WINDOW OF OPPORTUNITY

The Climatic Conditions of the Lewis and Clark Expedition of 1804–1806

BY PAUL A. KNAPP

The Corps of Discovery encountered generally favorable climatic conditions, avoiding the droughts that are frequent in some regions west of the 100th meridian

The expedition of Lewis and Clark from 1804 to 1806 in search of an inland Northwest Passage is widely considered the most important expedition in American history. While much has been written of the numerous biological, geographical, medical, and political aspects of this "great and epic trek" (Allen 1975, p. xiii), there has been little focus (Ambrose 1978; Large 1986) on the influence of the climatic conditions during their expedition. Although Meriwether Lewis and William Clark, under the directions of President Thomas Jefferson, typically made twice-daily weather observations, they did so without a comparative basis as the climatological knowledge of the American Northwest was limited. In fact, there is little evidence to suggest that either Lewis or Clark envisioned a climatic regime dramatically different than what they had experienced in the humid eastern United States. At the time of their departure, Jefferson, who had never been west of the Mississippi, was "probably the best informed meteorologist in the United States" (Cutright 1969, p. 2). Whether there was ever a discussion between Lewis and Jefferson about how different a climatic regime the expedition would encounter is uncertain.

At the onset of the Lewis and Clark expedition in 1803, Jefferson's (and Lewis') visions of the American Northwest were, in large part, based on their experiences in the Blue Ridge country of Virginia and the "absolute faith in the perfection of America" (Allen 1975, 112). Despite reports on the aridity of the interior western climate noted by Sir Alexander Mackenzie's travels a decade earlier (Gough 1997), Lewis entered the Northwest expecting to find a "fertile and well-watered" land (Allen 1975, p. 115) and "rivers longer and *deeper* [italics added] than any in the East" (Ronda 2001, p. 12). So great was this belief that even after spending a winter in the semiarid region of Fort Mandan in western North Dakota, Lewis found that this steppe landscape was "fertile in the extreme."[1] Further, in noting that game abundance

AFFILIATIONS: KNAPP—Department of Anthropology and Geography, Georgia State University, Atlanta, Georgia
CORRESPONDING AUTHOR: Paul A. Knapp, Department of Anthropology and Geography, Georgia State University, Atlanta, GA 30303
E-mail: gegpak@langate.gsu.edu
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[1] All quotes from members of the Corps of Discovery are verbatim (with frequent misspellings) from volumes 1–11 of *The Journals of the Lewis and Clark Expedition* (Moulton 1983, 1987a,b,c, 1988, 1990, 1991, 1993; Moulton and Dunlay 1996a,b, 1997, cumulatively referred to hereafter as "Moulton 1983").

had increased westward, Lewis wrote that, "our prospect for starving is therefore consequently small." Thus, in April 1805, as the "Corps of Discovery" (CD) began their trip along the upper Missouri River into the largely arid and semiarid American Northwest,[2] they *expected* to find a "garden," and in their minds, "[t]hose observers who presented contrary or derogatory details on the Great Plains were severely in error" (Allen 1975, p. 225).

In some regions of the arid and semiarid American Northwest, droughts are common (Cook et al. 1997; Knapp et al. 2004) and often persistent (Karl and Koscielny 1982; Soulé 1992; Meko et al. 1993; Knapp et al. 2004), with some areas experiencing either severe or extreme drought conditions greater than 15% of all years [National Drought Mitigation Center (NDMC) 2003]. This pattern of drought in the American Northwest is substantially different from that of regions east of the Mississippi River where severe droughts occur roughly one-quarter to one-half as frequently (NDMC 2003). Moreover, the pattern of drought in the American Northwest may be geographically delineated in that the occurrence of droughts on the west side of the Continental Divide does not always correspond with droughts on the east side [e.g., the drought of 1808 (Cook et al. 2004)]. Consequently, in a region so large, at least some part of it is often experiencing the effects of drought (Cook et al. 2004). To travel through this region for a 2-yr period while avoiding either the direct or lingering effects of a drought would require fortuitous timing.

It has been argued that for every successful expedition "one must have luck" and that luck is "a singular quality of great commanders" (Cookman 2002, p. 200). Given all the elements of the expedition that could have caused either severe delays or possibly halted the expedition, fate, skill, or a combination of these favored Lewis and Clark. Undoubtedly, the CD were lucky. For example, J. L. Allen (2004, personal communication) notes that Lewis and Clark did not encounter Native Americans in the summer 1805 in the "heart of prime game range" and that the CD crossed "the northern Plains during a period following significant Indian warfare which had left Indians wary of intruding groups they could not readily identify." Further, in August 1805, in desperate need to trade for horses with the Shoshone, Lewis and Clark learned that the Chief of the Shoshones, Cameahwait, was the brother of Sacajawea (Moulton 1983). Arguably, the expedition of the CD would have been delayed, if not stopped if there had been different outcomes with any of these situations. But what about the climatic conditions? Could have persistently adverse conditions either slowed their progress or stopped the expedition entirely? Certainly there is a precedent of this happening in the history of exploration. Adverse weather, and more importantly, unusual climatic conditions, have contributed to the demise of many explorers. The expeditions of Sir John Franklin (Cookman 2002), the Donner party (Stewart 1960), Elisha Kent Kane (Fleming 2001), Robert Falcon Scott (Solomon and Stearns 1999), and Ernest Shackleton (Alexander 1999) all failed in their intended purposes because of the unfortunate climatic conditions that they encountered.

My objective in this paper is to argue that the abundance of luck that followed Lewis and Clark on their expedition also applied to the generally favorable climatic conditions that they experienced. Specifically, the CD avoided the element of climate that could have substantially impacted their travel: a moderate to severe drought. I use the data from their daily weather observations at locations where they were encamped for weeks to months and compare these data to modern day records from nearby locations. Additionally, I place the years 1804–06 in a historical context in terms of overall climatic conditions for the American Northwest. Making climatic inferences from tree-ring-based reconstructions dating back to the 1700s, I show what the general climatic conditions were like relative to how wet or dry a year could be. Finally, I speculate on what might have happened to the CD if they had traveled during substantially drier years. In particular, I focus on the impacts to their food supplies/sources and how drier conditions would have affected their travel from the upper Missouri River and across the Bitterroot Mountains in August and September 1805.

