects—Thirty-two athletes from across the country competed at an MMA event held in Butte, Montana, and completed surveys that questioned the athletes about their overall training methods. The competitors for the event ranged in age from 19 to 41 years. An institutional review board approved this project and each subject signed an informed consent form that informed them of their rights relative to this survey.

***Procedures*—**The questionnaire consisted of three sections, and took ~15 min to complete. The first section of the survey addressed the athletes' overall MMA training and strength training volume.

The athletes were surveyed regarding the volume of MMA specific training four, three, two and one month away from an MMA bout, and volume of strength training when more than two months or less than two months out from an MMA bout.

The second section surveyed the athletes regarding anabolic-androgenic steroid (AAS) use and a final third section sought to gain information about the specific exercises the athletes used.

Previous research has shown that if the respondents of a survey know and trust the individual distributing the survey, the response rate will be higher than an unknown surveyor (10). The author was well acquainted with several of the coaches and most of the athletes competing at this event, and he was competing in the event, which may have had a positive influence on the 100 percent (32/32) survey return rate.

***Survey Distribution*—**The director of the event designated a 15-min period of time prior to the rules meeting for the surveys to be distributed. The rules meeting was held about 4 hrs before the start of the event. The survey was designed with efficiency of completion in mind and was short enough that the athletes would take their time in completing it. The survey also allowed us to gain more information than in previous surveys. Analysis of the data consisted of descriptive statistics that identified the responses to each item/question.

Results

Twenty five of 32 respondents participated in some type of weight training program in addition to their fight specific training. A slight change in the number of strength training (ST) sessions/week was noted as the bout neared within 2 mos (Table 1). When > 2 mos out from the bout, 17 athletes participated in ST sessions one to three times/week and eight participated in ST sessions three to six times/week, and 21 respondents performed one to three sets/exercise with the other four performing four or more sets/exercise. When the bout was within two months nineteen athletes participated in ST sessions one to three times/week and six athletes participated three to six times/week, and 19 performed one to three sets/exercise and six athletes performed four or more sets/exercise.

Table 1. Strength Training Sessions Per Week and Number of Sets Per Exercise

ST* Sessions/Week	More than 2 MO**	Less than 2 MO
1-2	5***	6
2-3	12	13
3-4	7	4
5-6	1	2
Sets/Exercise		
1	3	1
2	4	4
3	14	14
4 or more	4	6

* ST = Strength Training
** MO = Months out from bout
*** Number of athletes responding to this range or number

Frequency (sessions/wk) of MMA specific training sessions ranged from two to 10, and the volume of MMA specific training varied depending on how close the athlete was to the date of the bout. A summary of results from this section of the survey appear in Table 2. When the bout was more than four months away, 14 athletes trained two to three times/week, 11 trained four to five times/week and seven trained six or more sessions/week. When the bout was

Table 2. MMA-Specific Training Sessions Per Week

Sessions/Week	4 Months Out	3 Months Out	2 Months Out	1 Month Out
2-3	14*	9	6	6
4-5	11	15	17	17
6-7	4	4	4	3
8-9	2	3	2	3
10 or more	1	1	3	3

*Number of athletes responding to this particular frequency

one month away only six athletes trained two to three days/week, 17 trained four to five times/week, and nine trained six or more sessions/week.

Survey results also revealed that 16 of 32 athletes performed exercises specifically for the neck musculature, six used the power snatch, and eight used the power clean in their strength training program. Finally, two of 32 athletes responded positively to previous AAS use.

Discussion

Most athletes surveyed (25 of 32 respondents) participated in a ST program to prepare for their bout with only 16 of 25 performing exercises specific to the neck. In a previous study, Amtmann (2004) reported that only five of 28 athletes used exercises specifically for the neck, so 16 of 25 is a relative good percentage. The volume of ST, both number of ST sessions/week and sets/exercise varied only slightly as the bout neared. The volume of MMA-specific training sessions varied slightly more with the largest trend being an increase in MMA-specific training. This suggested that some of the athletes may understand and implement periodization and volume variation to suit their MMA specific needs. Obviously the best way to train for an MMA style bout is to participate in MMA-specific training, and results of this survey suggested that some athletes involved in this particular event understand that concept.

It isn’t always the athlete that trains the most, but the one who trains the smartest, who is successful. Smart training may include an adjustment to overall strength training volume to allow for metabolic conditioning specific to MMA, which may require increases in MMA specific training and adjustments to strength training. Smart training would also include training the entire musculature of the body, including the neck. Finally, smart training should exclude the AAS use.

One of the limitations to this study is that the sample was a convenience sample of athletes fighting at a specific event that included both amateur and professional fighters. Some of the professional fighters are sponsored and are able to train with much greater frequency than the amateur fighters who have to fit their training into work and family schedules.

Practical Applications

The sport of mixed martial arts combines several combative sports, and the overall volume of training for these athletes might likely be very high. As a bout nears it may be necessary to vary overall training volume to fit the individual needs of the athlete. This information is beneficial to the strength and conditioning specialist in several ways. First it appears that some of the athletes did not include strength training in their training. Second, many of those that did include strength training did not perform any strength training for the neck. Third, it appears that some of the athletes adjust their training volume to allow for more MMA specific training. The certified strength and conditioning specialist could be well-utilized by some of these athletes to develop sound programs specific to the needs of each individual MMA athlete.

Literature Cited

Amtmann, J. 2004. Self-Reported Training methods of mixed martial artists at a regional reality fighting event. Journal of Strength and Conditioning Research 18:194-196.

Amtmann, J., K. Amtmann, and W. Spath. 2008. Lactate and rate of perceived exertion responses of athletes training for and competing in a mixed martial arts event. Journal of Strength and Conditioning Research 22:645-647.

Cordes, K. 1991. Reasons to strength train for amateur boxing. National Strength and Conditioning Association Journal 13:18-21.

Ebben, W. 1997. Developing a strength power program for amateur boxing. Strength and Conditioning 19:42-51.

Grisaffi, D. 1996. Ballarmine prep's strength training program for wrestling. Strength and Conditioning 18:54-58.

Kovaleski, J., L. Gurchiek, and A. Pearsall. 2001. Musculoskeletal injuries: risks, prevention, and care. In Lippincott, Williams and Wilkins, editors, ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription. Baltimore, MD.

Lansky, R. 1999. Wrestling and Olympic style lifts: in-season maintenance of power and anaerobic endurance. Strength and Conditioning Journal 21:21-27.

Pulkkinen, W. 2001. The sport science of elite judo athletes. Pulkinetics. Guelph, Ontario, Canada.

Takahashi, R. 1992. Power training for judo: plyometric training with medicine balls. National Strength and Conditioning Association Journal 14:66-71.

Wagman, D., L. Curry, and D. Cook. 1995. An Investigation into anabolic androgenic steroid use by elite U.S. powerlifters. Journal of Strength and Conditioning Research 9:149-154.

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