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Forest Floor Moisture Content and Fire Danger Indices in Alaska

Randi Jandt
Jennifer Allen
Esther Horschel

Alaska

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Cover Photo

A forest floor sample is separated into fuel layers for weighing and sampling. Photo by E. A.Horschel.

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ABSTRACT

This report summarizes activities from 2002 to 2004 undertaken by the U.S. Bureau of Land Management's Alaska Fire Service and cooperating agencies to better understand the influence of forest floor moisture content on fire behavior in interior Alaska boreal spruce forest. Forest floor moisture measurements were derived by removing individual layers and oven-drying them. Forest fuel treatments (thinning and pruning) for fire hazard reduction were associated with drier moss and duff layers, indicating a fire behavior trade-off in those units designed to reduce forest fire hazard. Forest floor moisture contents were compared with indices of the Canadian Forest Fire Danger Rating System to "validate" the performance of the indices in Alaska for reflecting conditions in the moss and duff layers. In general, indices followed moisture trends, but during specific times during the season, disagreement was noted between indices and actual fuel moisture conditions. Results of experiments using automated electronic devices to estimate moss and duff moisture were encouraging and may provide a means to improve both start-up value determination for fire danger indices and rapid field assessment.

ACKNOWLEDGMENTS

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INTRODUCTION

Fire management decisions in Alaska are based on the ability to predict fire risk conditions and burn severity. Fire managers need a reliable method for predicting the likelihood of ignitions, rate of spread, duration, and depth of organic fuel consumption in order to achieve the desired objectives of prescribed and fire-use fires. Most fire management agencies in Alaska have been relying on the Canadian Forest Fire Danger Rating System (CFFDRS), described in the box below, as a method for predicting fire behavior, severity, and relative danger since 1992 (Alexander and Cole, 1994).

Duff Moisture and the Fire Weather Index Codes

Fuel moisture codes were designed to predict daily changes in moisture content of three forest floor fuel layers. The equations used to compute fuel indices from temperature, wind, and cumulative precipitation were derived empirically using field duff moisture measurements and weather data from mature jack pine/lodgepole forests in Canada (Stocks, et al. 1989). FFMC, DMC and DC are tabulated directly from weather station parameters (Canadian Forestry Service 1987). However, equations were subsequently developed to derive fuel moisture codes from field measurements, i.e., collecting forest duff layers and determining the moisture content (Lawson and Dalrymple 1996, Wilmore 2001). Destructive sampling of the forest floor for moisture content can be used to determine starting values of DMC and DC (Armitage 2000) or to verify calculated FWI's.

Although the FWI moisture code calculations are uniform across Canada and Alaska, fuel types and drying conditions (day length, permafrost, decomposition rate, soil type) are not. Thus, many regional offices in Canada have done their own studies to see how actual duff moistures track with the FWI moisture codes. In October 2003, the Alaska Interagency Research Committee identified the need to improve CFFDRS moisture estimates and its application in Alaska as one of its top priorities. Wilmore (2001) tracked FWI's and moisture codes in a black spruce/feather moss forest near Fairbanks. Rorig et al. (2003) evaluated FWI's and duff moisture in boreal forest at Caribou Creek, north of Fairbanks. We have attempted to continue the validation process she started and expand to other localities in the state with some of the data presented in an earlier unpublished BLM report (Allen and Jandt, Fuel & Duff Moisture Monitoring: 2001) and in this report.

Overview of the Canadian Forest Fire Danger Rating System

The Canadian Fire Weather Index (FWI) system is comprised of three moisture codes for forest duff layers and three indices of fire behavior (Lawson et al. 1997a). The moisture codes are intended to track the relative moisture content of three forest floor components and are calculated based on past and current weather station data (rainfall, relative humidity, temperature, and wind speed). The Fine Fuel Moisture Code (FFMC) is a numerical rating of the moisture content of litter and other cured fine fuels (mosses, needles, and twigs) and is generally representative of the top 1–2 cm of the forest floor. The FFMC fuels are affected by temperature, wind speed, relative humidity and rain. The Duff Moisture Code (DMC) is a numerical rating of the dryness of the moderately deep, loosely compacted organic forest floor. The DMC is affected by changes in temperature, relative humidity and rain. The Drought Code (DC) is a numerical rating of the average moisture content of deep, compact, organic layers. The DC is an indicator of seasonal drought and the amount of smoldering in deep duff layers. Air temperature and precipitation greater than 2.9 mm per day affect the Drought Code.

Duff Moisture in Shaded Fuel Breaks

Thinning and pruning spruce stands around homes or villages is an accepted technique to reduce fire hazard and increase defensibility of these structures. However, no one knows how thinning and pruning treatments affect permafrost, moss, and duff moisture. We compared moss and duff moistures at a recently created shaded fuel break in Tanacross and an experimental fuel break at Ft. Wainwright. Weather data loggers monitored temperature, relative humidity, and wind speed in a treatment and control stand. Treatment stands at Tanacross were white spruce forest thinned to approximately 12-foot spacing and pruned to a height of 6 feet (Fig. 1). The Ft. Wainwright treatment stand was thinned to 10-foot spacing, reducing the tree density from about 3600 stems/ac to 600 stems/ac.

Duff Moisture and Fire Effects

Canadian research (Lawson et. al. 1997a, 1997b) and Alaskan research (Norum and Miller 1984, Ottmar

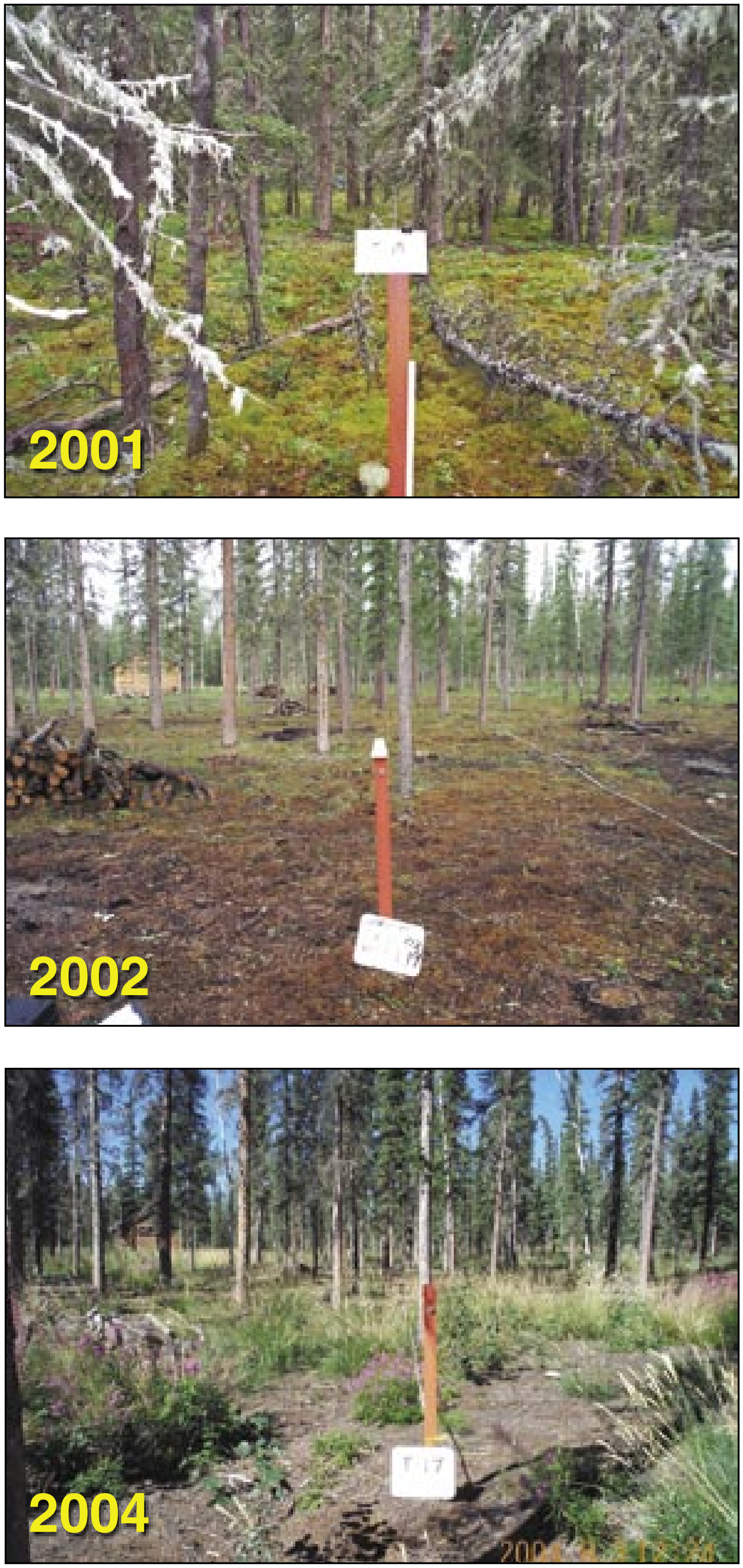


Figure 1. Shaded fuel break treatment at Tanacross, Alaska, pre-treatment and post-treatment after years 1 and 3.

2003) have shown that fire behavior and fire effects in the boreal forest are related to the moisture content and depth of the forest floor duff layers. Moisture content is the main factor controlling ignition and sustained combustion of forest fuels (Lawson et al. 1997b) as well as ultimate consumption of the forest duff (Frandsen 1987, Reinhardt et al. 1991, Hungerford et al. 1995). Fire effects and revegetation are directly related to the depth of forest floor consumption (Foote 1984).

OBJECTIVES

Duff moisture contents were measured: 1) to determine when units were within prescription for burning; 2) to compare forest floor moisture contents at canopy-manipulated sites; 3) to compare actual moisture contents with fire weather indices (FWI) calculated with the local weather station for validation of CFFDRS in Alaska and assessing start-up values of the DMC and DC for Remote Automated Weather (RAWS) stations; and 4) to evaluate electronic devices for measuring duff moisture.

STUDY AREAS AND METHODS

Study Sites

Duff fuel moisture contents were measured in various locations prior to proposed prescribed fires and following canopy-modifying hazard fuel reduction projects (Fig. 2). Sampling in 2002–2003 included two proposed prescribed fire areas: Chena Lakes F-Unit and the Manchu Firing Range. The F-Unit comprises 165 acres within the Chena Lakes Flood Control Project, located 15 miles east of Fairbanks, and is managed by the U.S. Army Corps of Engineers. The site is characterized by black spruce muskeg interspersed with wet meadows, aspen, and birch. The forest fuel types are classified under CFFDRS as fuel type C-2 (lowland black spruce) with patches of fuel type O-1a (open

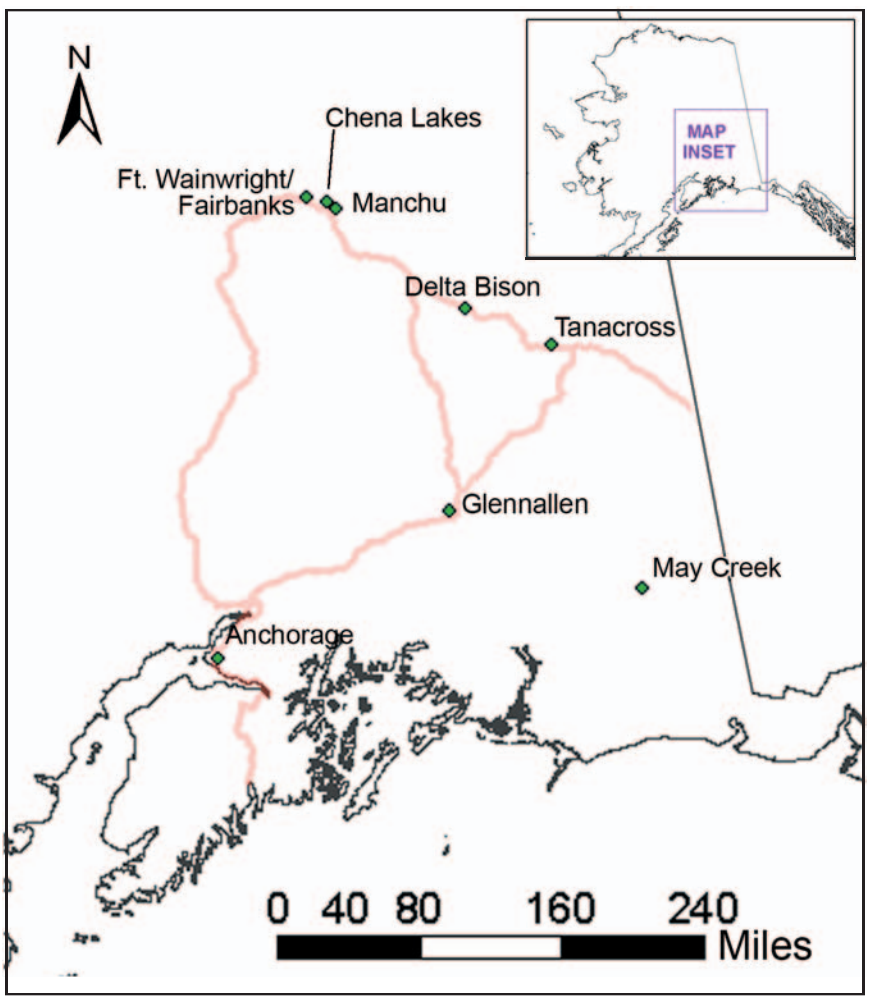


Figure 2. Location of duff moisture sampling sites, 2002–2003.

tussocks and sphagnum). The Manchu Firing Range on Eielson Air Force base is also a black spruce muskeg site on land managed by the U.S. Army-Alaska.