DATA AND METHODS. *Climatological data.* I reviewed the daily weather observations and accompanying comments recorded by Lewis and Clark from 25 October 1804 (the beginning of their stay at the Mandan Village area) until their return to the Mandan villages on 14 August 1806, using volume 6 of Thwaites (1959) where the data and comments have been placed into a separate chapter. Addition-

[2] Two notable exceptions to aridity exist along the Lewis and Clark route. First, the mountainous regions of Montana and Idaho can receive in excess of 180 cm of precipitation annually [Western Regional Climate Center (WRCC) 2004]. Second, the region from the Cascade Mountains to Pacific Coast receives from 100 to 200+ cm of precipitation annually (WRCC 2004).

ally, I chose this time frame because it corresponds with their time west of the 100th meridian and because it marks the onset of their travels into a region that was essentially unmapped (Ambrose 1996; Ronda 2001). Typical recordings included temperature (until 6 September 1805 when their last thermometer broke), sky conditions (e.g., fair, cloudy, rain, snow etc . . .) and wind direction. All observations were made at sunrise and again at 4 P.M.

Because of a variety of circumstances on their expedition, the CD were in a single location for approximately a month or longer at four locations (Fig. 1), a total period of 11 months that accounts for approximately half the time they were west of the 100th meridian. In these instances, I compared their meteorological observations with those averages of nearby National Weather Service (NWS) stations (Fig. 1) using daily data to replicate the time frame. Despite matching daily weather conditions at these sites for specific dates, I did not test for significant differences for three reasons. First, the temperature readings may not be precise as Lewis and Clark determined that calibrations were necessary for their thermometers as recordings were "8°F too low" (Thwaites 1959, 166; Large 1986). Second, it is unlikely either Lewis or Clark recorded temperature at the same location daily while encamped which could impact readings. Finally, no measurements of rainfall were recorded, and thus the precipitation amounts are not available. Given these restrictions, I use the comparisons to place the weather conditions in a broader historical context and to provide a general sense of what they experienced.

To gain a better understanding of the overall climatic conditions during the CD's expedition (i.e., what type of year it was, as opposed to what type of day it was), I used reconstructed summer (June, July, August) PDSI values from 1700–1978 created by Cook et al. (1999, 2004). These reconstructions were developed from tree-ring data and used to create PDSI values for 2° latitude × 3° longitude grids for the contiguous United States. For my analysis, I selected the data within those grids that fell within either the outbound and/or return routes of the CD. Ultimately, data from 16 grids were selected, ranging from 48°N, 124°W to 44°N, 100°W. From these data I evaluated the conditions for the decade 1800–09. Thus, in selecting this decade I was able to examine the antecedent conditions as well as the conditions from 1804–06. Additionally, I added the years 1807–09 to illustrate the onset of drought during those years. Finally, to show how frequently droughts occur, I determined the median interval between years of PDSI values <–2 (moderate drought or

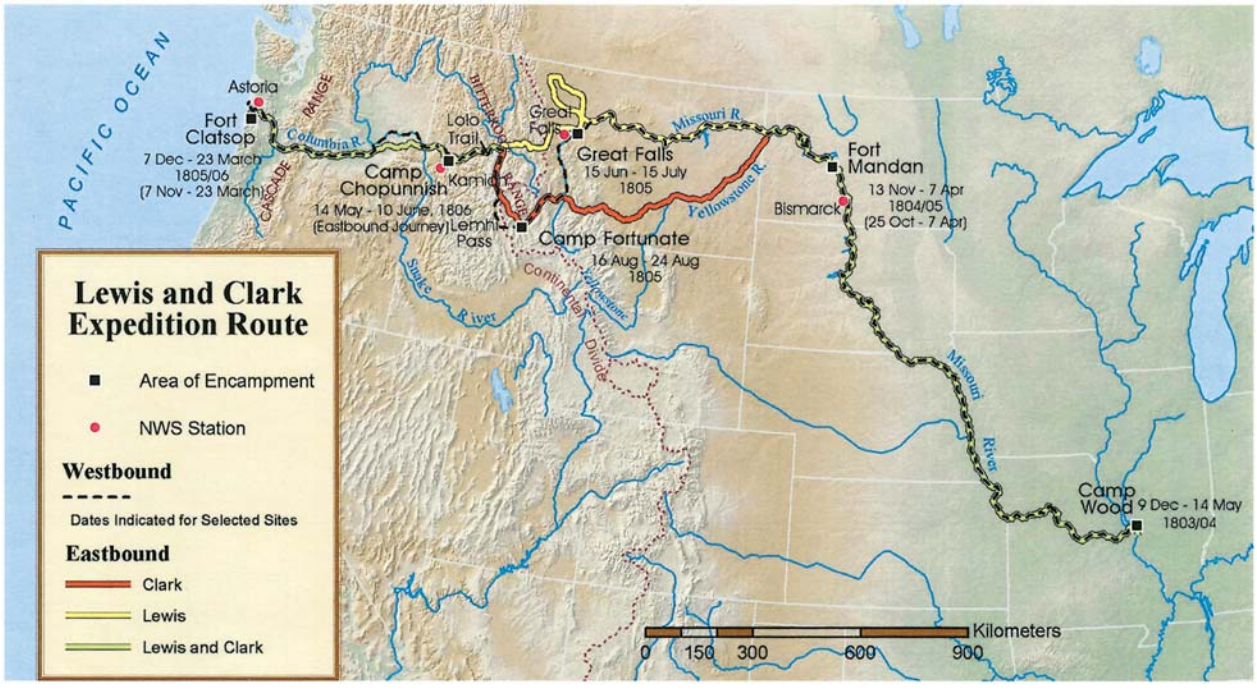

FIG. 1. Route and time spent at various locations by the Corps of Discovery. Dates shown parenthetically indicate periods when the Corps of Discovery were in the immediate vicinity of a camp, but had not yet occupied the camp.

greater)[3] starting with the first occurrence of PDSI values <–2, and overlaid this frequency by grid on the route of the CD to provide a spatial representation of drought frequency. I then used these data to calculate the probability of encountering a drought anytime during their outbound and return trip.

Among the many remarkable entries in the Lewis and Clark journals are the references to snowpack in the Lemhi and Bitterroot Ranges on both the outbound and return trips. Accordingly, I wished to determine snowfall amounts at sites surrounding the Lolo Trail (i.e., within 50 km) during years that matched both the Southern Oscillation Index (SOI) values [i.e., El Niño–Southern Oscillation (ENSO) phases of El Niño or La Niña] and Pacific Decadal Oscillation (PDO) conditions (i.e., warm or cold phase) that Lewis and Clark likely experienced. Several studies have suggested that the relative strength of an ENSO event may be impacted by the phase of the PDO in which it occurs (Gershunov and Barnett 1998; McCabe and Dettinger 1999; Cole et al. 2002), particularly if the ENSO mode and PDO phase are in agreement.

