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Salt-Affected Sites in the Teton Wilderness

by
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Salt-Affected Sites in the Teton Wilderness.

Advisor: Thomas H. DeLuca THD

Man-made salt licks have been created in the Teton Wilderness of Wyoming, USA to attract elk for hunting purposes. These sites have created adverse impacts to localized areas. The first part of this study was undertaken to examine physical and chemical characteristics of the sites. A total of 27 sites were identified and surveyed and paired with a non-affected control. Sites were analyzed for soil bulk density, electrical conductivity (EC), pH, organic matter percentage, sodium absorption ratio (SAR), and exchangeable concentrations of sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Sampling points were located both within salt sites and in representative control areas. Salt treated site centers were found to have elevated EC, bulk density, pH, SAR, and Na^+ concentration. Although EC levels were elevated, they did not qualify as saline soils. Sites had decreased organic matter content, Ca^{2+}, and Mg^{2+} concentrations. Observed differences were due to the addition of Na^+ to the soil solum and also removal and trampling of soil by ungulates. The second part of this study involved experimental restoration plots. A 2x2 factorial design was established at six salt sites using a control, aeration, and gypsum amendment. The purpose of aeration was to reduce soil bulk density caused by trampling. Gypsum was applied to alleviate the high Na^+ content of affected soils and to encourage flocculation. There was no appreciable vegetation establishment on the seeded plots after one growing season. Measured levels of EC and Ca^{2+} increased with gypsum amendment. Most importantly, aerating sites using hand tools did not act to improve bulk density. It is therefore recommended not to use aeration alone or with gypsum in rehabilitating salt affected sites in the Teton Wilderness. Rather, organic amendments or application of forest residues as a deterrent along with fencing to prevent trampling by ungulates is recommended.

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CHAPTER 1. History of Salt Licks and Literature Review.

Salt "Licks"

In 1792, Imlay was credited with implying that the word *lick* was a term used by hunters in colonial America. In Imlay's words, "A salt spring is called a 'Lick,' from the earth about them being furrowed out in a most curious manner by the buffalo and deer, which lick the earth on account of the saline particles with which it is impregnated" (cited in Jones and Hanson, 1985).

Many travelers and naturalists gave vivid descriptions of licks in the early nineteenth century (Jones and Hanson, 1985). Faux gave the following description of a lick on the Illinois frontier: "I saw a lick of singular size extending over nearly half an acre of land, all excavated three feet, that is to say, licked away, and eaten, by buffaloes, deer and other wild animals. It has the appearance of a large pond dried" (cited in Jones and Hanson, 1985).

History of Teton Salt Sites

The 585,468-acre Teton Wilderness is located just south of Yellowstone National Park in northwestern Wyoming, USA. It is boarded by Yellowstone National Park to the North, by Yellowstone and Grand Teton National Parks to the West, by Buffalo Valley to the South, and by the Washakie Wilderness to the east. It was designated a Primitive Area in 1934, and later made part of the National Wilderness Preservation System with passage of the Wilderness Act in 1964 (Wilderness Act, 1964).

Man-made wildlife salt licks exist in the Teton Wilderness, mainly along the Northern boundary with Yellowstone National Park. The main function of these licks is for attracting and hunting elk. Their location along the Yellowstone boundary helps pull large trophy elk out the park for hunting in the Teton Wilderness (Sandetto, 2000).

The Wyoming Game and Fish Department (WGFD) first created man-made salt licks in the Tetons. In the early 1940's, game managers realized that elk distribution seemed to be favoring Yellowstone Park and few elk herds were moving into appropriate habitat in the Teton Wilderness. This led to more harvesting on the National Elk Range and less in the Wilderness. To alleviate this, the WGFD experimented in 1945, 1946, and 1957 with placing mineral blocks in the wilderness area to see if differences in elk use patterns would occur (Sandetto, 2000).