Additional samples came from canopy-modified fuels treatment units in various locations around the state including Tanacross village (Fig. 1), Shannon Park Subdivision (Ft. Wainwright), and the Joint Fire Science Fuels Demonstration sites at Ft.Wainwright and the Delta Bison Range. These areas had canopy thinning and/or pruning treatments applied 1–3 years prior to sampling. To extend the geographic area of sampling, we took samples in 2003 at May Creek, a National Park Service (NPS) station near Glennallen, and the Campbell Tract Bureau of Land Management (BLM) office site near Anchorage (Fig. 2). Sample information was recorded on standard field forms used by the Alaska interagency fire effects group (Appendix A).

Duff Sampling

Methodologies for duff sample collection generally followed those of Wilmore (2000, 2001). Standardized squares of duff were cut, separated to component layers, and returned to the office to determine the moisture content of the forest duff fuel layers. Duff plugs (approximately 4” square on top) were cut with a 12” compass saw from the live moss down to mineral soil or ice (see cover photo). Between two and six duff core samples, consisting of four layers each, were taken each sampling day. Sample sites were randomly selected by wander method, although they were limited to areas described as upland or lowland spruce sites with feather moss (*Hylocomium splendens* or *Pleurozium schreberi*).

Extracted plugs were subdivided into fuel layer types as follows: live moss, dead moss, upper duff, and lower duff. Live moss is defined as the green, actively photosynthesizing top of stalks, while “dead” moss is defined as brown parts of the stalks with intact leaves, still mostly oriented vertically (Wilmore 2000). Upper duff is randomly oriented, compacted moss and organic material that is just beginning to decompose, while lower duff is a (usually) thin, dark humic layer of mostly decomposed material and some soil particles. Materials were placed in airtight, autoclavable Nalgene® bottles. Total core depth, the thickness of each layer, and fuel layer types were recorded for each sample on the data collection sheet (Appendix A). Volumetric (size of sample carefully measured and standardized) methods as described by Wilmore (2001) were used for some samples, time permitting, to be able to calculate the bulk density of the material. In general, we rely upon gravimetric moisture contents (using before-and-after-drying weight of sample, only) for routine fuel moisture monitoring. Samples were returned to the lab, weighed wet, and placed in a drying oven. Samples were dried at 100°C for 24 hours or until a constant weight was attained. When lower temperatures are used, such as 70°C, it can take up to 72 hours for samples to dry, especially if packed too tightly in small bottles.

Conductivity Sensors for Measurement of Duff Moisture

In 2003, a cooperative BLM, NPS, and U.S. Fish and Wildlife Service (FWS) duff moisture monitoring project was launched with the assistance of the U.S. Forest Service (USFS) Pacific Wildland Fire Sciences Laboratory. Weather stations with time-domain reflectometer (TDR) probes were deployed to assess fuel moisture in the dead moss and upper duff in real time. Similar monitoring equipment was used on the Interior Alaska Frostfire experimental burn in 1999–2000 (Ferguson, et al. 2003). Study sites were located at the BLM Campbell Tract field office site in Anchorage (see photos online at: http://www.fs.fed.us/pnw/airfire/fm/) and the NPS May Creek field station east of Glenallen in the Wrangell-St.Elias National Park. Periodic destructive sampling provided data for calibration of moisture probes and for comparison with FWI. The indices used in this report were generated by the nearest standard RAWS station (Table 4) because some technical difficulties were encountered with generating FWI for the on-site weather stations.

In 2004 we evaluated a handheld conductivity device to measure duff moisture (Campbell Scientific DMM600) as a means of fuel moisture rapid assessment. Twelve paired samples were taken in each of three forest floor layers (live moss, dead moss, and upper duff) using the duff moisture meter in the field, in combination with oven-drying and weighing an adjacent forest floor sample. The method was relatively quick, although care is required in finely chopping the sample to assure a homogenous contact surface for the electrodes. Voltage readouts were calibrated to gravimetric fuel moistures using equations provided by the USFS Rocky Mountain Research lab (Appendix C).

Analysis

Gravimetric moisture contents of live moss, dead moss, upper duff, and lower duff were calculated for each sample using the following equation:

Moisture content (%) = [(wet weight - dry weight)/(dry weight - bottle weight)] x 100

Because the same container was used for the wet weights and dry weights, the tare weight (empty bottle weight) is only subtracted from the denominator. Comparisons between treatment and control site duff moistures were conducted using t-test for paired (dependent) samples.

Temporary or permanent weather stations provided the data to calculate FWI moisture codes. Several equations have been developed to equate duff moisture contents to DMC and DC for varying forest and forest floor conditions (Lawson and Dalrymple 1996). The Canadian system generally uses the depth of the sample material (0–2 cm for FFMC, 5–10 cm for DMC, 10–20 cm for DC) to define the layer that relates to the indices. However, there are major regional and local differences in moss thickness (also influenced by the age of the stand). Also, the varying densities of the different material types strongly influence drying rate. Therefore it seems preferable to define DC "layer" by a material type rather than a depth in the duff profile. Wilmore's (2001) research in black spruce/feather moss types specifically compared methodologies of sampling according to depth (Canadian methodology) versus fuel types, and found that the FWI correlated better with material type (live moss, dead moss, upper duff, lower duff) than depth alone. Thus, we compared live moss moisture to FFMC, used moisture content of the dead moss layer to calculate DMC, and used upper duff moisture content to calculate DC.

RESULTS

I. Measurements of Duff Moisture

Measured fuel moistures in 2002–2003 for all sites, in percent gravimetric moisture, are shown in Tables 1 and 2. Moisture contents varied considerably throughout the season in the different duff layers. High variability can be observed between same-day samples at a given site leading to a high standard deviation. Live moss moisture in 2003 on undisturbed sites ranged from a high of 350% (May 15 at Tanacross) following a precipitation event (Table 2), to a low of around 15% at Delta in mid-June, 2003 (Table 2). Live and dead moss became extremely dry after long sunny or rain-free periods, particularly on fuel treatment sites with an open canopy. The summer of 2003 was very dry in the eastern Interior, with only 1.7 inches of rainfall recorded from May 15 to August 15, compared to 7.2 inches during the same period in 2002. Ft.Wainwright had 6.4 inches during this period in 2002 and 4.9 inches in 2003. Ideally, live moss should be sampled at the same time during the day, as it responds to diurnal changes in relative humidity. Unfortunately, that was not always possible under field working conditions.

Dead moss layer moisture ranged from lows around 30% in June 2003 to 400%. The latter represents a supersaturated condition after half an inch of rain at Tanacross the preceding day (May 15, 2002) (Table 1). The lag time (time for the fuel to lose two-thirds of its free moisture content) for dead moss is expected to be 12 days (compared to 16 hours for FFMC and 52 days for the DC).

The moisture content of the upper duff tended to decrease during the summer, responding to long solar days and the loss of seasonal ground ice, until significant rainfall occurs. August is usually the rainy season in Interior Alaska, with an average of 2.4 inches of rainfall—30% of the annual rainfall. Early upper duff moisture observations in mid- to late-May were around 200–250% (Tables 1, 2). The notable exception occurred in southcentral Alaska (Campbell Tract) where upper duff was dry (60% moisture content) as early as June 2, but this region becomes snow-free about a month earlier than the northern Interior. In the drought summer of 2003, upper duff was thoroughly dried by July and remained below 75–100% moisture content (duff feels dry to touch and would sustain combustion) for all of July and August (Table 2). Precipitous drying of upper and lower duff was recorded at the Manchu Firing Range from June 27 to July 8, 2003 (Fig. 3) despite an increase in live moss moisture. This phenomenon, familiar to fuel specialists experienced with the area, occurs when seasonal ground ice thaws to a depth that allows rain and meltwater to drain effectively (M. Musitano, G. Theisen, pers. comm.).

Lower duff also dried progressively throughout the summer with a tendency to start to rebound by mid-August, although it did not recover to spring moisture content levels. Lower duff appears drier than upper duff, but actually the higher mineral content means it has less water weight and thus gravimetric moisture contents appear lower. Certainly lower duff in some areas, notably south-central Alaska (Campbell Tract) in July and September of 2003, was dry enough to sustain combustion. Severe drought in 2004 affected north-central and eastern Alaska so that drying was observed all the way into lower duff around Central (Appendix B) and Tok (Ottmar, unpubl. data). These duff conditions correlated with dramatic fire growth, deep burning, and extreme fire behavior.

Table 1. Summary of fuel moisture by fuel type—all sites, 2002.

Site	Date (2002)	Live Moss %MC	Dead Moss %MC	Upper Duff %MC	Lower Duff % MC	Sample size
Fire A283-SW	17-Jul	81.9	198.0	271.9	188.6	2
JFS-Ft.WW RX	17-Jun	20.5	94.3	98.8	152.9	2
JFS-Ft.WW RX	10-Jul	30.6	164.8	139.9	217.6	4
JFS-Ft.WW RX	30-Jul	160.6	177.3	139.0	195.7	4
JFS-Ft.WW RX	14-Aug	141.7	254.1	155.5	192.1	2
JFS-Ft.WW Control	17-Jun	14.8	96.1	304.2	366.6	2
JFS-Ft.WW Control	10-Jul	66.0	154.3	301.9	489.7	4
JFS-Ft.WW Control	30-Jul	275.7	150.3	123.8	271.6	4
JFS-Ft.WW Control	14-Aug	224.6	273.9	151.4	278.4	2
Manchu Range	2-Aug	137.5	220.0	206.0	228.1	4
Tanacross Control	16-May	354.2	424.4	210.6	211.3	3
Tanacross Control	22-May	47.0	137.4	183.9	115.7	3
Tanacross Control	29-May	14.9	55.2	96.3	88.4	3
Tanacross Control	7-Jun	346.7	349.1	248.7	138.0	3
Tanacross Control	12-Jun	236.3	341.7	272.6	130.2	3
Tanacross Control	19-Jun	67.3	253.2	157.0	70.2	3
Tanacross Control	26-Jun	181.2	360.9	215.4	86.5	3
Tanacross Control	3-Jul	54.9	240.9	198.0	90.0	3
Tanacross Control	15-Jul	169.2	318.1	246.7	104.8	3
Tanacross Control	26-Jul	167.2	264.9	166.7	56.3	3
Tanacross Control	31-Jul	260.5	379.5	196.9	69.8	3
Tanacross Control	8-Aug	260.1	267.3	130.8	60.7	3
Tanacross Control	15-Aug	234.6	331.7	181.2	104.0	3
Tanacross Control	27-Aug	440.7	480.7	227.0	100.2	3
Tanacross Control	5-Sept	237.5	345.0	238.6	89.9	3
Tanacross RX	16-May	159.9	276.1	206.7	204.2	3
Tanacross RX	22-May	14.5	64.6	149.1	93.5	3
Tanacross RX	29-May	12.0	20.5	101.2	100.9	3
Tanacross RX	7-Jun	67.9	183.9	203.5	105.8	3
Tanacross RX	12-Jun	127.7	243.5	246.5	133.7	3
Tanacross RX	19-Jun	21.0	47.6	116.7	59.1	3
Tanacross RX	26-Jun	85.4	263.5	195.0	75.9	3
Tanacross RX	3-Jul	19.7	67.2	149.7	98.1	3
Tanacross RX	15-Jul	14.8	84.7	161.7	107.6	3
Tanacross RX	26-Jul	59.0	99.1	160.1	98.6	3
Tanacross RX	31-Jul	55.6	208.1	172.3	94.3	3
Tanacross RX	8-Aug	113.0	160.4	186.0	109.6	3
Tanacross RX	15-Aug	50.9	203.7	191.5	123.0	3
Tanacross RX	27-Aug	80.7	230.0	226.2	123.4	3
Tanacross RX	5-Sept	44.4	174.3	228.9	153.0	3

Table 2. Summary of fuel moisture by fuel type—all sites, 2003.

Site	Date (2003)	Live Moss %MC	Dead Moss %MC	Upper Duff %MC	Lower Duff % MC	Sample Size
CL_F-Unit	9-Jun	94.0	209.1	199.7	277.3	7
CL_F-Unit	24-Jun	69.5	86.8	129.6	270.2	10
Delta control	17-Jun	11.6	32.0	61.0	114.8	2
JFS-Ft.WW RX	23-May	27.3	60.6	189.3	273.7	2
JFS-Ft.WW Control	23-May	92.9	185.2	289.0	(frozen)	2
Manchu Range	27-Jun	38.2	225.5	282.5	315.5	4
Manchu Range	8-Jul	172.0	165.6	86.6	106.5	5
May Creek	5-Jun	158.2	292.0	220.4	183.0	3
May Creek	6-Jun	257.0	338.1	306.6	210.5	6
May Creek	22-Jun	217.4	323.7	201.0	165.4	5
May Creek	12-Aug	265.9	240.0	100.0	120.4	6
Campbell Tract	2-Jun	31.5	32.2	55.9	93.4	5
Campbell Tract	26-Jun	74.8	48.2	83.2	65.6	5
Campbell Tract	7-Jul	31.1	87.8	54.6	60.8	5
Campbell Tract	11-Sep	302.9	276.2	65.2	45.4	5
Renee RAWS	21-Jul	30.8	60.7	135.2	200.5	3
SPAA32control	5-Jun	15.9	82.9	157.8	234.7	2
SPAA32-RX	5-Jun	40.8	199.2	214.1	232.2	2
Tanacross-Control	15-May	347.6	267.0	209.3	151.5	3
Tanacross-Control	21-May	61.2	195.4	167.1	177.0	3
Tanacross-Control	4-Jun	15.3	62.2	135.5	79.0	3
Tanacross-Control	12-Jun	21.7	97.0	91.0	62.0	3
Tanacross-Control	20-Jun	180.7	228.6	119.9	71.0	3
Tanacross-Control	1-Jul	47.9	142.4	98.7	65.6	3
Tanacross-Control	9-Jul	18.2	60.0	88.6	44.0	3
Tanacross-Control	24-Jul	26.0	83.5	73.3	45.2	3
Tanacross-Control	1-Aug	79.5	77.8	82.6	54.3	3
Tanacross-Control	7-Aug	74.8	123.3	86.6	50.4	3
Tanacross-Control	15-Aug	18.8	39.6	68.4	50.5	3
Tanacross-Control	29-Aug	34.7	116.4	107.8	63.6	3
Tanacross-RX	15-May	160.8	208.1	191.4	146.6	3
Tanacross-RX	21-May	47.7	184.2	226.5	169.5	3
Tanacross-RX	4-Jun	11.3	32.8	132.8	141.4	3
Tanacross-RX	12-Jun	16.4	31.8	121.1	114.7	3
Tanacross-RX	20-Jun	87.5	129.9	116.6	119.9	3
Tanacross-RX	1-Jul	14.4	60.2	115.9	109.8	3
Tanacross-RX	9-Jul	12.6	23.5	73.4	60.8	3
Tanacross-RX	24-Jul	14.4	52.2	59.3	46.4	3
Tanacross-RX	1-Aug	31.3	40.2	49.7	59.6	3
Tanacross-RX	7-Aug	25.8	66.5	75.0	71.7	3
Tanacross-RX	15-Aug	12.4	19.9	53.6	54.5	3
Tanacross-RX	29-Aug	30.7	122.4	128.3	49.4	3
Alphabet Hills	19-Jul	15.6	61.6	191.5	255.3	5