In the Pacific Northwest, the pattern of wetter winters (with greater snowfall) is often associated with both La Niña events (Redmond and Koch 1991; Cayan 1996) and a cold phase PDO regime (Peterson et al. 1999; Mantua 2001), a relationship that becomes "consistent" in its effect when the two oscillations are in phase (Gershunov and Barnett 1998, p. 2715). To determine the extent of this effect, I examined snowfall data from six Snowpack Telemetry (SNOTEL) stations in Idaho that are near the Lolo Trail–Cool Creek, Crater Meadows, Hemlock Butte, Lolo Pass, Savage Pass, and Shanghi Summit. The data were electronically accessed from the Natural Resources Conservation Service [see Natural Resources Conservation Service (NRCS) 2004], and complete records for the six SNOTEL sites exist from 1961 through 2002. The 1 May snow water equivalent (SWE)[4] values for the years represented by La Niña conditions (Stahle et al. 1998) embedded in a cold phase PDO (Gedalof and Smith 2001)—1963, 1967, 1971, and 1974—were compared with 1 May SWE values for the remaining years between 1961 though 1998[5] ($n = 34$) and tested for significance using a one-tailed Student's t test.

Hydrological data. Within the travel routes of the CD, only the Upper Yellowstone River flow has been reconstructed earlier than the nineteenth century (Graumlich et al. 2003) although relationships between ENSO events and historical streamflow exist in the western United States (e.g., Redmond and Koch 1991; Cayan et al. 1999). To place streamflow for the decade 1800–09 for the Upper Yellowstone River in a broader historical perspective, I determined the percentage of average of reconstructed streamflow for each year of that decade based on the entire record from 1706–1977.

Map constructions. All figures that illustrate the outbound and return routes by the CD were created in ArcMap 8.3. Several of the layers for the map including the hill-shaded image, Digital Elevation Model, rivers and other water bodies, and trail symbolized to show the direction and party were developed by ESRI (www.esri.com/lewisandclark/). Additionally, a Shapefile of the 2° latitude × 3° longitude PDSI zones was created. The Shapefile attributes include the PDSI values, median drought interval values, and drought probabilities for each grid. Graphs of the PDSI values from 1800–09 were created in ArcMap and modified in Micrografx Designer.

Food consumption. I used the data compiled by Burroughs (1961, 283) on the "game killed by the Lewis and Clark Expedition May 14, 1804 to Sept. 24, 1806" to assess food consumption of the CD and the relative distribution of game along the Lewis and Clark Trail. Additionally, from the period 14 August 1805 (where Lewis begins commenting on the lack of food near Lemhi Pass) until 22 September (when the CD received food from the Nez Perce), I recorded the daily comments of either Lewis or Clark regarding their food consumption.

RESULTS. *Climatological conditions.* Based on summertime PDSI reconstructions from 1700–1978

[3] In the statistical process used in the calibration and reconstruction of PDSI values, there is a loss of explained variance. Thus, thresholds (e.g., PDSI<–2.00 for moderate drought or greater) based on reconstructed PDSI values are not exactly comparable to thresholds based on instrumental PDSI values, but rather represent approximations.

[4] Snow water equivalent is the amount of water contained in the snowpack and is an excellent proxy measure of actual snowfall totals. I used 1 May values as this represents the typical peak snowpack depth for the selected sites along the Lolo Trail.

[5] PDO conditions post-1998 have been inconsistent, and there are insufficient data to determine if a phase shift has occurred. Thus, I did not consider possible cold phase PDO–La Niña years after 1998.

(Cook et al. 1999, 2004), Lewis and Clark traveled from Ft. Mandan to the Pacific and back during a period marked by the absence of significant drought conditions (Fig. 2). From 1804–06, only one of the 2° latitude × 3° longitude gridded regions (16 grids × 3 yr; $n = 48$) experienced PDSI values <–1.5 and no regions experienced conditions <–2.00, the threshold for moderate droughts (Fig. 2). This period was, in large part, marked by the lack of extreme conditions. Of the 48 PDSI values that were generated for the years 1804–06, approximately 65% of the values fell between –1 and 1, thus indicating that neither dry nor wet conditions prevailed (Fig. 2).

Despite the relatively moderate conditions that were widespread during the period 1804–06, there is substantial geographic variability in drought frequency. The median interval for moderate or more severe droughts (i.e., PDSI values <–2.00) ranged from 4 to 12 yr (Fig. 3). Drought frequency was highest in the Columbia Plateau area and in the high plains centered on Great Falls. Droughts were less frequent on the Pacific Coast and along the spine of the Rockies. This pattern was repeated for the probability of incurring drought during a 2-yr period (to the Pacific Ocean and return). The probability values ranged from 0.16 to 0.44 (Fig. 3) indicating the chance of incurring drought ranged from 16% to 44%. Thus, as Lewis and Clark traveled from Ft. Mandan to the Pacific Ocean, they passed through areas that historically were more (less) prone than others to experience significant droughts.

Reconstructed winter Southern Oscillation index values for the period 1706–1977 suggest that El Niño conditions existed in 1804, while La Niña conditions dominated during 1805 and 1806 (Stahle et al. 1998). Several studies that have reconstructed PDO conditions using tree-ring data from the North American West Coast (e.g., D'Arrigo et al. 2001; Gedalof and Smith 2001) suggest a phase shift from a warm to cold regime occurred at the end of the eighteenth century and continued through 1815 (Gedalof and Smith 2001). Thus, during the period of exploration for the CD, successive La Niñas embedded in a cold phase PDO marked the climatic conditions.

Snowpack totals, based on 1 May SWE data observations ($n = 24$) from stations near the Lolo Trail, were significantly greater ($p < 0.01$) averaging 127% of normal when the climatic oscillations (i.e., La Niña and cold phase PDO) were in agreement. Accordingly, comparing inferred conditions from the begin-