Wyoming Game and Fish Department Job Completion Reports of 1956-1959 indicated that "no definite conclusions can be drawn from the salting experiment except that the animals apparently prefer a trace of mineral block over a calcium-phosphorous block. Careful evaluation of all factors over a period of several years will be necessary to determine the effects, if any, of this salting practice on the migration pattern or natural summer distribution of the elk." Even though the results were inconclusive and the practice halted, the WGFD allowed salting to continue by permitted outfitter/guides in the Teton Wilderness (Sandetto, 2000).

Section 2(c) of the Wilderness Act defines wilderness as: A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value (Wilderness Act, 1964).

Salting to influence big game distribution is not consistent with the Wilderness Act or philosophy of wilderness management. The establishment of Wilderness is meant to protect nature from human interference. Placing salt to influence wildlife distribution is affecting nature and thus wilderness. Additionally, the Bridger-Teton National Forest land management plan states that "visitor actions which tend to alter the natural behavior of wildlife in wilderness are not allowed." Salt sites are therefore illegal to create and cause visual and potential ecological impacts to the wilderness resource (Sandetto, 2000).

Another law regarding salting, clause R4-D6, is in all current Special Use Permits for outfitter/guiding in the Teton Wilderness. The clause states "The possession or distribution of salt is prohibited except as provided for in the Operating Plan for pack or saddle stock nutrition, trophy preservation, and culinary use. Periods of use, location, and method of livestock utilization will be provided by the holder and approved by the Forest Service Authorized Officer" (Sandetto, 2000).

More recently, there have been rising concerns over salt placement in the Teton Wilderness. In the fall of 1999 there was concern about lack of enforcement regarding salting regulations and potential human/bear conflicts around salt sites. This has led the United States Forest Service (USFS) to take action by initiating a study to determine the impacts to salt-affected sites (Sandetto, 2000).

History of Salt for Game Management

The use of salt to control movements of big game has historically been a common practice. In the early twenties in the Bitterroot Mountains of Idaho, it was noticed that big game were attracted to salt supplied for livestock. This led in 1921 to the distribution of two tons of salt on known game ranges by the State Fish and Game Department of Idaho (Case, 1938). This became the first big game salting program in the United States (Dalke et al., 1965).

This initial experiment was so successful that the Idaho State Fish and Game Department continued, and gradually increased yearly purchases and distribution of salt until every big natural lick was receiving a quota of salt. The USFS frequently assisted in the transportation and placement of salt, which was the most costly part of the salting program (Case, 1938).

The original objectives of the Idaho salting program were to place salt on naturally occurring licks. However, during the hard winters of 1931-1932 and 1932-1933, the loss of deer was so alarming, both forest managers and game wardens sought a remedy (Case, 1938).

The idea of putting salt on the summer range was mentioned in an Idaho Fish and Game biennial report in 1930, with the assumption that it would retard seasonal movement to the winter ranges. It was also thought that salt on the summer range would hasten the animals' return in the spring to the summer range (Dalke et al., 1965).

By 1931-1932, 61 tons of salt was spread on summer range by the Idaho Fish and Game Department, the USFS, and private sportsmen. The peak of salt distribution occurred in 1947 when 235 tons were dropped from the air. By 1954, the amount of block salt distributed had decreased to 129 tons and by 1960 to less than five tons (Dalke et al., 1965).

This initial Idaho salting program laid the foundation for other states. In 1953 all eleven western states except Nevada were distributing salt in varying quantities and for several different purposes. The salting program in Montana began in 1942 when six tons of salt were distributed in the Sun River, primarily to draw elk away from natural licks (Rognrud, 1955).

The use of salt on big game ranges in Montana increased after the program began in 1942. In 1951, a total of 80 tons were distributed for big game and in 1954 a total of 72½ tons were dispersed (Rognrud, 1955). Like Idaho, nearly all the objectives for the Montana salting program centered around salt to influence movements of big game. The most common objective was to lessen utilization of winter range forage (Rognrud, 1955).

Sodium, Salt Licks, and Animal Use

Intentional ingestion of soils, or geophagy, is a common practice by wild and domesticated animals (Arthur and Alldredge, 1979 and Beyer et al., 1994). The deliberate ingestion of soil by animals is well documented. Over 50 species have been found ingesting soils at salt licks (Beyer et al., 1994). Concentrations of some elements in ingested soil may be so high in comparison with the concentrations in the animal's diet that the soil becomes an important source of nutrients (Arthur and Alldredge, 1979; and Beyer et al., 1994). Soil ingestion may be important to the animals by supplying nutrients or by interfering with absorption of nutrients (Garcia-Bojalil et al., 1988).