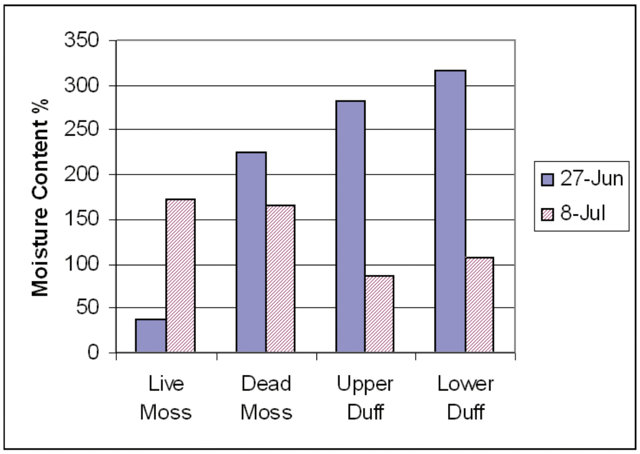


Figure 3. Change in moisture content of forest floor at Manchu Firing Range from June 27 to July 8, 2003.

II. Duff Moisture in Shaded Fuel Break Treatments

The U.S. Fish and Wildlife Service Tetlin Refuge staff recorded paired data at a canopy-modified stand and control stand at Tanacross on 15 dates from mid-May through August in 2002, and on 12 dates from mid-May to September in 2003 (Tables 1, 2). Most sampling was conducted by the same observer, increasing the value of this data set. At Ft. Wainwright shaded fuel break demonstration site, duff moisture data was collected four times during 2002 and once in 2003. A single observation was taken at an operational fuel break west of Ft. Wainwright (Shannon Park subdivision) in 2003. Data from both Tanacross and Ft. Wainwright sites clearly show a trend towards drier live and dead moss layers in the treated (thinned and pruned) stands throughout the fire season (Fig. 4). This was more pronounced in the summer of 2002 than in the drought summer of 2003. The observed differences in dead moss moisture of 150–200% in 2002 and 50–100% in 2003 were large enough to change fire danger ratings of the DMC index (Table 3). Only in early summer (June 5: Shannon Park) was higher moss moisture observed in a thinned area—possibly due to more advanced thaw in the open stand.

Moisture trends for duff are less clear, but the upper duff layer of thinned fuel breaks was consistently drier than the control in the warmest months, from mid-June to late July in 2002 and July–August in 2003 (Fig. 5, Table 3). Late in the summer the pattern was reversed, with the control upper duff appearing equal or slightly drier. In 2003 the treatment was not significantly drier than the control (as in 2002, Table 3) but the pattern remained the same—drier except during rainy periods, when opened canopies may allow better penetration and infiltration of rainfall at treatment sites. The drying rate of treatment stands may be slowed by reduced water uptake due to lower stand densities. Early summer observations in 2003 varied among three fuel treatments, with a drier treatment at Shannon Park on June 5, moister treatment at Ft. Wainwright JFS site on May 23, and no difference at Tanacross on June 4 (Fig. 4).

Lower duff was significantly wetter in 2003 in the Tanacross fuel break than in the control stand (Table 3) but was similar to the control in 2002 (although tending to become drier by September, Fig. 5). Conversely, the Ft. Wainwright fuel break was consistently drier in the lower duff layer (Fig. 5). This layer is strongly influenced by subsurface drainage, thawing seasonal frost or permafrost, and soil characteristics, making it hard to distinguish the effects due to thinning.

III. Comparison of Measured Duff Moistures and Fire Weather Indices

Weather Stations

Ideally weather stations would have been established at each site in early spring. However, this was not always

Table 3. Comparison of duff moisture in canopy-modified (RX) and control stands (C), 2002–2003. Pairs with significant difference ($p < 0.05$) are in bold.

	Moisture Content (%)									Effect on FWI (Average difference)	
	Live Moss		Dead Moss		Upper Duff		Lower Duff				
Year	RX	C	RX	C	RX	C	RX	C	N	Change DMC	Change DC
2002	**67**	**192**	**159**	**275**	**170**	**203**	128	154	19	+12	+48
2003	**88**	**126**	**88**	**126**	125	127	**118**	**89**	14	+8	+4
2-yr avg.	**76**	**164**	**129**	**212**	**151**	**171**	124	126	33	+10	+33

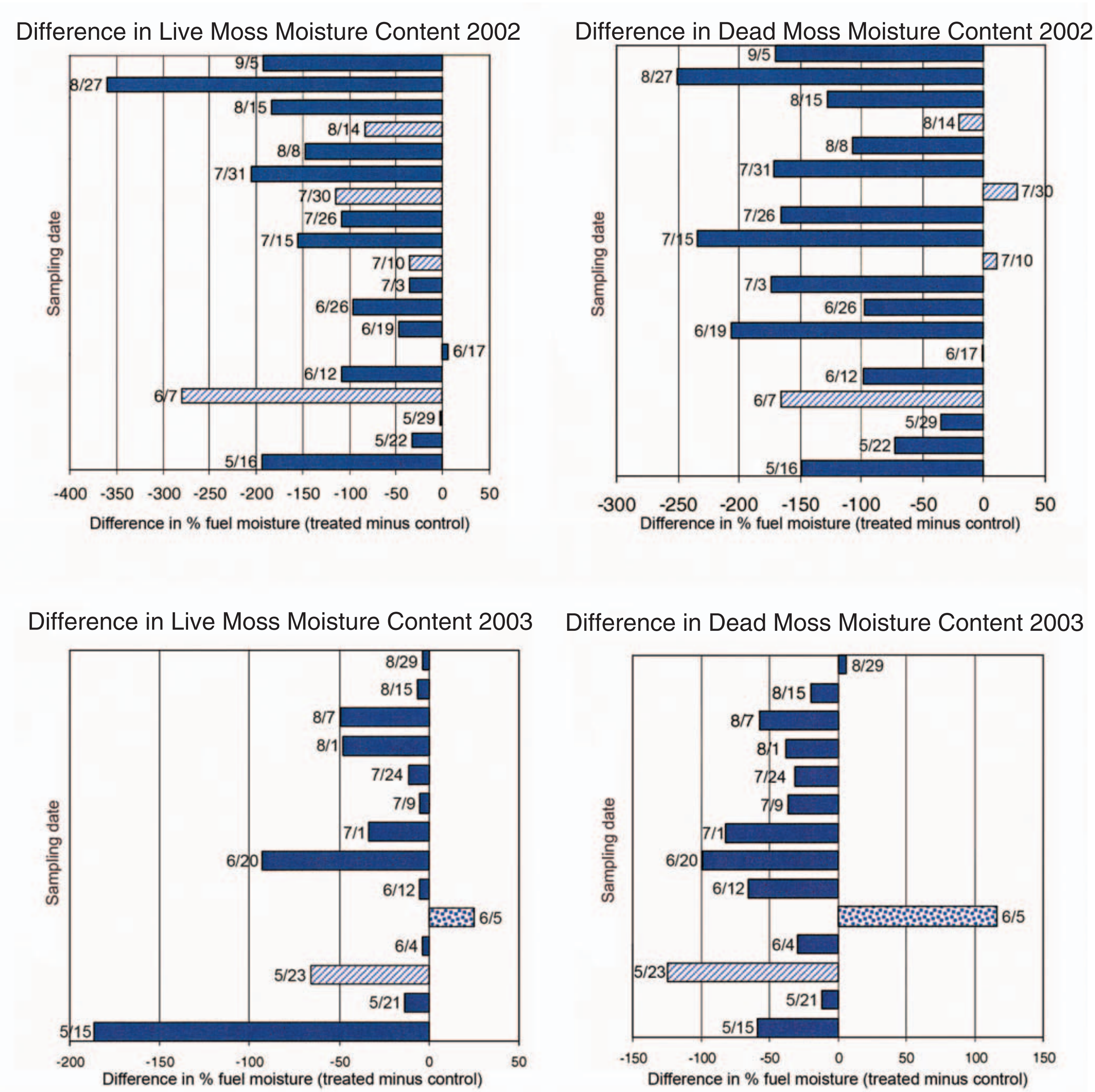


Figure 4. Difference between live and dead moss moisture in treated fuel break vs. control areas in 2002–2003 (treatment minus control). Tanacross has solid bars, Ft. Wainwright observations are hatched, and Shannon Park observations are stippled. A negative value means treatment drier than control. Data tables in Appendix B.

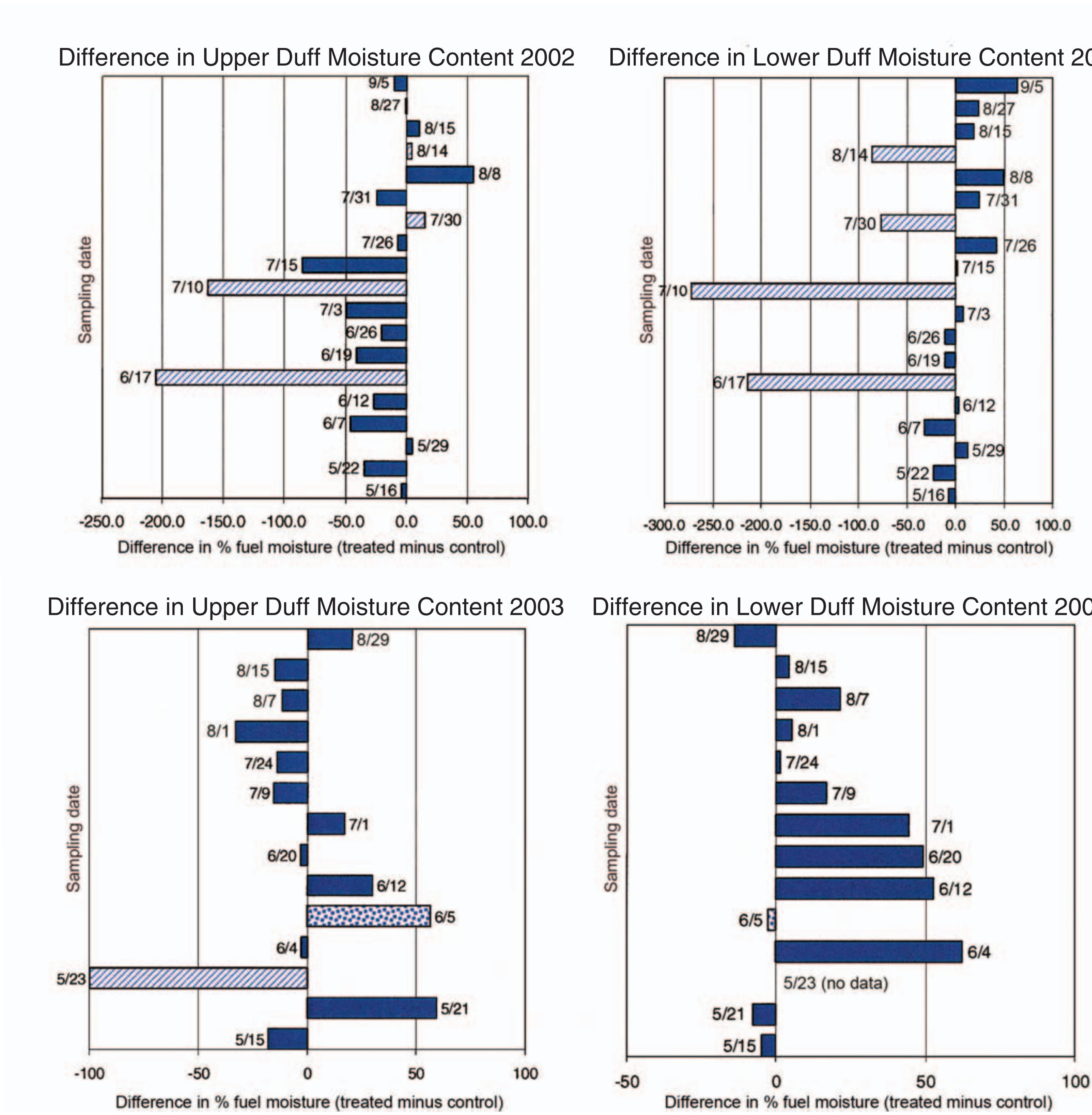


Figure 5. Difference between upper and lower duff moisture in treated fuel break vs. control areas in 2002–2003 (treatment minus control). Tanacross observations are solid, Ft. Wainwright observations are hatched, and Shannon Park observations are stippled. A negative value means treatment drier than control. Data tables in Appendix B.

possible. At times, technical problems after the stations were established resulted in loss of data. Although the Ft. Wainwright JFS site had on-site Hobo™ weather dataloggers, FWI values were calculated from the RAWS station about 2 miles away. In 2003, weather stations were installed on-site at Tanacross, while in 2002 we used the nearest RAWS station (TOK) for comparison (Table 4). Weather stations linked with probes to assess duff moisture were established at both the Campbell Tract and May Creek sites in 2003 by an interagency effort. Precipitation data was from these stations, but we used the nearest established RAWS station for calculated FWI. Most weather stations were started in the spring with default FWI values (FFMC 85, DMC 6, and DC 15). The Anchorage station (ANC) was started with a value of 50 for the DC based on low snow and over-wintered drought conditions in 2003.