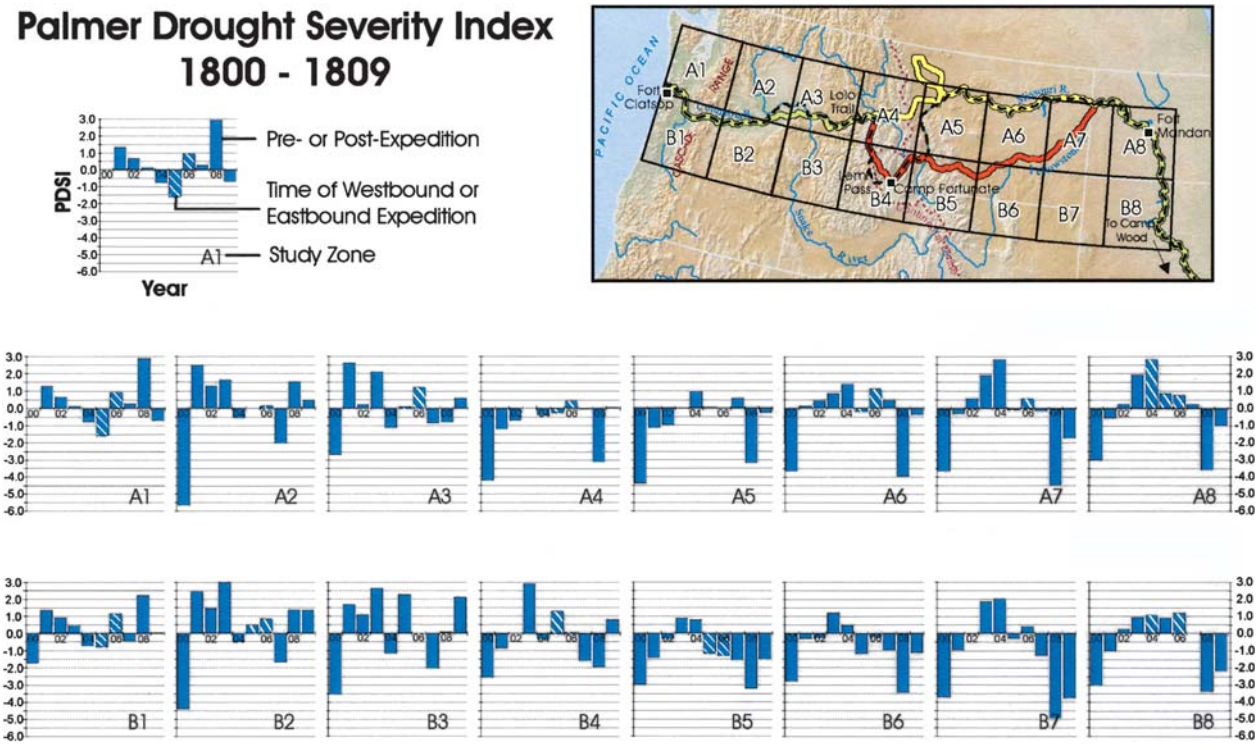

Fig. 2. PDSI values for decade of 1800–09 based on data from Cook et al. (1999, 2004). PDSI values for each grid are shown and referenced to a location along the Lewis and Clark Trail. Hachured bars represent year(s) the Corps of Discovery would have been at that location. PDSI values of <–2.00 are considered moderate or greater droughts.

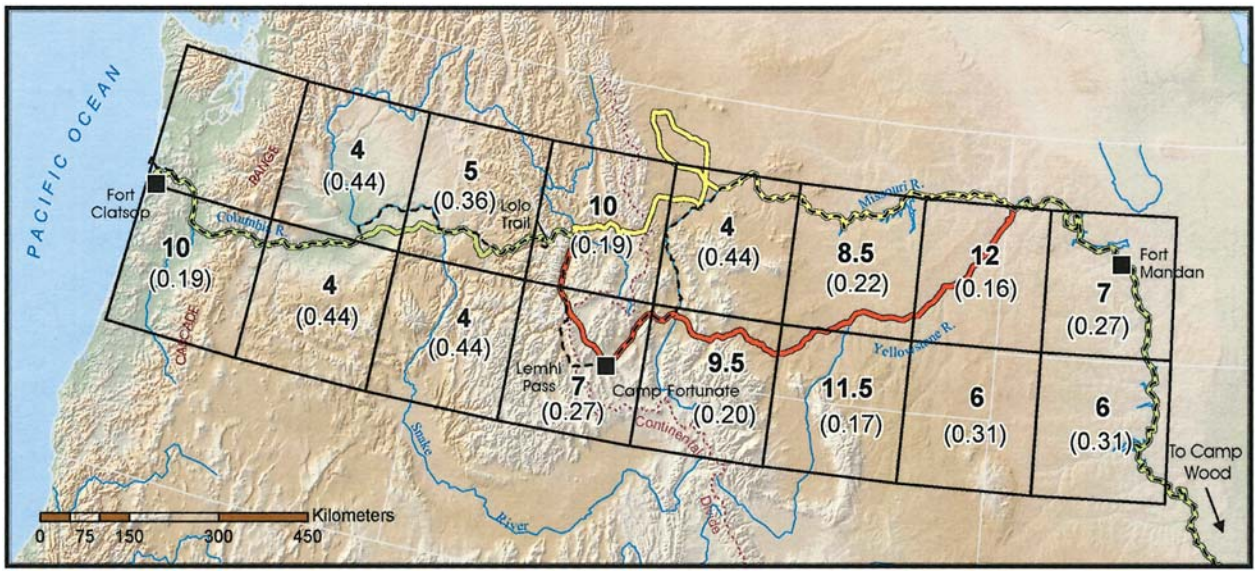

Fig. 3. Median drought interval (years in bold face) and probabilities of incurring a drought (parenthetically in light face) along the Lewis and Clark Trail based on PDSI values from Cook et al. (2004). Probabilities indicate the chance (i.e., 0.44 = 44%) of experiencing a drought of PDSI <–2.00 during a 2-yr period (outbound and return) based on period 1700–1978.

ning of the nineteenth century to known conditions of the twentieth century records suggests that, when the two cold phases are in agreement, as was the case in the winters of 1804–05 and 1805–06, substantially more snowfall occurs.

Meteorological comparisons. Comparisons of meteorological observations recorded by Lewis and Clark from 1804–06 with long-term averages at nearby NWS recording stations (www.ncdc.noaa.gov/oa/climate/stationlocator.html) provides the opportunity to place the conditions they experienced in a relative context. In four locations, the CD remained encamped for periods of nearly a month to greater than 5 months, and comparisons were made at Ft. Mandan, Great Falls, Ft. Clatsop, and Camp Chopunnish (Fig. 1).

During their 165-day hiatus in the Ft. Mandan area between 25 October, 1804 and 7 April 1805, Lewis and Clark recorded 35 days (21%) with precipitation (Table 1). These conditions were consistent with long-term averages of 37 days (22%) of precipitation recorded from 1879–2002 in Bismarck, North Dakota, which is approximately 55 km SE of and 20-m lower in elevation than Ft. Mandan. Monthly temperature averages were slightly warmer at Ft. Mandan in October and November and again in March and April, but appreciably colder at Bismark in December, January, and February (Table 1).