Almost all ungulates use salt licks to some extent to supplement their diet. In the Rocky Mountains, sheep and goat use different licks than other ungulates. They lick away almost solely at dry earth exposures, many which are white earth slopes. Many times dry, friable rock, which may be essentially unweathered, is eaten. For moose and mountain caribou, wet, muck licks and mineral springs are preferred while white-tailed and mule deer frequent dry licks, and elk visit both types equally (Jones and Hanson, 1985).

In a review of natural deer salt licks, Weeks (1974) analyzed food items eaten throughout the year as well as soil from licks that deer used. He evaluated the morphology of their adrenal glands and the intensity of their use of licks. Weeks (1974) concluded that Na^+ is the main draw of animals for use of mineral licks. He concluded that high levels of K^+ in spring forage, particularly grasses, and the succulent condition of herbage at this season creates conditions for decreased efficiency of tubular resorption in the kidneys and a diarrheic condition that further contributes to Na^+ loss (Weeks, 1974).

Studies by Fraser et al. (1984), Dalke et al. (1965), as well as many quoted in Jones and Hanson (1985) all point to Na^+ as the chemical component in both soil and water samples at salt licks that attract wildlife. Dalke et al. (1965) commented that "sodium in the spring and seep waters seemed to be the element attracting game to these areas. The sodium content ranged from 0.75 to 3.96 meq/L (18-91 ppm). Such low concentrations are apparently detectable by big game as no other element analyzed was found in comparable amounts."

Although animals have a physiological need for Na^+, Rognrud (1955) suggests that in big game it becomes an acquired taste. A study by Black (1955) of salt consumption by deer in Oregon showed increased use of salt licks each year the study was in progress. Black (1955) suggested that salt consumption probably reflects the degree that deer have acquired the salt habit (cited in Rognrud, 1955).

Ungulates may also find Na^+ via runoff from road deicing salts. In northern Ontario, where there is relatively poor availability of environmental Na^+, natural mineral springs and roadside pools contaminated by highway de-icing salt provide native animals with supplementary Na^+ (Fraser, 1985). Fraser (1985) documented moose and white-tailed deer at these artificial roadside sites.

Each winter in this area, de-icing salt (NaCl) is spread on the highway at an estimated rate of 30-40 metric tonnes/km. Subsequently, many pools of stagnant water near the roadside have a high Na^+ content (100-600 ppm). Because the roadside areas are laden with Na^+, many pools are recharged with brine at each rainfall and show little tendency for Na^+ levels to decline during the summer (Fraser, 1985).

In the same area, Fraser and Thomas (1982) found that moose were very sensitive to even small amounts of salt. They found that on one highway, it was only sanded in the winter and a small amount of salt was used to prevent the sand from clumping. However, even this minimal amount was sufficient to attract ungulates (Fraser and Thomas, 1982).

In a study on roadside salt licks in New Hampshire, Miller and Litvaitis (1992) found that during the spring, levels of Na^+ were higher at licks (628.5 ppm) than in puddles (45.9 ppm) or streams (5.2 ppm) with smaller differences for K^+, calcium (Ca^{2+}), and magnesium (Mg^{2+}). Even though the puddles in their study contained much higher concentrations of Na^+ than streams, they infrequently observed moose using the puddles. This reinforces Na^+ as the main attraction for ungulates.

In their study, Miller and Litvaitis (1992) reported that moose used roadside salt licks in spite of availability of ponds that contained aquatic plants. Although aquatic plants contain higher amounts of Na^+ then terrestrial plants (Fraser et al., 1984), the use of licks may have been advantageous because licks provide a more efficient means of obtaining Na^+ than aquatic plants.