Calculating FWI

Several different equations have been developed to convert duff moisture contents to DMC and DC for varying forest and forest floor types (Lawson and Dalrymple 1996, Lawson et al. 1997a). In 2000–2001, the Whitehorse white spruce/feather moss model worked best for the DMC (Appendix C), while the black spruce/feather moss model developed locally by Wilmore (2001) best fit the DC observations (Jandt and Allen, unpubl. data). The interagency fuels program group has recommended the use of the Whitehorse white spruce and undifferentiated duff model (Appendix C, Equation 5) for deriving a DC value from observed fuel moistures (T. Howard, pers. comm.). For comparison, both DC values are shown in the graphs. Only control stands were used in these validation graphs to avoid detecting a treatment effect rather than a true departure from predicted fuel moisture.

Table 4. Summary of remote weather stations used to compile FWI data.

Year	Site	Weather Station	Distance
2002	JFS-Ft. WW	FBK	>1 mile
"	Tanacross Control	TOK	>1 mile
2003	Shannon Park AA32	FBK	<1 mile
"	Campbell tract	ANC	>1mile
"	Manchu Range	FBK	>1 mile
"	JFS-Ft. WW	FBK	>1 mile
"	Tanacross Control	AP5	On site
"	May Creek	MYK	<1 mile

Results—Interior Alaska

Ft. Wainwright-area DMC's derived from duff samples are shown along with RAWS values and precipitation events in Figs. 6 and 7 (table of all values in Appendix B). Differences in observed and calculated values of DMC are notable for both 2002 and 2003. DMC does not appear to be a good predictor of dead moss moisture at Ft. Wainwright (Fig. 6), although both observed and RAWS-computed DMC were in the "low" fire danger category (<70). Some of the variation could be due to microsite differences and local ground moisture conditions, since this RAWS station was located about a mile from the sampling site. DC's derived with the Whitehorse equation—although ostensibly for white spruce— fit with RAWS-calculated drought code better (Fig. 7) than DC's derived using the black spruce/feather moss equation (Wilmore 2001). Although Wilmore's equation was developed using 1999 data from this site and this RAWS, it was a relatively wet summer, so she was unable to test her equation for drier conditions. The black spruce-feather moss equation gives DC values "off the chart" during critically dry periods (July 2003, Fig. 7). A DC >450 is generally considered "extreme" drought condition.

In contrast, dead moss showed dramatic drying at Tanacross in May 2002 during a rain-free interval with excellent correspondence to the RAWS DMC curve (Fig. 8). Although the initial drying curve was captured well by the prediction, RAWS DMC in mid-summer tended to predict drier conditions (DMC up to 73 on July 3) than those actually observed. Measured dead moss moistures remained high from June through August in 2002, ranging from 240–380% (DMC 25–35). The same trend was observed in 2003, a much warmer and drier season in Tanacross, where RAWS DMC's were >90 ("extreme") for most of the period from June 11 to August 21. In contrast, DMC's calculated from measured fuel moistures only exceeded 70 ("moderate") in early August, although they generally followed the same increasing or decreasing trend as the RAWS DMC. In both years, the argument could be made that small precipitation events (≤0.1 in) seem to have a cumulative effect on dead moss moisture, slowing the drying rate so that largest disparities are observed late in the summer. Recall that precipitation less than 1.5 mm (0.06 in) does not factor in the DMC prediction. It is also possible that using a depth stratum (5–10 cm) alone would have given different results, as the dead moss layer at Tanacross was somewhat superficial at about 3–8 cm deep.

In permafrost areas, it has been recommended that the starting value for DC generally be set at the default value (15) because ground ice holds fall moisture in addition to any melting snow moisture and recharges the duff layers (Wilmore 2001). However, two years of data from Tanacross demonstrate the value of using an actual measurement of upper duff moisture to set the initial value. In 2002, duff was already "moderately" dry (DC = 225 on May 16) when the RAWS station was deployed. By July, after a few rainfall events, predicted and observed moisture codes had achieved reasonable convergence. In contrast, in 2003, duff sampling was used to set the initial value of the DC for the RAWS at 246. Good agreement between RAWS DC and actual moisture conditions was observed until mid-summer in 2003, although the CFFDRS equations slightly overestimated drying rate, so that by July 23 measured upper duff moisture was 59% (DC 508) while the predicted value was 667, both still in the "extreme" fire danger range.

As at Ft. Wainwright, using the Whitehorse white spruce/duff equation (Eq. 5, Appendix C) to derive a DC from fuel moisture at Tanacross appeared to provide a more reasonable fit. Wilmore's equation (Eq. 4, Appendix C) gives "extreme" values of DC from May 21 on in 2003 (Fig. 9), with most values "off the chart." Fire behavior observations from the 2003 Black Hills fire indicated the duff layer was quite dry. In August, with the region still experiencing drought conditions, duff consumption was measured on this actively burning fire south of the Tanacross study site. Dead moss measured 100% moisture content (DMC equivalent 53) and upper duff 106% (DC equivalent 409), and the fire consumed 68% of the forest floor—a relatively deep burn—well into the upper duff layer (Ottmar 2003, unpublished data).

Results—Other Alaska Locations

Four sets of duff moisture sampling data are available from the Campbell Tract and May Creek experimental sites in 2003. Fuel moisture for all four layers at May Creek (Table 2) is presented in Fig. 10. Live moss and dead moss layers were wetter at May Creek than at Campbell Tract (Table 2). This may be partially attributed to characteristics of the primary feather moss species—stairstep moss (*Hylocomium splendens*) at Campbell Tract and red-stem feathermoss (*Pleurozium schreberi*) at May Creek.

After initial startup, RAWS-calculated DMC fit reasonably well with observed dead moss moisture using the limited May Creek data (Fig. 11, upper graph). The DC's derived with the Whitehorse equation again fit best with RAWS-calculated DC at May Creek (Fig. 11, lower graph). At Campbell Tract RAWS DMC and dead moss moisture were not well correlated (Fig. 12, upper graph). Dead moss moisture varied little throughout the season. The dead moss layer was generally thin and superficial, occurring at 3–7 cm. It is also possible that local site precipitation differed substantially from that of the ANC RAWS we used to compute indices. For the upper duff layer at Campbell Tract, only the Whitehorse equation DC is shown because all black spruce-feather moss (Wilmore) values were "off the chart" (Fig. 12). RAWS DC was not a good predictor of observed upper duff fuel moistures at Campbell Tract (Fig. 12, lower graph). Observed upper duff moistures were consistently drier than those predicted by the FWI index.

Performance of Automated Duff Moisture Devices

Data from in-situ duff moisture TDR probes will be analyzed in more detail in a future report; only 2003 results are presented here. TDR sensors have been used elsewhere for real-time tracking of duff moisture and seemed useful in monitoring relative moisture conditions over the course of a season. The TDR sensors measure bulk soil dielectric constant, which is an effective index of soil water content (Rorig et al. 2003). It has been difficult to calibrate the TDR output to absolute duff moisture content, however, because the sensors are very sensitive to changes in bulk density, which is highly variable in organic duff (Appendix D). Probes buried at 6 cm seemed to track well with the moisture content of duff samples at Campbell tract (Fig. 13). The upper duff layer did not offer much of a range in moisture values, making it hard to compare readings from upper duff probes with the small sample size (Fig. 13).

The Campbell Scientific, Inc. weather stations functioned throughout the winter, with solar packs maintaining batteries, and continued to log data through the 2004 season. Duff probe data revealed that the Campbell Tract site duff thawed on April 9, 2004. The average snow-free date for the representative area around Anchorage was April 13. Normally RAWS stations are initiated three days after the snow-free date, but the PANC RAWS site initiated April 25 (F. Cole, pers. comm.). If 2003 was similar, the delay in initiation of the drying equations could partially explain why our 2003 spring duff samples were substantially drier than the DMC/DC indicated (Fig. 12, lower graph).

Field fuel moistures determined with the handheld duff moisture meter (DMM600, Campbell Scientific,

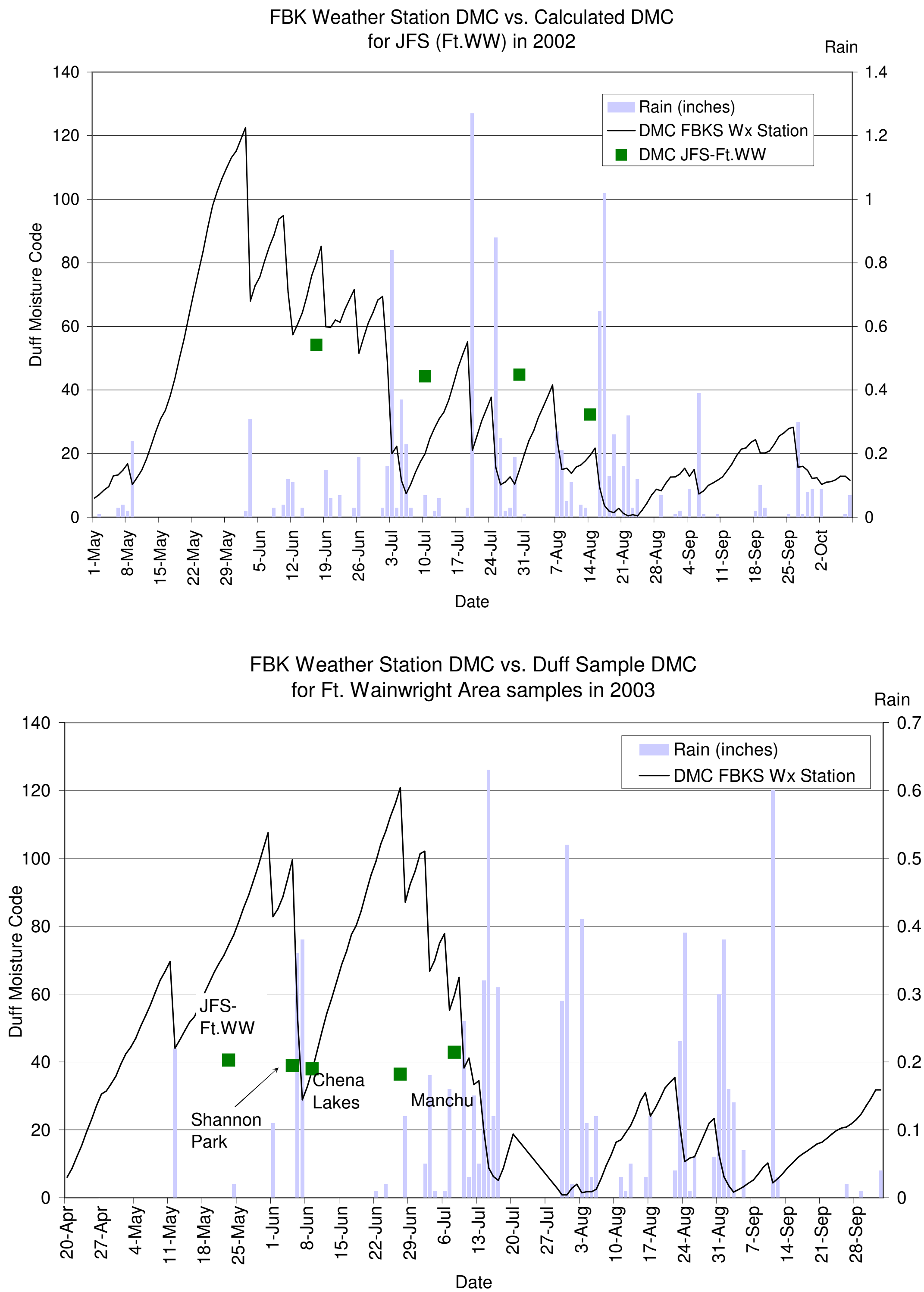
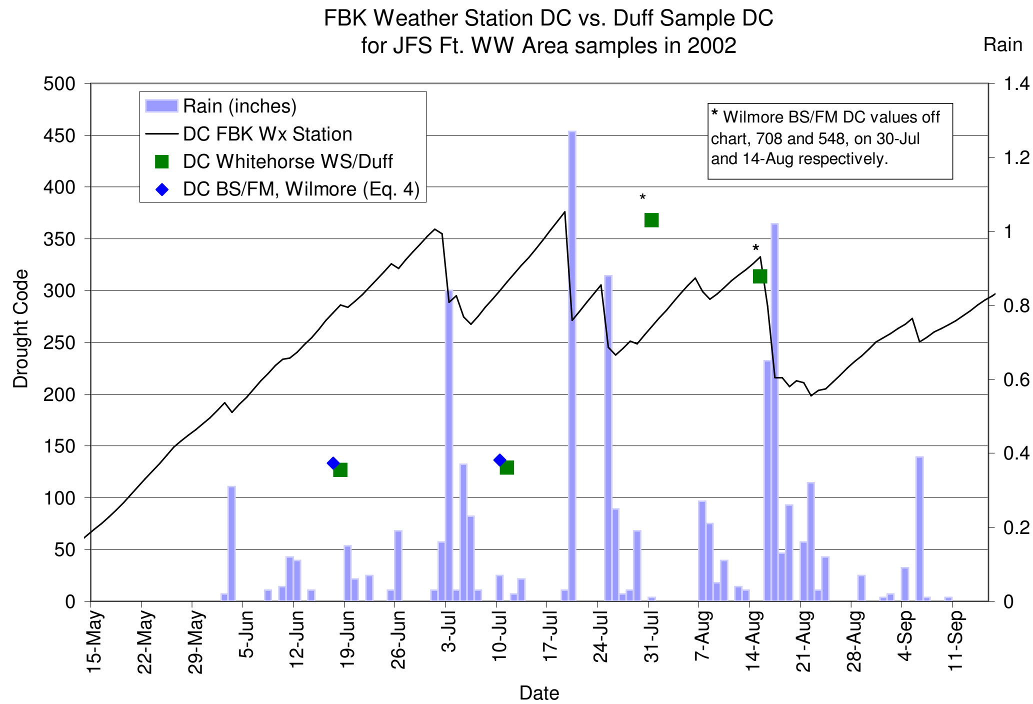


Figure 6. Comparison of Duff Moisture Code (DMC) generated from FBK remote weather station and DMC calculated from actual duff moisture data collected at Ft. Wainwright projects, 2002 and 2003.