Between 15 June and 15 July 1805,[6] Lewis and Clark spent 31 days around Great Falls in an effort to portage their canoes from a lower portage camp to an upper portage camp (Moulton 1983). During this period, they experienced 16 days (51%) with precipitation, which is approximately 6 days more than averages from the Great Falls airport based on the period 1948–2002 (Table 1). Mean daily highs in 1805 averaged approximately 3.5°C less than airport records, while mean daily lows between sites were identical (Table 1).

The CD were in the Ft. Clatsop area from 7 November 1805 to 23 March 1806 as they prepared for their return trip. During this period of 137 days, 121 days (88%) had some form of precipitation, which in most instances was rain[7] (Table 1). Comparisons with records from the nearby (< 8 km) Astoria Airport based on the period 1953–2003 show an average number of precipitation days to be 94 (69%). For each month, conditions during the winter of 1805–06 exceed the long-term averages from Astoria. No temperature recordings were made at Ft. Clatsop. Lewis did, however, remark on the "temperate weather" and

[6] This period represents when the entire CD were at Great Falls as Lewis had arrived 2 days earlier.

[7] Lewis and Clark recorded precipitation for 49 consecutive days from 19 November 1805 through 6 January 1806.

Table 1. Climatological comparisons between areas of encampment of Lewis and Clark between 1804–06 and nearby NWS stations based on exact date comparisons. Precipitation data are shown as percentage of days with measurable precipitation (i.e., ≥ 0.01") with the number of days shown parenthetically. Temperature data (°C) are shown as averages of daily highs and lows. (4 P.M. and sunrise readings from journal entries, respectively.)

Location/Measure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Precipitation													
Ft. Mandan area	32 (10)	14 (4)	23 (7)	29 (2)						0 (0)	17 (5)	23 (7)	21 (35)
Bismarck NWS[a]	23 (7)	24 (7)	24 (7)	23 (2)						18 (1)	20 (6)	23 (7)	22 (37)
Great Falls area						38 (6)	67 (10)						51 (16)
Great Falls NWS[b]						37 (6)	30 (4)						34 (10)
Ft. Clatsop area	81 (25)	82 (23)	87 (20)								92 (22)	100 (31)	88 (121)
Astoria NWS[c]	71 (22)	67 (19)	66 (15)								67 (16)	72 (22)	69 (94)
Camp Chopunnish					61 (11)	30 (3)							54 (14)
Kamiah NWS[d]					38 (6)	38 (4)							38 (10)
Temperature													
Ft. Mandan area—High	–18.4	–7.7	1.8	8.5						12.2	3.9	–13.3	–1.9
Ft. Mandan area—Low	–20.7	–15.4	–5.7	–2						1.5	–2.3	–18	–8.9
Bismarck NWS—High	–6.9	–4.4	2.5	9.6						11.5	3.8	–3.5	1.8
Bismarck NWS—Low	–18.8	–16	–8.7	–3.8						–2.4	–7.5	–14.6	–10.3
Great Falls area—High						21	23.7						22.4
Great Falls area—Low						10	11.4						10.7
Great Falls NWS—High						24.2	27.5						25.9
Great Falls NWS—Low						9.8	11.6						10.7

[a]Bismarck: Averages based on period 1879–2002, except 25–31 Oct and 1–7 Apr that are based on 1971–2000 means (Enz and Mahoney 2003).

[b]Great Falls Airport: Averages based on period 1948–2002 excluding 14 days in Jun and Jul 1995 [National Climatic Data Center (NCDC) 2003].

[c]Astoria Regional Airport: Averages based on period 1953–2003 (NCDC 2003).

[d]Kamiah, Idaho: Averages based on period 1949–98 excluding 8 days missing data (NCDC 2003).

noted that he had "never experienced a winter so warm as the present has been" (Thwaites 1959). Despite the mildness, there is evidence that the CD did experience at least one significant cold snap that lasted nearly 2 weeks. Between 25 January until 6 February the predominant wind direction was from the northeast and Lewis notes on 6 February that it was "very cold last night think that it is rather coldest night that we have had" (Thwaites 1959). How cold it was is speculative, but only a week earlier, Lewis estimated the morning low on 28 January "as low as 15°[F]" (Thwaites 1959, p. 204).

The CD were at Camp Chopunnish from 14 May to 10 June 1806 waiting to cross the Bitterroot Mountains. During this period, precipitation occurred on 14 (54%) of the 27 days (Table 1). These conditions exceed those of the average of 10 days (38%) recorded from the NWS station at Kamiah, Idaho, for the period 1949–98.

Hydrological data. Streamflow for the decade 1800–09 averaged 88% of the mean flow of all reconstructed years (i.e., 1706–1977). In particular, however, are the years 1800 (67% of average) and 1804, 1805, and 1806 (89%, 92%, and 93% of average, respectively). Thus, in the years that the CD used the Upper Missouri (1805 and 1806) and Yellowstone Rivers (1806) as sources of navigation, streamflow was only slightly below average, but not at the extreme low flow that occurred in 1800. From 1706–1977, the median interval between low-flow periods (i.e., in bottom 20th percentile) for the Yellowstone River was 5 yr.

Food consumption. The CD's daily consumption of meat was "astonishing" (Burroughs 1961, 282) and has been estimated to be as much as "nine or ten pounds" with a caloric intake, including nonmeats, exceeding 6000 calories (Ambrose 1966, 217). Of the game killed, deer were the principal food source for much of the trip except for the high elevation areas in the Bitterroots (Table 2). Elk and bison were also common food sources, but their distributions were geographically limited. West of the Continental Divide, the Corps of Discovery supplemented their diet with Native American's dogs. At various locations, both westbound and eastbound, they consumed bears, beaver, geese, ducks, grouse, and plovers (Table 2). Upon near-starvation on the Lolo Trail, horses became food sources (Table 3).

The CD "alternated between periods of feasting and starvation" (Burroughs 1961, 282). Clearly, no period of starvation was more severe than their time spent around Lemhi Pass and then crossing the Lolo Trail. For the 40-day period from 14 August to 22 September 1805, concerns about the lack of food were reported on an almost daily basis (Table 3). By 28 August, Lewis had reported that "my flesh I find is declining" and by 21 September that he had found himself "growing weak for want of food and most of the men complain of similar deficiency and have fallen off very much."