Belovsky (1978) calculated that a moose at a lick ingests Na^+ 15 times faster than when feeding on aquatic plants. Additionally, aquatic plants have a lower energy content than terrestrial browse species. It ends up being very advantageous for an ungulate to use a salt lick for Na^+ consumption as opposed to aquatic plants (Miller and Litvaitis, 1992).

There have been a handful of studies on artificial salting and animals use. However, few articles have addressed detrimental impacts of salt sites. In the Montana and Idaho Game and Fish salting studies, the main focus was to determine the success in management of game to conserve winter range. Some useful observations of their impacts were made however. Dalke et al. (1965) found that when salt was placed in the fall, on top of snow pack, little salt was actually wasted because elk ingested the salt-impregnated soil. They also found that salt blocks were very frequently consumed before there was any noticeable soil ingestion.

When searching for placed artificial salt licks, Rognrud (1955) noted that they "could be located from the air by the appearance of trails radiating from the site. Depending on the relative number of animals using the salt lick, the site was trampled in areas of different size, with the salt blocks consumed and weathered to a varied degree. When salt was completely consumed, holes were licked in the ground at the place salt had been." These observations are very similar to the salt sites in the Teton Wilderness.

Other authors have observed soil consumption after salt blocks have been eaten. Jones and Hanson (1985), in their review of salt licks, found that wild animals avoid salt blocks to eat the soil surrounding or underneath the blocks. The most reactive portion of the soil and lick earth is the clay-size fraction, leading them to hypothesize that lick soils would likely be enriched in clay-sized material (Jones and Hanson, 1985).

Salts, in particular Na^+ leaching into the soil solution can bring about many concerns for contamination. One concern is that this may act to salinize the soil. Soil salinity refers to the presence of major dissolved solutes in aqueous samples (Lilley, 1982 and Rhoades, 1996). The predominant solutes responsible for salinity include the cations Na^+, Ca^{2+}, and Mg^{2+}, and the anions sulfate (SO_4^{2-}) and chloride (Cl^-). Minor amounts of K^+, carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and nitrate (NO_3^-) may also be present in salinized soils (Bernstein, 1975 and Janzen, 1993). Soil salinity is quantified in terms of the total concentration of these soluble salts. The diagnosis, assessment, management, and need for reclamation of saline soils are evaluated using information of soil and water salinity (Bresler et al., 1982 and Lima et al., 1990).

Soil salinity is a problem in the limitation of productivity from certain soil types throughout the world. The accumulation of soluble salts in the soil profile restricts plant growth through the increase of osmotic potential of the soil solution and inducing ion toxicities of nutrient imbalances (Bernstein, 1975 and Bresler et al., 1982). Additionally, salts also limit plant growth by harmful effects on soil structure. High concentrations of Na^+ on cation-exchange sites will disperse soils and impede water and air movement (Bernstein, 1975).

Elevated levels of Na^+ and subsequent sodium absorption ratios (SAR) cause several negatives attributes of soil including swelling, clay dispersion and plugging of water conducting pores by the dispersed clay, and slaking of large soil aggregates into smaller aggregates (Abu-Sharar et al., 1987 and Barzegar et al., 1996). These soil effects prevent root elongation, water infiltration, aeration and subsequent plant growth.

In the past, it has been accepted that SAR of >13 affects structural and hydraulic properties of soil (Richards, 1954). However, more recent authorities feel that this value may need reconsideration because negative soil attributes may occur at even lower values (Crescimanno et al., 1995). Agassi et al. (1985), Crescimanno et al. (1995), McIntyre (1979), and Rengasamy et al. (1984) all propose SAR values greater than five to be considered sodic.

Crescimanno et al. (1995) found an almost linear relationship between SAR and negative soil properties such as clay swelling and dispersion, slaking of unstable aggregates, and hydraulic conductivity, leading them to conclude that there is no critical SAR threshold. They also reported that an effective hazard of soil quality degradation can be forecasted at a 2 to 5 SAR range in a low cationic concentration (Crescimanno et al., 1995).