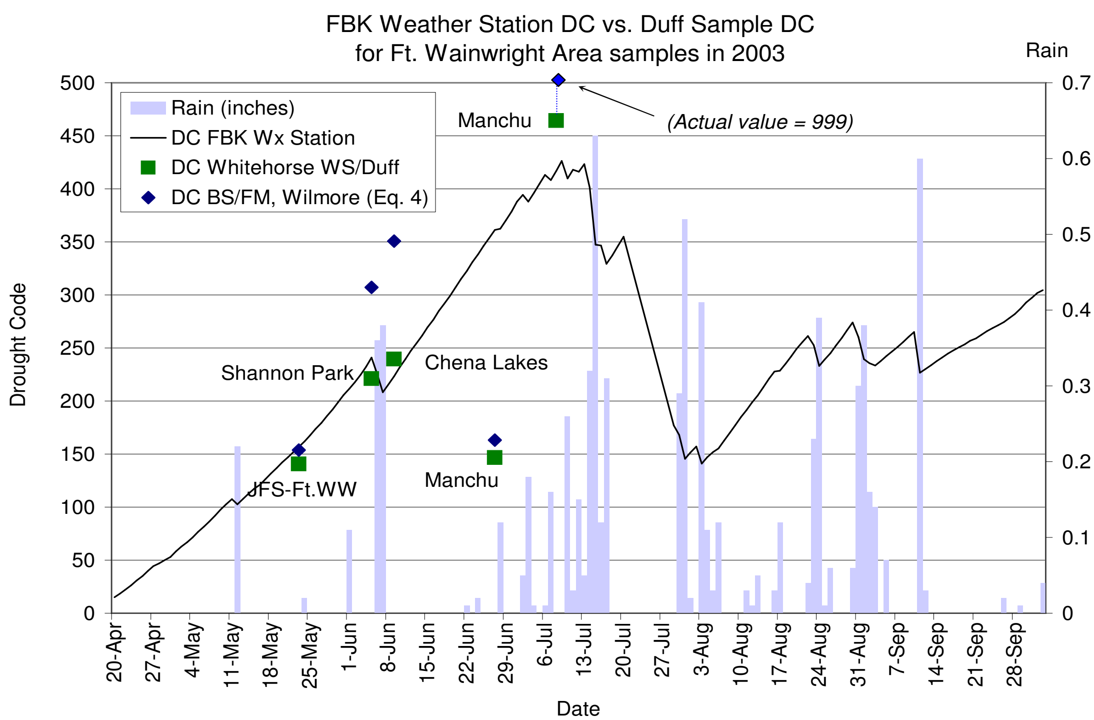
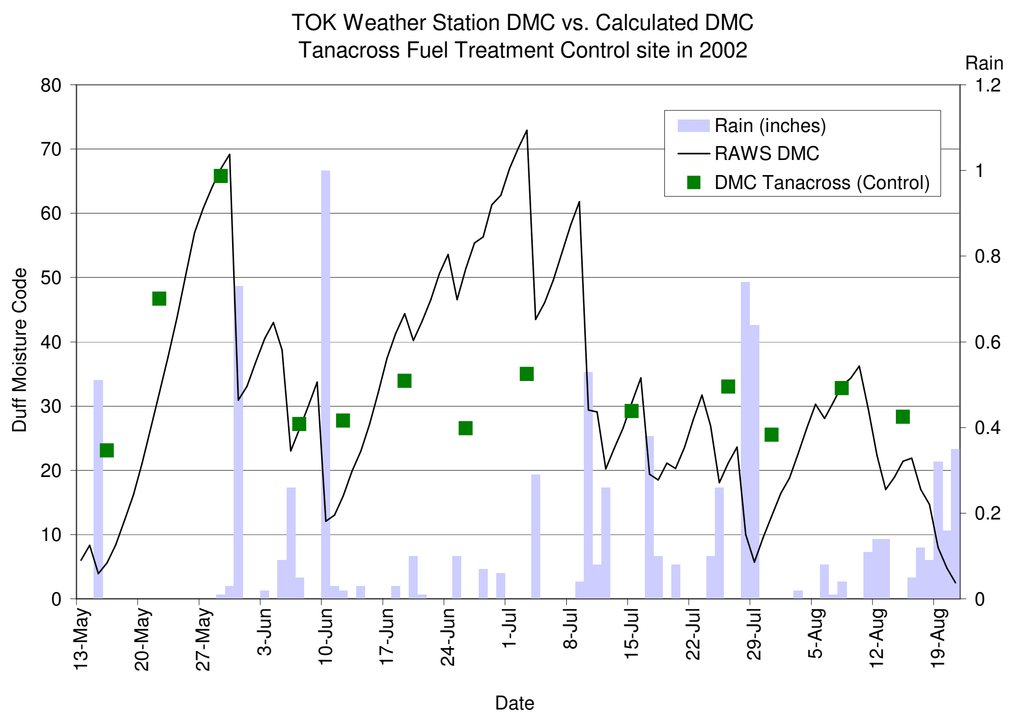


Figure 7. Comparison of Drought Code (DC) generated from FBK RAWS and DC calculated from actual duff moisture data collected at Ft. Wainwright projects, 2002 and 2003.



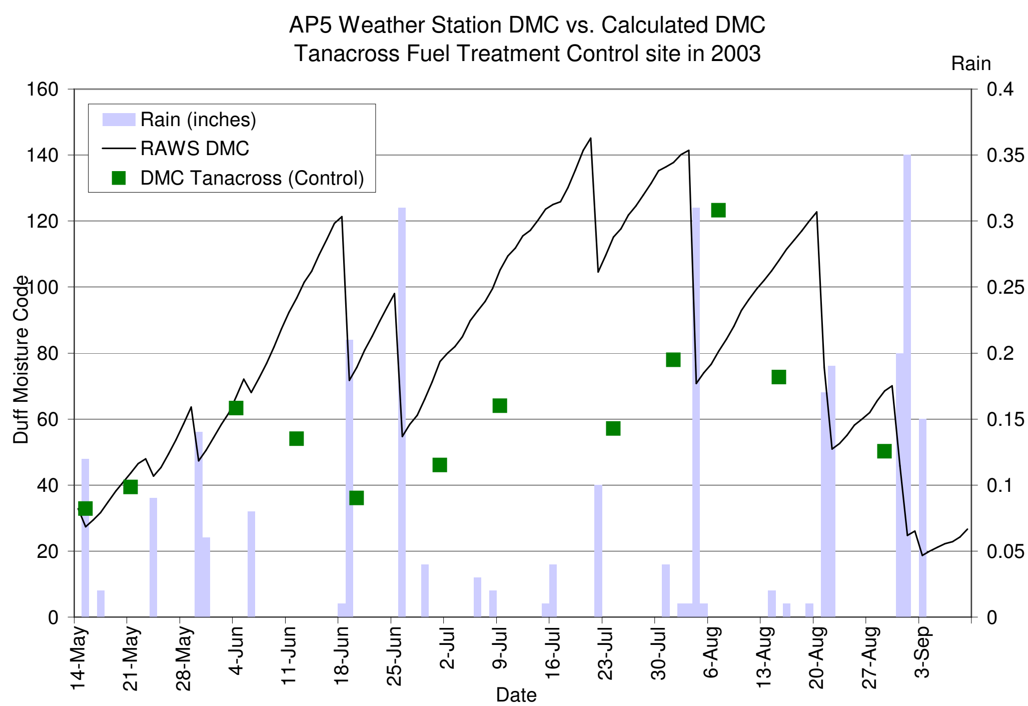
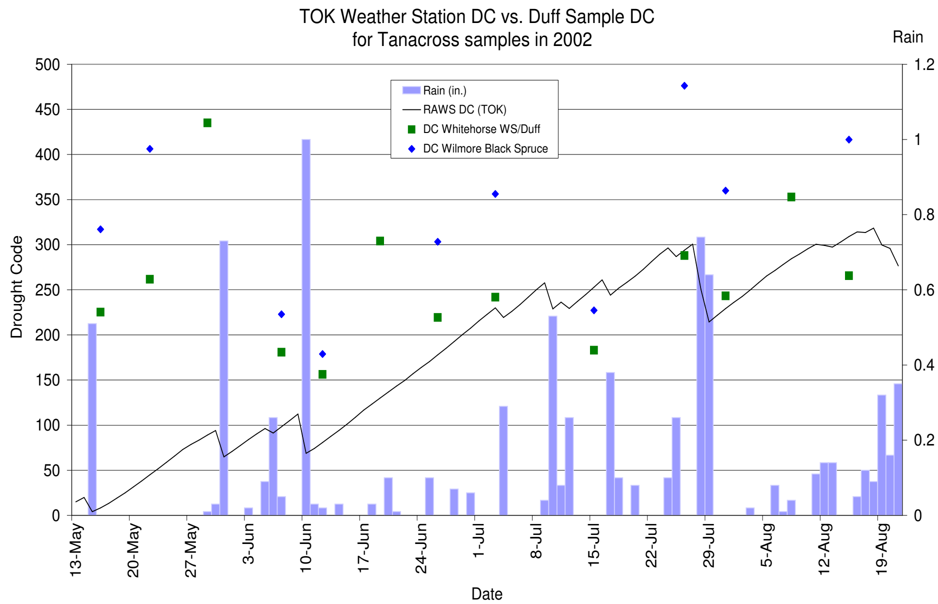


Figure 8. Comparison of Duff Moisture Code (DMC) generated from TOK remote weather station (2002) or on-site remote weather station AP5 (2003) and DMC calculated from actual duff moisture data collected at Tanacross control stand.



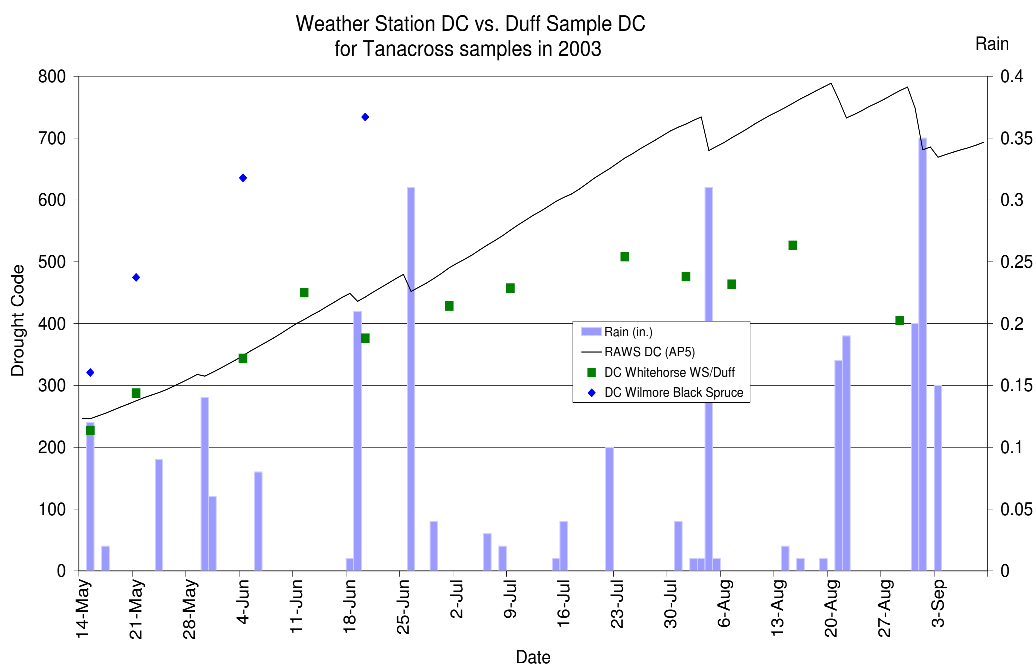


Figure 9. : Comparison of Drought Code (DC) generated from TOK remote weather station (2002) or on-site remote weather station AP5 (2003) and DC calculated from actual duff moisture data collected at Tanacross control stand.