DISCUSSION. *Climatological assessment.* Climatic reconstructions inferred from tree-ring data at multiple sites along the Lewis and Clark route combined with daily meteorological observations recorded between 1804 and 1806 all suggest that the CD explored the American Northwest during a period of relatively mild conditions. [A sequence of maps that show PDSI conditions from 1800–09 (Cook et al. 2004) are available online at www.ngdc.noaa.gov/paleo/pdsiyear.html.] In particular, they avoided the severe drought of 1800 that affected nearly all areas along their route. The drought of 1800 was followed by several years of above-average moisture conditions that would have ameliorated the residual effects of this drought. The period 1804–06 was remarkable in that near-average conditions prevailed over much of the American Northwest and preceded the onset of a multiyear drought that was well-expressed east of the Rocky Mountains beginning in 1808.

Weather and food supplies. The beginning of the climatological "luck" for the CD began at Ft. Mandan during the winter of 1804–05 where they heavily relied on Mandan corn as a major food source (Ambrose 1996). Ambrose (1996, p. 200) speculates "had the Mandans not been there, or had they had no corn to spare . . . the Lewis and Clark Expedition might not have survived its first winter." Reconstructed PDSI values for the summer of 1804 around Ft. Mandan (Fig. 2, grid A8), the growing season for the corn, suggest above-average moisture conditions that would have been favorable for this crop growing in a semiarid environment. Whether these conditions would have translated in a bumper crop is speculative, but clearly the conditions favored this, making it much more likely that the Mandans would have traded their corn.

Despite the packaging of nearly 7 tons of nonperishable foods (Burroughs 1961), the CD relied heavily on its hunters to acquire meat on a daily basis. West of Ft. Mandan, and out of an area where trade with Native Americans for food was likely, their ability to shoot game for sustenance became paramount to the vitality of the expedition. However, the availability of

TABLE 2. Number of game killed by Lewis and Clark expedition with comments about the geographical distribution of the game (Burroughs 1961). All quotes are from Burroughs unless bracketed.

Animal	No. killed	Geographical distribution of kills	Comments
Deer spp.	1001	Uniform	The principal food source for much of the trip. Scarce in the Bitterroots.
Elk	375	Uneven	Abundant in vicinity of Ft. Clatsop and in region between Council Bluffs and the Beaverhead River valley.
Bison	227	Uneven	Common between Ft. Mandan and Great Falls; no sightings west of the Gates of the Mountains.
Pronghorn	62	Uneven	Common in favorable sites from Ft. Mandan to Three Forks. Uncommon on west side of Bitterroots.
Bighorned sheep	35	Rare	Found from confluence of Missouri/Yellowstone Rivers west to Beaverhead Mtns.
Black bears	23	Uneven	Not reported east of Bitterroot Mtns. Several killed near Sandy River and Clearwater River region.
Grizzly bears	43	Uneven	Frequent sightings between eastern Montana and Great Falls. Six killed near Kamiah Idaho on return trip.
Beaver	113	Uneven	Common east of continental divide. None reported between Bitterroot Mtns. and Columbia River.
Otter	16	Uniform	Commonly sighted, but considered an "inferior" food source [Lewis].
Geese and brant	104	Uneven	The brant and four species of geese were often sighted and abundant except Bitterroot Mtns.
Ducks and coots	45	Uneven	
Grouse spp.	46	Uneven	
Turkeys	9	Uncommon	
Plovers	48	Uneven	
Wolves ("only one eaten")	18	Uneven	Common where ungulates were present.
Native American's dogs ("purchased and consumed")	190	NA	Purchased on west side of Bitterroots. Considered favorite of Lewis, but not Clark.
Horses	12	Uneven	Purchased for transportation at Camp Fortunate. In times of starvation used for food.

TABLE 3. Journal entries from members of the Lewis and Clark expedition regarding hunger and food acquisitions between 14 Aug and 22 Sep 1805. All quotes are listed verbatim from Moulton (1983). (Table 3 is continued on the next page.)

Month	Day	Comment
Aug	14	"I had eat nothing yesterday [14 Aug] except one scant meal of the flour and berries..." [Lewis]
	15	"I now cooked and among six of us eat the remaining pound of flour stirred in a little boiling water." [Lewis]
	16	"I sent Drewyer and Shields before this morning to kill some meat as neither the Indian nor ourselves had anything to eat." [Lewis]
	17	"I made McNeal cook the remainder of our meat which afforded a slight breakfast . . ." [Lewis]
	18	"One of our hunters that was out killed a deer, which he brought to our camp." [Whitehouse]
	19	"we caught a number of fine Trout covred all with black spots in Stead of red. in the afternoon the hunters returned to Camp & had killed and brought in 2 deer." [Ordway]

Table 3. Continued.

Month	Day	Comment
	20	"the game Scarse." [Ordway]
	21	"neither of the hunters returned this evening and I was obliged to issue pork and corn." [Lewis]
	22	"Our stock of provision is now so low that it would not support us more than ten days." [Lewis]
	23	"(we have but little and nothing to be precured in this quarter except Choke Cheres & red haws not an animal any kind to be seen and only the track of a Bear)" [Clark]
	24	"Brackfast on buries." [Clark']. "supperless went to rest for the night." [Gass]
	25	"remained supperless." [Lewis] "I had three hunters out all day, they saw one Deer, killed nothing." [Clark]
	26	"not one mouthful to eate until night as our hunters could kill nothing . . ." [Clark]
	27	"my party hourly Complaining of their retched Situation and [contemplating?] doubts of Starveing in a Countrey where no game of any kind except a few fish can be found . . . [Clark]
	28	"my flesh I find is declineing." [Lewis]
	29	"this [deer] meet was a great treat to me as I had eate none for 8 days past." [Clark]
	30	"our hunters killed three deer." [Lewis]
	31	"our hunters killed one Deer a goose & Prairie fowl." [Lewis]
Sep	1	"we giged 4 Sammon & killed one Deer to Day." [Clark]
	2	"no game of any kind to be Seen in these mountains." [Ordway]
	3	"but little to eate." [Clark]
	4	"but nothing but berries to eate." [Clark]
	5	"the women brought us a few berries & roots to eate." [Clark]
	6	"nothing to eate but berries, our flour out, and but little corn, the hunters killed two pheasents only." [Clark]
	7	"one of the hunters killed 2 deer; which was a subject of much joy and congratulation." [Gass]
	8	"two of our hunters came up with us at 12 oClock with an Elk, & Buck—"; "Drewyer killed a Deer. I killed a prarie fowl" [Clark]
	9	"we breakfasted on a scant proportion of meat which we had reserved from the hunt of yesterday." [Clark]
	10	"The Latd. 46° 48'28" as the guide report that no game is to be found on our rout for a long ways . . ." [Clark]
Lolo Trail→	11	"In the bottoms here, there are a great quantity of cherries." [Gass]
	12	"our hunters killed only one Pheasent this after noon. Party and horses much fatigued." [Clark]
	13	"One Deer & Some Pheasants killed this morning." [Clark]
	14	"we wer compelled to kill a Colt for our men & Selves to eat for want of meat and we name the South fork Colt killed Creek"; "...our men and horses much fatigued." [Clark]
	15	"nothing killed today except 2 Phests." [Clark]
	16	"Killed a second colt which we all Suped hartily on and thought it fine meat." [Clark]
	17	"Killed a fiew Pheasents which was not Sufficient for our Supper which compelled us to kill Something. a coalt being the most useless part of our Stock he fell a Prey to our appetites." [Clark]
	18	"we dined and suped on a skant proportion of portable soupe." [Lewis]
	19	"Several of the men are unwell of the disentary. Brakings out, or irruptions of the Skin, have also been common with us for some time." [Lewis]
	20	"[we] made a hearty meal on our horse beef much to the comfort of our hungry stomachs." [Lewis]
	21	"I find myself growing weak for want of food and most of the men complain of a similar deficiency and have fallen off very much." [Lewis]
	22	"I divided the fish roots and buries, and was happy to find a sufficiency to satisfy completely all our appetites." [Lewis]