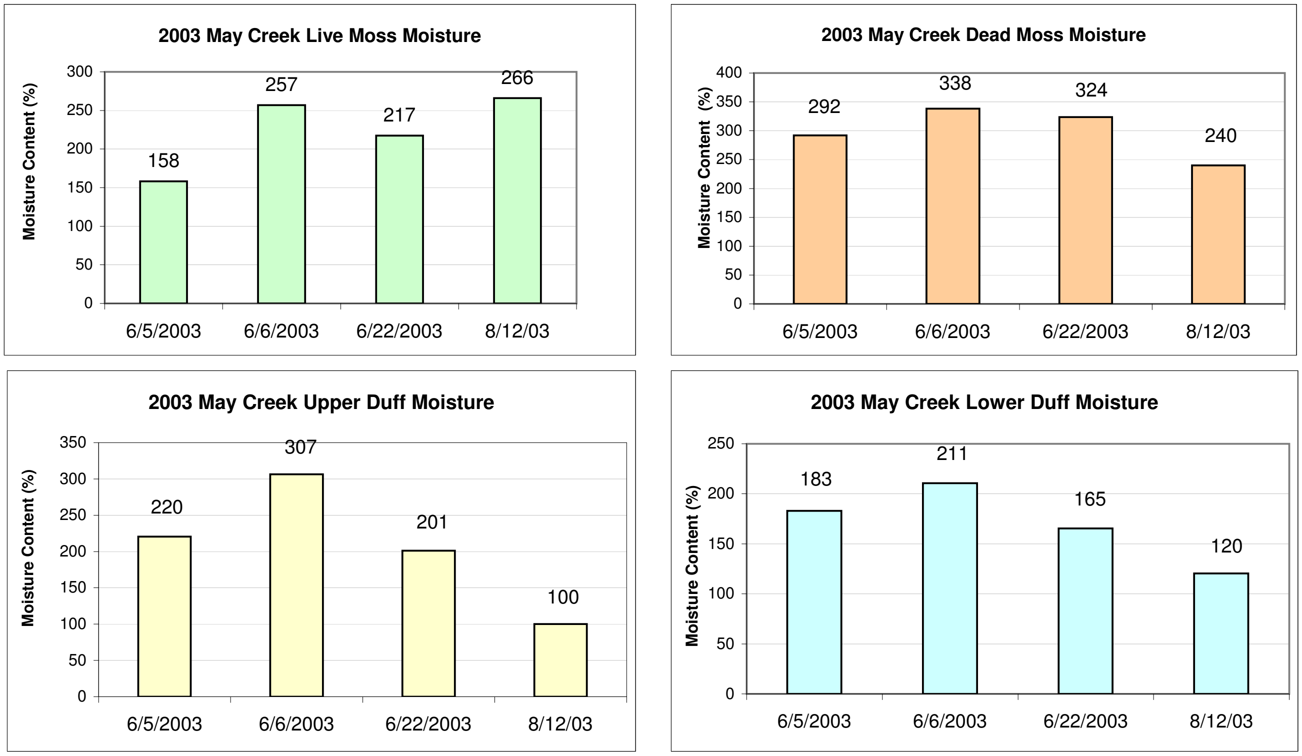


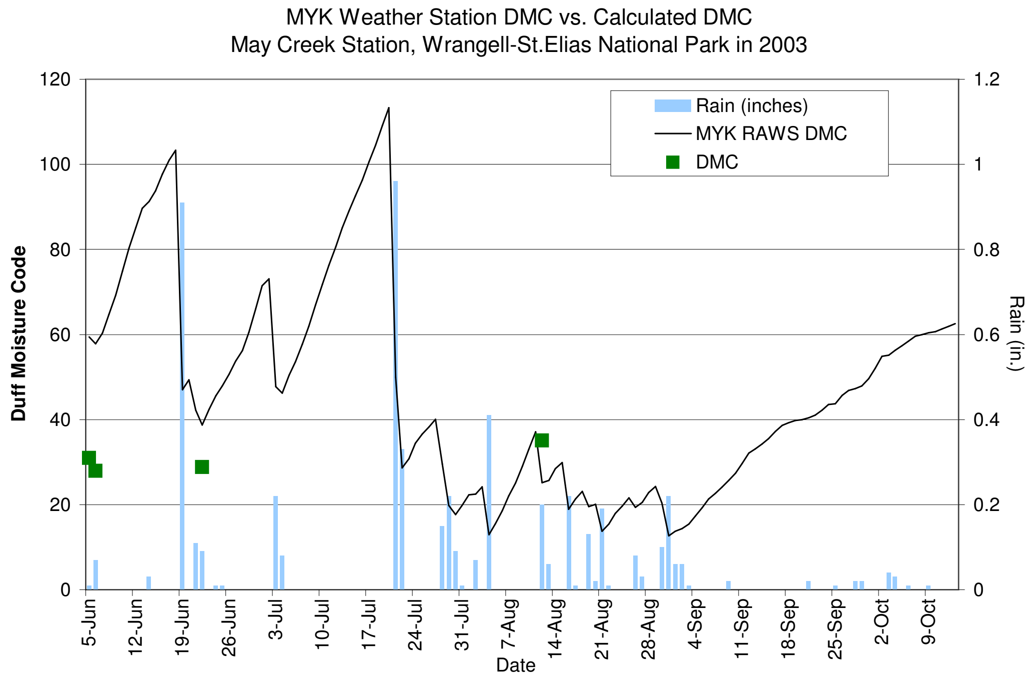
Figure 10. Fuel moistures for four layers of forest floor observed at May Creek Field Station, Wrangell-St.Elias National Park in 2003.

Inc.) were reasonably close to oven-dried fuel moistures (Figs. 14, 15). The tendency was to overestimate moisture content with the instrument; live moss, dead moss, and upper duff moisture contents were 7%, 10%, and 15% less, respectively, when determined by oven drying. Consistent error at a given location is probably related to the instrument calibration and could be subjected to a correction factor. Mineral content of the duff in the sampling location strongly influences the calibration to gravimetric moisture content (Frandsen 1987).

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Standardized collection methods for destructive sampling of moss and duff moisture have proven useful in allowing comparison of data gathered cooperatively among different investigators and agencies. Recent efforts to standardize the methods and cross-train members of the interagency fire community provided a larger set of data to analyze statewide. The standardization of collection methods allows comparison of samples from different areas and times, increasing the value of the data for validation of FWI Moisture Codes. A written, illustrated sampling manual has been completed (Wilmore 2000) and provided to interested cooperators. Fuel types (live moss, dead moss, upper duff, and lower duff) can be separated on appearance and feel, as well as statistically (Wilmore 2001), but it requires some practice and good communication among the samplers defining the layers to avoid introduction of "noise" into the data. Collection of three typical forest floor samples and foliar fuels can be accomplished in 1–2 hours by trained specialists. Still, the collection is relatively labor-intensive, and collection of a relatively small number of sample-days reported here required a team effort by BLM, USFWS, NPS, and USFS-Pacific Northwest Research Station (PNW). We were not able to achieve sample sizes as large as those used by Wilmore (28–30 sample days, averaging 9 samples/site/day).

Duff underlain by permafrost often begins the season in a saturated condition in the layers that represent the DC and DMC. Determining the duff moisture content at a given site is very helpful in determining whether a station should begin with indices at default (saturated) conditions or at some other level. Winter snowpack does not seem to be a reliable index of duff moisture in spring, likely due to differential run-off and evaporation in spring when the organic layers are still frozen.



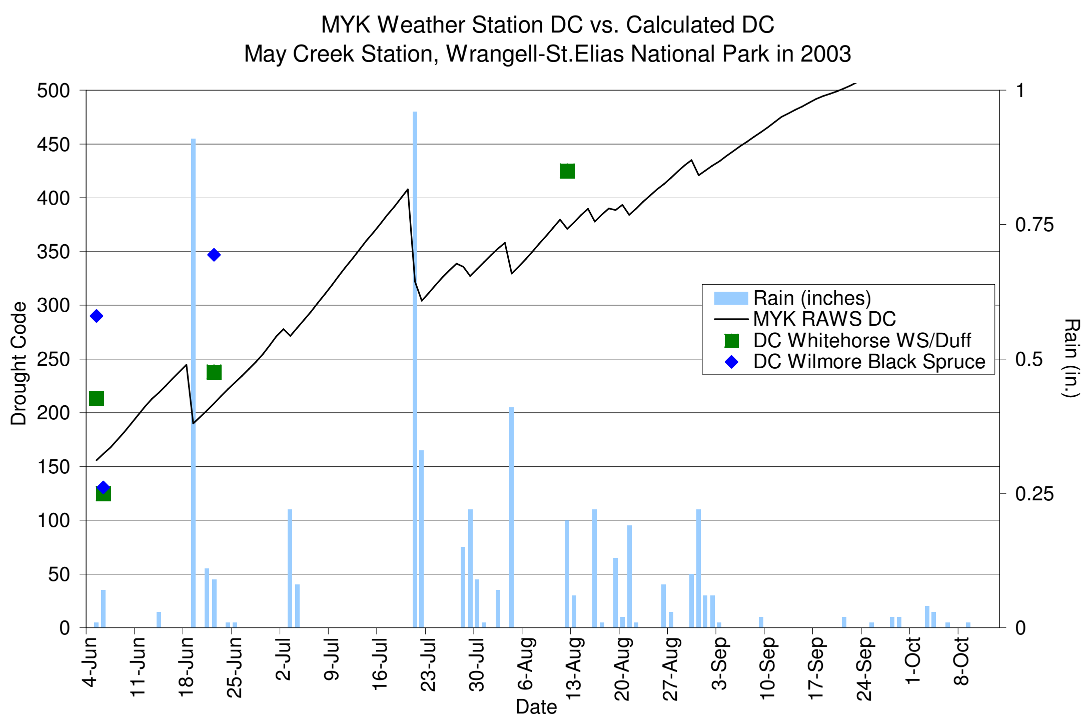
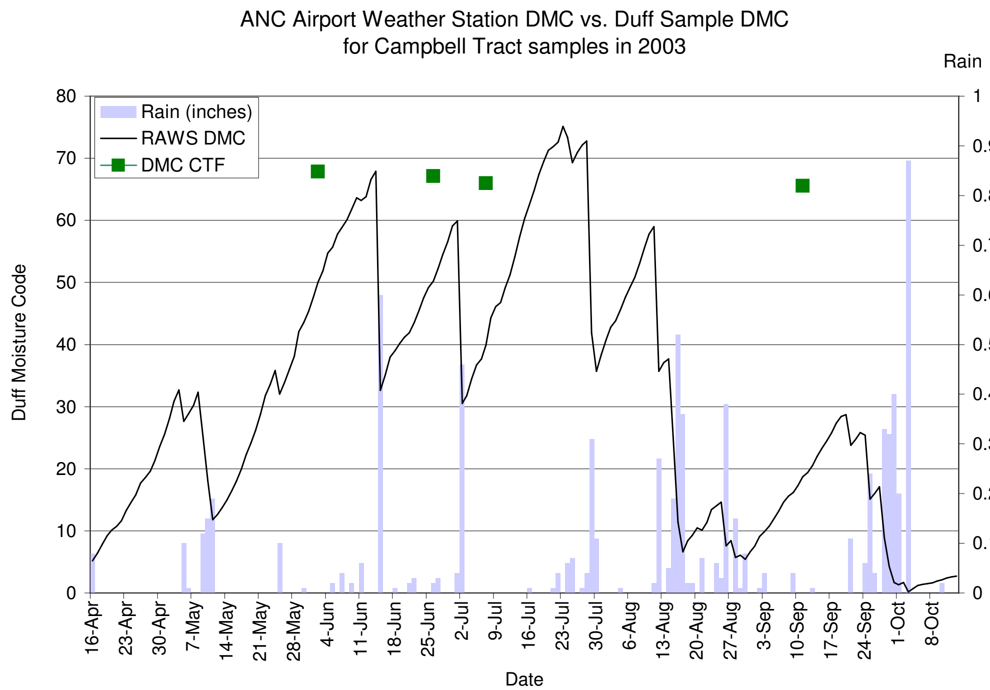


Figure 11. Comparison of DMC and DC generated from remote weather station MYK in 2003 and indices calculated from actual duff moisture data collected at May Creek NPS station.



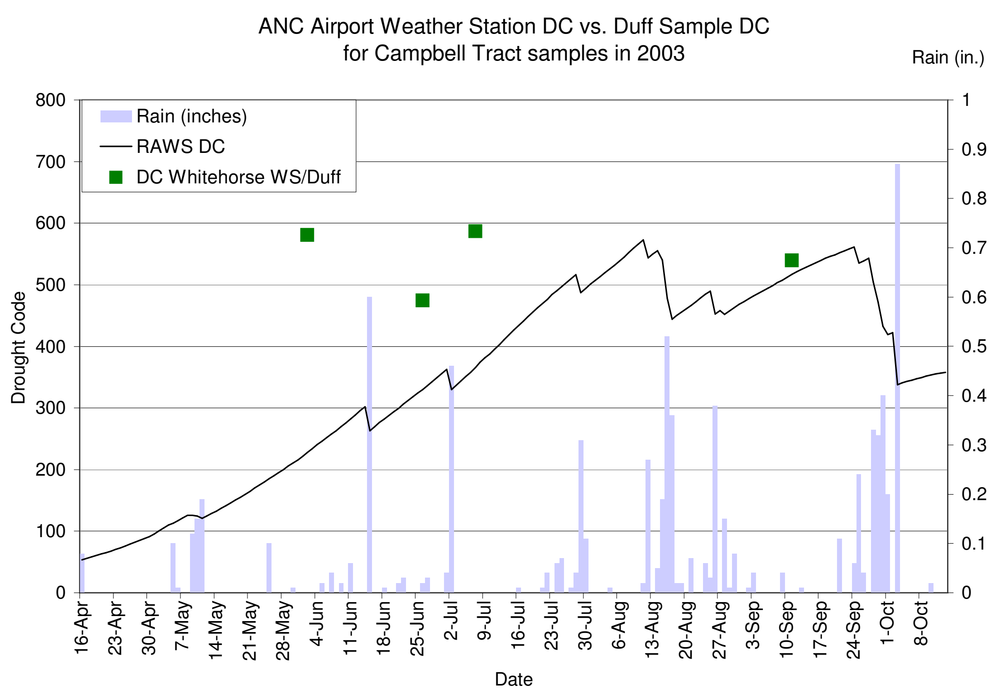


Figure 12. Comparison of DMC and DC generated from remote weather station PANC in 2003 and indices calculated from actual duff moisture data collected at Campbell Tract station.

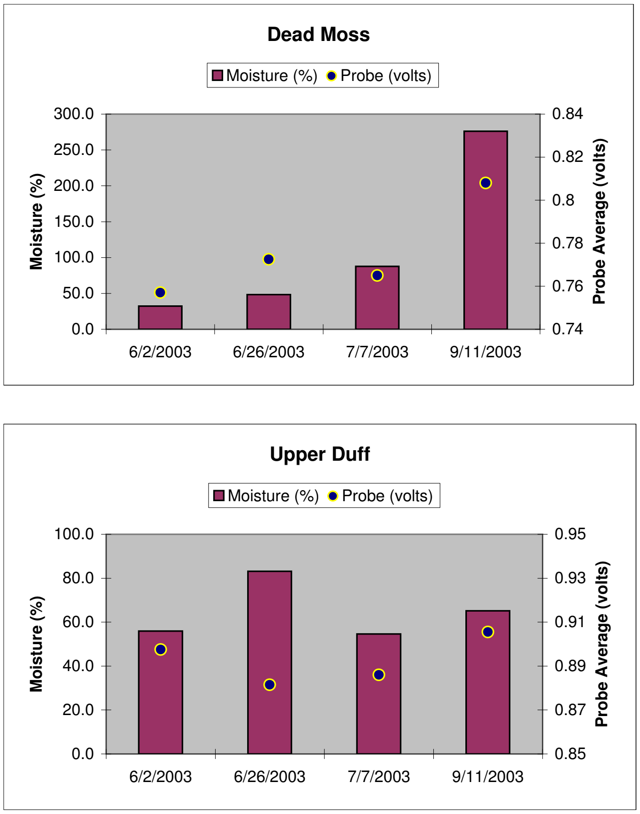


Figure 13. Comparison of moss and duff moisture content and TDR probe readings at Campbell Tract in 2003. Two probes were located at 6 cm to represent dead moss (upper graph), and two probes at 12 and 15 cm to represent upper duff (lower graph).

Dramatic drainage and drying of upper and lower duff layers in permafrost zones occurs at the point where the seasonal frost layer reaches into the mineral soil, allowing drainage. Often this change is not captured by the FWI indices. The Manchu Firing Range was a good illustration of this occurring around July 1 at a low-lying black spruce muskeg site (Fig. 3).

The effects of thinning and pruning treatments on forest floor moss and duff moisture require further study, as effects will certainly change as the treatments age. Opening the stands changed the local environment, and some effects were not anticipated. Paired data loggers for temperature, solar radiation, relative humidity, and wind speed were set up in the Joint Fire Science fuel demonstration treatment and control units from 2002–2004 and the Tanacross fuel break in 2002–2003. Patterns of microclimate change at all sites were similar in that relative humidity was higher in the thinned treatment areas and temperature was slightly lower during the afternoon, although warmer overnight (Jandt and Ott, unpublished data). Sensor arrays were reversed (treatment and control) in different years to ensure that differences were not a factor of the individual instrument. Wind speed was higher in all the thinned treatments by 0.5–2 mph, which meant modeled rates of spread doubled in thinned units on hot days (Theisen 2003) and fire intensity theoretically increased (even without considering the difference in duff moisture).

Shaded fuel break treatments are used to create defensible space around structures and villages. However, there appears to be a fire behavior trade-off in that recently opened stands generally had much drier moss layers. These are the fuel layers that determine the probability of ignition and rate of fire spread. On the other hand, reduction in bulk crown densities and ladder fuel removal dramatically reduced the treatment stand's potential for crown fire behavior, and thus for torching and spotting (Theisen 2003). Surface fires are more amenable to direct attack and defensive options (like setting up sprinklers). However, drier duff means more energy released by fire, tending to counteract this benefit. Drier fine fuels around homes and settlements definitely increase the risk from ignitions from within, such as trash burning, cigarettes, barbeque grills, and motorized equipment.

Comparison of measured duff moistures with the FWI's indicated general agreement, but also some consistent patterns of deviation. In the spring, feather moss duff is capable of drying at a rate faster than that predicted by the equations, so there may be a short, variable time period, generally early summer, when duff conditions are drier than predicted by the DMC and DC. This happened, for example, at Manchu in 2003 and Tanacross and Ft. Wainwright in 2002 (Figs. 7 and 9). More comparison work is needed in south-central Alaska, where Campbell Tract was uniformly drier in DMC and DC layers than the RAWS-predicted indices, which should be of interest to fire managers. Note that the Campbell tract area had the highest bulk density values for moss and duff (Appendix D), making gravimetric moisture content appear drier. The more common deviation from FWI, however, was for over-prediction of drying, particularly in the late summer when a clear divergence can be seen starting when rainfall starts to increase. This pattern was observed in Tanacross data in 2003 and was also re-ported by Wilmore (2001) at Ft. Wainwright. Thus, observations of "extreme" DMC and DC in late summer should be verified by field duff measurements before basing critical decisions on those values.

Earlier studies have recommended using material types to compute and compare FWI indices rather

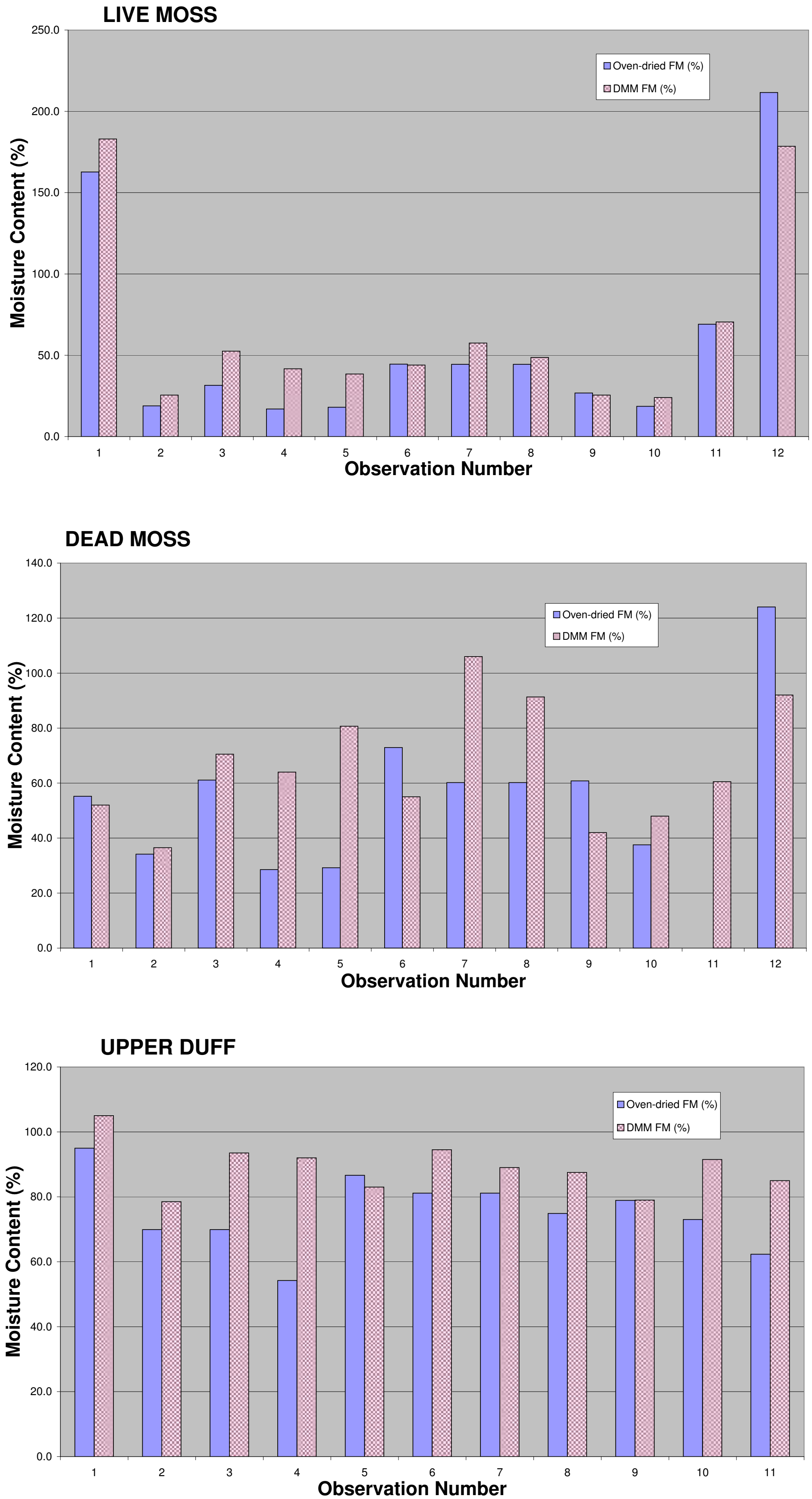


Figure 14. Fuel moistures determined by duff moisture meter vs. oven drying, 2004.

Figure 15. Technician J. Hrobak measures duff moisture with handheld DMM600 (Campbell Scientific, Inc.).

than depth strata alone (Wilmore 2001) due to the very different bulk densities and drying capacities of these layers (Appendix D). However, data from Tanacross and Anchorage suggests that when the dead moss layer is superficial, it can respond to precipitation events smaller than those used by the drying equations. When differentiating fuel layers proves difficult or layers have been disturbed (such as in thinned areas with disturbed moss), we recommend samplers revert to depth strata for collecting samples, ensuring the sample for dead moss layer is about 5–10 cm and the upper duff sample about 10–20 cm. In time, ongoing research may provide a table to relate duff moisture directly to ignition/consumption, providing a more direct means to predict site-specific fire behavior.

Comparisons of FWI indices and duff moisture are best accomplished with an on-site RAWS station. Even when the nearest RAWS was close, it proved difficult to tease out patterns of deviation from variance due to local weather and microsite conditions. The "Whitehorse" equation (Eq. 5, Appendix C) provided a better fit over a wider range of values to calculate a DC from observed upper duff moisture contents, even though Wilmore's black spruce/feather moss equation fits data better when samples are relatively moist.

In the future, conductivity-based moisture sensing instruments may prove to be a useful tool for validation of FWI trends and for rapid site assessment. In situ moisture probes on remote weather stations placed by the PNW AirFire group have proven to be durable and low maintenance. The probes appear to be providing useful moisture trend data to "truth" trends in RAWS-generated FWI, although calibration to specific moisture content is difficult. Ongoing research may provide new innovations and calibration equations to improve the ability to estimate actual moisture content. In addition, the buried probes record the actual thaw date of the relevant duff layers in the spring, so that managers know the exact date to start calculations of drying.

A handheld conductivity device to measure duff moisture (DMM600, Campbell Scientific, Inc.) proved a useful means of fuel moisture rapid assessment, particularly after local calibrations for gravimetric moisture content were developed (Appendix C). Mineral content in duff (especially wind and flood-deposited) affects bulk density (and therefore weight-based moisture content) as well as the ability to sustain combustion. The duff moisture meter tended to slightly overestimate fuel moisture compared to oven-drying in our small study ($N = 12$). However, these samples were taken in the Tok area using a Fairbanks bulk density calibration. Finely chopping the samples and selecting representative sites to sample are key to achieving consistent results.

In conclusion, our studies from 2002–2004 have yielded important information about forest floor moisture characteristics and means to assess it, but much remains to be learned about its effects on fire behavior. The Joint Fire Science Program is currently conducting research on effects of forest floor moisture on depth of duff consumption and smoke production on wildfires (Ottmar and Babbitt, pers. comm.). These studies as well as Hungerford's (1996) work and ongoing work by Jim Reardon at the USFS Rocky Mountain Research Station demonstrate that moisture and inorganic con-tent are both key factors that influence whether ignition occurs and thus how much duff is consumed. With up to 170 tons/acre of biomass in the forest floor, compared to about 20–40 tons/acre of above-ground biomass, the implications for smoke are clear. Also, fire events that produce deep, smoldering ground fires result in more substantial and enduring ecological changes.

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Appendix A. Sample data collection form for duff moisture.

Project name ____________________ Recorders: ____ Date: ____/____/____
Plot ID ____________ Fuel Type Sampling __________________ Phenology: _______________________ Time: _________
Location: _____________________ Lat: _________ Long: _________ Datum: _________
Avg slope (%): __________ Elevation: _____________ Aspect: __________

Sample #	Type	Fuel Codes	Sample Depth (cm)*	Thick-ness (cm)**	V/G*	Bottle #	Wet Wt	Dry Wt	Tare Wt		
1	Duff	lm	0-3cm	3	V	23	75.3	58.7	52.9		Example
1	Duff	dm	3-7cm	4	V	22	80.5	58.7	52.9		Example

Fuel Codes: lm=live moss (feather), dm = dead moss, ud = upper duff, ld = lower duff
pima = black spruce, pigl = white spruce, lepa = labrador tea, vavi = cranberry, spha = sphagnum

Appendix B. Data summaries, 2002–2004. Bold indicates DMC or DC values in the "high" or "extreme" fire danger range.