game, using the number of game killed by the CD as a proxy indicator of game abundance, varied considerably from Ft. Mandan to Ft. Clatsop (Martin and Szuter 1999; Lyman and Wolverton 2002). Game was scarce from Ft. Mandan to the confluence of the Missouri and Yellowstone Rivers (Martin and Szuter 1999), but was plentiful westward until the upper reaches of the Beaverhead River as they approached Camp Fortunate (Fig. 2 in Lyman and Wolverton 2002). From Camp Fortunate westbound game numbers remained low until Ft. Clatsop (Lyman and Wolverton 2002).

The CD suffered tremendously from want of food and a balanced diet despite the climatically favorable conditions, and nowhere was this problem more acute than from Lemhi Pass/Camp Fortunate to Camp Chopunnish (Table 3). During this 40-day period, the health of the CD declined substantially. On 19 September 1805 Sergeant Gass wrote, "the men are becoming lean and debilitated, on account of the scarcity and poor quality of provisions on which we exist." Lewis also noted, "irruptions of the Skin have been common with us for some time." At this point, the CD, "suffering from malnutrition and . . . susceptible infections," were in the "early stages of starvation." (Chuinard 1979, 320). Mirsky (1946) views their physical condition as even more serious, speculating that the men were suffering from scurvy. Food consumption increased dramatically as the CD moved out of the high country as they were able to purchase roots and salmon from the Nez Perce near Camp Chopunnish.

Although the men experienced starvation and the ill effects of malnutrition, they were arguably fortunate to have successfully crossed the Bitterroots for they proceeded up (and down) the Missouri River and its tributaries during wet years that would have favored an abundance of grasses and other forage species to feed the deer, bison, and elk that were their principal sources of food. Within the American West, herbage production has high interannual variability that is highly correlated with precipitation amounts (Tomanek and Hulett 1970; Owensby et al. 1999). Forage yields during droughts in the plant communities similar to those the CD crossed between 1804–06 (i.e., sagebrush steppe, Palouse prairie, Great Plains shortgrass) ranges from approximately 22% to 46% of that of optimal years (Blaisdell 1958; Sneva and Hyder 1962; Tomanek and Hulett 1970).

Because of the spatial and temporal variability in drought, and how this affects forage availability of different species, the specific impact of climate on large herbivore populations varies considerably and is both age and species dependent (Gaillard et al. 2000). Several studies, however, suggest significant linkages between drought and declines in populations of game (Frank and McNaughton 1992; Singer et al. 1997; Woodhouse et al. 2002) that were major food sources of the expedition members. For bison populations in the western Great Plains, Woodhouse et al. (2002, p. 1485) have speculated that sustained drought in the mid-nineteenth century was a significant factor that contributed to the "abrupt decimation" of the bison population. In Yellowstone National Park, both Frank and McNaughton (1992) and Singer et al. (1997) found elk and/or bison populations were reduced the year following drought.

The linkage between drought and horse populations is intriguing, for although horses were a small component of the CD's diet, they were critical for travel across the Bitterroots and, on the return journey, from Celilo Falls (near The Dalles, Oregon) eastward (Moulton 1983). Because horses are bulk feeders that can subsist on low-quality forage, they are less susceptible to environmental variability than other ungulates (Saltz 2002) and typically have high annual survival rates (Garroty and Taylor 1990). During severe droughts, however, horse populations can suffer significant declines (Berger 1983). Thus, their numbers too could have been impacted by drought conditions.

Climatic conditions are only a partial control on the abundance/absence of large game. Martin and Szuter (1999) argued that Lewis and Clark found abundant large game along the upper Missouri and Yellowstone Rivers in part because the continual conflict between Native American groups left the region between the rivers unoccupied. Conversely, the lack of game in the Bitterroots may have been a result of the continuous hunting pressure by Native Americans. Therefore, while the role of Native Americans was critically important in determining game numbers, the waxing and waning of the game population was also dependent upon recent climatic events that affected grazing conditions. Thus, it can be argued that despite the lack of game that led to their starvation, grazing conditions were actually *favorable* for game. To attempt to follow this route under drought conditions would have subjected the CD to an earlier onset of starvation that would have substantially diminished their chance of success in crossing the Bitterroot Mountains.

In the CD's contact with the Shoshone, Lewis reported their herd at approximately 400 horses, most of them "fine," and approximately 30 of which they wished to acquire (Moulton 1983). Of these however, many were not available for purchase, for many of the

Shoshone were preparing to travel down the Missouri for buffalo hunting and would thus require many horses (Lavender 1988). Given the high demand for horses, and the fact that the Shoshone knew the necessity of horses for the CD, Lewis and Clark paid handsomely (including trading Clark's pistol) for 29 horses. Further, these horses were the "castoffs" (Ambrose 1996, 283) that Clark noted suffered "nearly all from Sore Backs" and could not carry "large loads," and thus prompted additional purchases and exchanges with the Flatheads a week later. Thus, again given favorable conditions where forage would have been plentiful, and would have favored a large healthy herd of horses, the CD had been lucky. If they had arrived during a drought, certainly the herd size would have been smaller, the animals in poorer health, and the cost of procuring horses greater.