Site	Date 2002	Live Moss %MC	RAWS FFMC	Dead Moss %MC	RAWS DMC	Calc DMC from %GrvMC (EQ3)	Upper Duff %MC	RAWS DC	Calc DC from UD GrvMC% w/EQ4	Calc DC from UD GrvMC% w/EQ5	Lower Duff % MC
A283SW	17-Jul-02	81.9	**	198.0	**	39.1	271.9	**	179.9	156.9	188.6
JFS-1 10P	17-Jun-02	20.5	93.2	94.3	**80.2**	54.6	98.8	278.6	892.6	**428.2**	152.9
JFS-1 10P	10-Jul-02	30.6	84.9	164.8	20.0	42.9	139.9	299.7	610.3	335.0	217.6
JFS-1 10P	30-Jul-02	160.6	86.9	177.3	14.9	41.4	139.0	256.9	615.3	336.7	195.7
JFS-1 10P	14-Aug-02	141.7	84.0	254.1	19.5	33.9	155.5	326.0	528.1	306.6	192.1
JFS-1 Control	17-Jun-02	14.8	93.2	96.1	**80.2**	54.2	304.2	278.6	133.4	126.8	366.6
JFS-1 Control	10-Jul-02	66.0	84.9	154.3	20.0	44.3	301.9	299.7	136.3	128.8	489.7
JFS-1 Control	30-Jul-02	275.7	86.9	150.3	14.9	44.8	123.8	256.9	708.0	**367.7**	271.6
JFS-1 Control	14-Aug-02	224.6	84.0	273.9	19.5	32.3	151.4	326.0	548.4	313.7	278.4
Manchu	2-Aug-02	137.5	91.7	220.0	27.2	36.9	206.0	280.9	331.0	231.3	228.1
Tanacross C	16-May-02	354.2	52.0	424.4	5.6	23.1	210.6	8.3	317.1	225.3	211.3
Tanacross C	22-May-02	47.0	94.8	137.4	32.1	46.7	183.9	45.0	406.2	261.7	115.7
Tanacross C	29-May-02	14.9	92.4	55.2	67.0	65.8	96.3	89.0	913.4	**435.0**	88.4
Tanacross C	7-Jun-02	346.7	65.5	349.1	26.4	27.2	248.7	98.3	222.9	180.8	138.0
Tanacross C	12-Jun-02	236.3	72.3	341.7	16.0	27.7	272.6	80.7	178.8	156.2	130.2
Tanacross C	19-Jun-02	67.3	90.4	253.2	44.4	33.9	157.0	130.1	520.7	304.0	70.2
Tanacross C	26-Jun-02	181.2	88.6	360.9	51.4	26.5	215.4	177.9	303.3	219.3	86.5
Tanacross C	3-Jul-02	54.9	90.4	240.9	72.9	35.0	198.0	230.0	356.3	241.8	90.0
Tanacross C	15-Jul-02	169.2	90.3	318.1	30.5	29.2	246.7	252.9	227.2	183.0	104.8
Tanacross C	26-Jul-02	167.2	82.1	264.9	21.2	33.0	166.7	293.9	476.2	288.0	56.3
Tanacross C	31-Jul-02	260.5	85.3	379.5	12.9	25.5	196.9	229.2	359.9	243.3	69.8
Tanacross C	8-Aug-02	260.1	85.5	267.3	33.2	32.8	130.8	284.4	663.7	**352.9**	60.7
Tanacross C	15-Aug-02	234.6	83.1	331.7	21.4	28.3	181.2	309.1	416.5	265.7	104.0
Tanacross RX	16-May-02	159.9	52.0	276.1	5.6	32.1	206.7	8.3	328.9	230.4	204.2
Tanacross RX	22-May-02	14.5	94.8	64.6	32.1	62.5	149.1	45.0	560.2	317.8	93.5
Tanacross RX	29-May-02	12.0	92.4	20.5	67.0	**86.5**	101.2	89.0	872.6	**421.6**	100.9
Tanacross RX	7-Jun-02	67.9	65.5	183.9	26.4	40.6	203.5	98.3	338.6	234.5	105.8

Appendix B (continued). Data summaries, 2002–2004.

Site	Date 2002	Live Moss %MC	RAWS FFMC	Dead Moss %MC	RAWS DMC	Calc DMC from %GrvMC (EQ3)	Upper Duff %MC	RAWS DC	Calc DC from UD GrvMC% w/EQ4	Calc DC from UD GrvMC% w/EQ5	Lower Duff % MC
Tanacross RX	12-Jun-02	127.7	72.3	243.5	16.0	34.8	246.5	80.7	227.5	183.2	133.7
Tanacross RX	19-Jun-02	21.0	90.4	47.6	44.4	68.9	116.7	130.1	756.1	**383.5**	59.1
Tanacross RX	26-Jun-02	85.4	88.6	263.5	51.4	33.1	195.0	177.9	366.6	246.0	75.9
Tanacross RX	3-Jul-02	19.7	90.4	67.2	72.9	61.7	149.7	230.0	557.5	316.9	98.1
Tanacross RX	15-Jul-02	14.8	90.3	84.7	30.5	56.8	161.7	252.9	498.9	296.2	107.6
Tanacross RX	26-Jul-02	59.0	82.1	99.1	21.2	53.5	160.1	293.9	506.1	298.8	98.6
Tanacross RX	31-Jul-02	55.6	85.3	208.1	12.9	38.0	172.3	229.2	452.3	279.2	94.3
Tanacross RX	8-Aug-02	113.0	85.5	160.4	33.2	43.5	186.0	284.4	398.4	258.7	109.6
Tanacross RX	15-Aug-02	50.9	83.1	203.7	21.4	38.5	191.5	309.1	378.6	250.9	123.0
Alphabet Hills	19-Jul-03	15.6	92.6	61.6	54.0	63.5	191.5	215.3	378.6	250.8	255.3
Black Hills	7-Aug-03	69	**	100.0	**	53.4	106.0	**	834.9	**409.3**	199.0
CL_F-Unit	9-Jun-03	94.0	88.4	209.1	37.6	37.9	199.7	223.2	350.8	239.5	277.3
CL_F-Unit	24-Jun-03	69.5	91.2	86.8	**108.0**	56.3	129.6	338.5	670.9	**355.4**	270.2
Delta control	17-Jun-03	11.6	91.8	32.0	**97.9**	77.2	61.0	339.7	1266.3	**557.4**	114.8
JFS-1 10P	23-May-03	27.3	91.3	60.6	74.5	63.8	189.3	156.8	386.3	253.9	273.7
JFS-1 control	23-May-03	92.9	91.3	185.2	74.5	40.5	289.0	156.8	153.6	140.6	**
Manchu	27-Jun-03	38.2	92.0	225.5	**120.8**	36.4	282.5	**361.2**	163.1	146.7	315.5
Manchu	8-Jul-03	172.0	84.7	165.6	59.7	42.8	86.6	**417.1**	999.0	**463.4**	106.5
May Creek	5-Jun-03	158.2	90.9	292.0	59.4	31.0	220.4	155.7	289.8	213.2	183.0
May Creek	6-Jun-03	257.0	80.4	338.1	57.8	27.9	306.6	161.7	130.6	124.8	210.5
May Creek	22-Jun-03	217.4	66.5	323.7	38.7	28.8	201.0	208.6	346.7	237.9	165.4
May Creek	12-Aug-03	265.9	60	240.0	25.2	35.1	100.0	**371.1**	882.8	**425.0**	120.4
PNW-1(CTF)	2-Jun-03	31.5	87.6	32.2	50.0	77.0	55.9	228	1327.1	**580.7**	93.4
PNW-2 (CTF)	26-Jun-03	74.8	84.3	48.2	50.2	68.6	83.2	329.8	1030.9	**474.2**	65.6
PNW-3 (CTF)	7-Jul-03	31.1	85.8	87.8	39.9	56.1	54.6	**365.4**	1343.2	**587.0**	60.8
PNW-4 (CTF)	11-Sep-03	302.9	84.7	276.2	18.7	32.1	65.2	**516.7**	1217.8	**539.5**	45.4
Renee RAWS	21-Jul-03	30.8	89.5	60.7	61.3	63.8	135.2	231.6	637.2	344.1	200.5
SPAA32control	5-Jun-03	15.9	94.0	82.9	**99.6**	57.3	157.8	240.9	517.0	302.7	234.7

Appendix B (continued). Data summaries, 2002–2004.

Site	Date 2002	Live Moss %MC	RAWS FFMC	Dead Moss %MC	RAWS DMC	Calc DMC from %GrvMC (EQ3)	Upper Duff %MC	RAWS DC	Calc DC from UD GrvMC% w/EQ4	Calc DC from UD GrvMC% w/EQ5	Lower Duff % MC
SPAA32-RX	5-Jun-03	40.8	94.0	199.2	**99.6**	38.9	214.1	240.9	307.1	220.9	232.2
Tanacross C	15-May-03	347.6	69.9	267.0	27.4	32.8	209.3	246.2	320.9	227.0	151.5
Tanacross C	21-May-03	61.2	91.6	195.4	43.7	39.4	167.1	275.0	474.6	287.4	177.0
Tanacross C	4-Jun-03	15.3	93.6	62.2	66.9	63.3	135.5	348.3	635.7	343.6	79.0
Tanacross C	12-Jun-03	21.7	94.5	97.0	**96.7**	54.0	91.0	**406.6**	959.0	**450.1**	62.0
Tanacross C	20-Jun-03	180.7	81.2	228.6	75.7	36.1	119.9	**443.0**	734.1	**376.3**	71.0
Tanacross C	1-Jul-03	47.9	95.3	142.4	77.4	46.0	98.7	**490.3**	893.2	**428.4**	65.6
Tanacross C	9-Jul-03	18.2	94.4	60.0	**105.2**	64.0	88.6	**551.1**	980.7	**457.3**	44.0
Tanacross C	24-Jul-03	26.0	94.8	83.5	**115.1**	57.1	73.3	**667.8**	1129.8	**508.1**	45.2
Tanacross C	1-Aug-03	79.5	84.4	77.9	**137.7**	58.6	82.7	**722.8**	1036.2	**475.9**	54.3
Tanacross C	7-Aug-03	74.8	91.1	123.3	**80.5**	49.0	86.6	**700.5**	999.2	**463.5**	50.4
Tanacross C	15-Aug-03	18.8	91.7	39.6	**108.1**	72.7	68.4	**756.6**	1182.0	**526.5**	50.5
Tanacross C	29-Aug-03	34.7	91.3	116.4	68.5	50.2	107.8	**776.8**	821.1	**404.8**	63.6
Tanacross Rx	15-May-03	160.8	69.9	208.1	27.4	38.0	191.4	246.2	379.0	251.0	146.6
Tanacross Rx	21-May-03	47.7	91.6	184.2	43.7	40.6	226.5	275.0	273.8	205.9	169.5
Tanacross Rx	4-Jun-03	11.3	93.6	32.8	66.9	76.7	132.8	348.3	651.5	348.9	141.4
Tanacross Rx	12-Jun-03	16.4	94.5	31.8	**96.7**	77.3	121.1	**406.6**	726.0	**373.6**	114.7
Tanacross Rx	20-Jun-03	87.5	81.2	129.9	75.7	47.9	116.6	**443.0**	756.9	**383.7**	119.9
Tanacross Rx	1-Jul-03	14.4	95.3	60.2	77.4	64.0	115.9	**490.3**	761.8	**385.3**	109.8
Tanacross Rx	9-Jul-03	12.6	94.4	23.5	**105.2**	**83.6**	73.4	**551.1**	1128.3	**507.6**	60.8
Tanacross Rx	24-Jul-03	14.4	94.8	52.2	**115.1**	67.0	59.3	**667.8**	1286.0	**564.9**	46.4
Tanacross Rx	1-Aug-03	31.3	84.4	40.2	**137.7**	72.4	49.7	**722.8**	1405.9	**612.3**	59.6
Tanacross Rx	7-Aug-03	25.8	91.1	66.5	**80.5**	61.9	75.0	**700.5**	1112.6	**502.1**	71.7
Tanacross Rx	15-Aug-03	12.4	91.7	19.9	**108.1**	**87.1**	53.6	**756.6**	1356.3	**592.2**	54.5
Tanacross Rx	29-Aug-03	30.7	91.3	122.5	68.5	49.1	128.3	**776.8**	679.5	**358.2**	49.4
Central-1	21-Aug-04	27.9	89.1	52.8	**95.8**	66.7	83.1	**576.0**	1031.9	**474.5**	139.4
Central-2	21-Aug-04	20.2	89.1	32.9	**95.8**	76.6	86.2	**576.0**	1002.9	**464.7**	191.7

Appendix C. Equations.

Two Alaska feather moss/duff calibration equations were provided by the USFS Rocky Mountain Research Station for the Campbell Scientific, Inc. duff moisture meter, based on testing over a range of moisture conditions at two Alaska locations with differing mineral concentrations in duff (Fairbanks and Delta). Lab DMM600 samples were within 10% of actual gravimetric moisture content.

Eq. 1: Fairbanks (25 % average mineral content)
Gravimetric Moisture content = (-1.234 * Frequency 2) + 63.134 * (Frequency) - 479.815

Eq. 2: Delta (40 % average mineral content)
Gravimetric moisture content = (-.75 * Frequency 2) + 33.511 * (Frequency) - 84.321

Three equations were used to convert observed moisture values to moisture index codes. MC is the percent gravimetric moisture content of a specific duff layer, either by depth or by fuel type. Based on work by B. Wilmore (2001), we calculated the Drought Moisture Code (DMC) from the moisture content of the "Dead Moss" layer, and the Drought Code (DC) from the moisture content of the "Upper Duff" layer. The following equation was used to calculate the DMC:

Eq. 3 White spruce/feather moss (Whitehorse, Yukon) (Lawson et. al. 1997a)
DMC = {[ln(MC)](-20.9)} + 149.6

The following equations were used to calculate the DC:

Eq. 4 Black spruce/feather moss (Fairbanks, AK) (Wilmore 2001)
DC = 1 / exp[(MC - 833.15) / 108.09]

Eq. 5 White spruce duff (Whitehorse, Yukon) (Lawson and Dalrymple 1996)
DC = [ln(488.4/MC)] x 267.9

Appendix D. Bulk densities (mg/m^3) for feather moss determined in various Alaska locations, 2003.

Site	**Live Moss**	**Dead Moss**	**Upper Duff**	**Lower Duff**
Ft. Wainwright, JFS Control	0.024	0.030	0.036	**
Ft. Wainwright, JFS Treatment	0.021	0.033	0.076	0.186
Campbell Tract	0.050	0.207	0.425	0.983
Tanacross, Control	0.009	0.024	0.044	0.075
Tanacross, Treatment	0.018	0.035	0.063	0.091
May Creek	0.021	0.042	0.106	0.279
Ft. Wainwright (Wilmore 2001)	0.012	0.021	0.041	0.107