ENSO/PDO conditions. Reconstructions of both ENSO and PDO conditions indicate that the winters of 1804–05 and 1805–06 were in phase (i.e., La Niña and cold PDO). Daily weather records at Ft. Clatsop during the winter of 1805–06, at Camp Chopunnish in May and June 1806, and reported snowpack depths in the Bitterroots in June 1806, indicate that these conditions were concurrent with an unusually wet and snowy year. Equally remarkable to the nearly 90% of the days spent around Ft. Clatsop marked by precipitation, were the snowpack depths recorded by Lewis and Clark in the Bitterroots. As the CD first viewed the Bitterroots on 7 May 1806 on their return trip, Lewis noted, "The spurs of the rocky Mountains which were in view from the high plain today were perfectly covered with snow." Further, the expedition, anxious to return home learned from the Nez Perce that crossing the Lolo Trail would not be possible until late the following month (Moulton 1983). The expedition first attempted crossing in mid-June, but on the third day out (17 June, and finding themselves, as Lewis noted, "inveloped in snow 12 to 15 feet deep even on the south sides of the hills with the fairest exposure to the sun" they were forced to retreat to Weippe Prairie near Camp Chopunnish (Moulton 1983). A week later, the expedition made a successful 6-day crossing of the Bitterroots with the help of Nez Perce guides, but still remarked on the exceptional snow depth.[8]

While the wet conditions at Ft. Clatsop were chiefly an annoyance to the CD, it did not significantly affect their travels, nor impact their activities. Conversely, the CD were delayed crossing the Lolo trail in the Bitterroots in June 1806 because of the exceptional snowpack. Ambrose (1996) has noted that because Lewis and Clark intended to continue exploring the region east of the Continental Divide on their return, particularly the Marias and Yellowstone Rivers, that the CD desired to get across the Bitterroots by no later than 1 July. Thus, the net result of the unusually heavy snowpack was a travel delay that did not significantly alter their plans.

Hydrological conditions and navigation. From Ft. Mandan until Camp Fortunate, the principal means of hauling the supplies and equipment of the CD was by advancing their pirogues and canoes up the Missouri River, then the Jefferson River, and finally the Beaverhead River. With the exception of the portage around the Great Falls, navigation along the Missouri was typically uncomplicated by shallow water and was achieved via paddling, pulling, and poling the canoes. By late July 1805 the CD had reached the Three Forks of the Missouri and navigation conditions became progressively worse with the onset of travel up the Jefferson River and then the Beaverhead River. By 4 August the difficulty of proceeding upstream was reported by Clark as, "the method that we are compelled to take to get on is fatigueing & laborious in the extreen, haul the Canoes over the rapids, which Suckceed each other every two or three hundred yards and between the water rapid oblige to tow & walke on Stones the whole day except when we have poleing men wet all day Sore feet &c." Navigation conditions did not improve either as Clark repeatedly mentioned the exhaustive impact of hauling the canoes over rapids until the arrival of the CD at Camp Fortunate on 17 August (Moulton 1983).

As difficult as travel had been to Camp Fortunate, stream conditions could have been substantially worse if drought conditions had prevailed. Using reconstructed streamflow along the upper Yellowstone River (Graumlich et al. 2003) as a proxy indicator of conditions experienced by the CD (the rivers are separated by approximately 160 km), streamflow in 1805 was 92% of average. If these conditions were compa-

[8] The snow depth conditions of 1806 are uncommon, but comparable depths may have occurred at least twice in the past 4 decades. Based on the period 1961–2002 at the Cool Creek SNOTEL station near the Lolo Trail (46.77°N, 115.30°W, 1915 m), mid-June snow depths were 15.4 feet and 15.1 feet in 1997 and 1999, respectively. These depths were converted from SWE data assuming snow density at 30%.

rable for the Jefferson and Beaverhead Rivers, then near-average conditions likely prevailed. Whether these conditions were optimal is uncertain, but hauling the canoes up the rivers clearly left the CD exhausted. Further complications caused by low flow (i.e., hauling the canoes greater distances) that would have taxed the CD would have been costly. The overall health of the men would have been impaired, the meeting with the Shoshones delayed, and the crossing of the Bitterroots would have occurred later into the fall (if then possible).

CONCLUSIONS. Scholars of the Lewis and Clark expedition repeatedly cite that the exceptional decision-making and leadership qualities of Lewis and Clark cannot alone account for the success of the CD and that they benefited from an abundance of luck (e.g., Chuinard 1979; Ambrose 1996). In the context of the climatic conditions they experienced, luck prevailed as well. The CD traveled through the American Northwest during a climatically favorable period that favored their success. They entered the region 4 yr after one of the most severe droughts within the past several centuries,[9] and they concluded their travel 2 yr before the onset of another major drought. Although they did experience an exceptionally wet winter at Ft. Clatsop and were delayed by a deep snowpack on their return trip, these conditions did not significantly impact the intended goals of the expedition. Alternatively, a drought would have, in all likelihood, substantially altered their expedition. Given the frequency, persistence, and severity of droughts within this region, and the distance that they traveled, the CD had, unbeknownst to them, a window of opportunity to successfully complete their trip.

Perhaps the greatest, and ultimately unanswerable, question is what would have happened if the CD had traveled during an intense drought period through the American Northwest? Certainly their food sources, particularly the game they shot on a daily basis, would have been less abundant. So too, would have been the other smaller, but important food sources (e.g., berries and roots) they consumed on a regular basis. Travel clearly would have been impacted, as low streamflow would have forced them to portage more often, slowed their progress, and would have required more labor and food.

The implications of the climatic conditions that the CD experienced between 1804 and 1806 are significant. First, given that the CD nearly did not successfully cross the Lolo Trail during favorable conditions and that they traveled the Lolo Trail near the end of the crossing season, it would have been unlikely that they would have arrived at the Pacific Ocean in the fall of 1805 if drought conditions had prevailed. Instead, the CD would have been forced to spend fall, winter, and spring east of the Columbia River drainage, which would have taxed their limited supplies, increased their chances of incurring misfortune, and perhaps would have demoralized the CD. Further, the climatic conditions that the CD did encounter influenced their perceptions of land quality in the American Northwest. Lewis and Clark ultimately had highly favorable impressions of the semiarid northern Great Plains likely in part because of the above-average precipitation conditions they encountered. Conversely, their negative assessment of the Pacific coast as a region that was "dank and choked with timber and underbrush" (Allen 1975, p. 326) was influenced by the exceptionally wet and stormy conditions they experienced during their winter at Ft. Clatsop.

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[9] Knapp et al. (2002) determined that 1800 was the sixth most severe single-year drought between 1500 and 1998 in the interior Pacific Northwest. A map of reconstructed PDSI values for the year 1800 by Cook et al. (2004) also shows the impressive extent of the drought ranging from the Pacific Coast to the central Great Plains.

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