Although no published attempts at rehabilitating artificial salt sites have been found there have been efforts to reclaim salt-affected agricultural systems. There has been success in reforming degraded soil aggregates using various amendments. One of these amendments is a synthetic polymer, polyacrylamide (PAM). Helalia and Letey (1988) report that PAMs can stabilize soil aggregates. The aggregates to be stabilized must have been previously formed or created via a mixing process (Cook and Nelson, 1986). This lengthy process along with the high cost of materials makes PAMs unattractive (Terry and Nelson, 1986).

Gypsum, or calcium sulfate ($CaSO_4 \bullet 2H_2O$) is commonly used as a chemical amendment for replacement of exchangeable Na^+ on cation exchange sites. The Ca^{2+} in the gypsum acts to replace Na^+ on the exchange sites as the Na^+ leaches further into the soil substrate and the Ca^{2+} is available for plant uptake. Additionally, this process helps the physical properties of Na^+-saturated soils by decreasing dispersion of clay particles and slaking of aggregates, promoting flocculation and subsequently increasing the amount of aggregates present (Richards, 1954).

Despite the fact that no study rehabilitating artificial salt licks has been attempted, there have been a few useful studies of animal use of salt sites. The wealth of publications from agricultural systems concerning rehabilitation of salt-affect soils is a useful tool, however wilderness soils require a creative and different evaluation because they are not under active agricultural management. One of the primary concerns of any rehabilitation attempt on the Teton salt sites will be the remote location and the laws governing management of Wilderness Areas. It would be unfeasible to attempt any intensive management program.

Literature Cited

Abu-Sharar, T.M., F.T. Bingham, and J.D. Rhoades. 1987. Stability of soil aggregates as affected by electrolyte concentration and composition. Soil Science Society of America Journal. 51:309-314.

Agassi, M., J. Morin, and I. Shainberg. 1985. The effect of water drop impact energy and water salinity on the infiltration rates of sodic soils. Soil Science Society of America Journal. 49:186-190.

Arthur, W., and A. Alldredge. 1979. Soil ingestion by mule deer in northcentral Colorado. Journal of Range Management. 32:67-70.

Barzegar, A.R., J.M. Oades, and P. Rengasamy. 1996. Soil structure degradation and mellowing of compacted soils by saline-sodic solutions. Soil Science Society of America Journal. 60:583-588.

Belovsky, G. 1978. Diet optimization in a generalist herbivore: the moose. Theoretical Population Biology. 5:105-134.

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Annual Review of Phytopathology. 13:295-312.

Beyer, W.N., E.E. Conner, and S. Gerould. 1994. Estimates of soil ingestion by wildlife. Journal of Wildlife Management. 58:375-382.

Black, H.C. 1955. Salt use by mule deer in the Dechutes National Forest of Central Oregon. Master's thesis, Oregon State College, Corvallis, OR, USA.

Bresler, E., B.L. McNeal, and D.L. Carter, (eds.). 1982. Saline and sodic soils: principals-dynamics-modeling. Springer-Verlag., New York, NY, USA.

Case, G. 1938. The use of salt in controlling the distribution of game. Journal of Wildlife Management. 2:79-81.

Cook, D.F., and S.D. Nelson. 1986. Effect of polyacrylamide on seedling emergence in crust-forming soils. Soil Science 141:328-333.

Crescimanno, G., M. Iovino, and G. Provenzano. 1995. Influence of salinity and sodicity on soil structural and hydraulic characteristics. Soil Science Society of America Journal. 59:1701-1708.

Dalke, P., R. Beeman, F. Kindel, R. Robel, and T. Williams. 1965. Use of salt by elk in Idaho. Journal of Wildlife Management. 29:319-332.

Fraser, D. 1985. Mammals, birds, and butterflies at sodium sources in Northern Ontario forests. The Canadian Field-Naturalist. 99:365-367.

Fraser, D., and E. Reardon. 1980. Attraction of wild ungulates to mineral-rich springs in central Canada. Holarctic Ecology. 3:36-40.

Fraser, D., and E. Thomas. 1982. Moose-vehicle accidents in Ontario: relation to highway salt. Wildlife Society Bulletin. 10:261-265.

Fraser, D., E. Chavez, and J. Paloheimo. 1984. Aquatic feeding by moose: selection of plant species and feeding areas in relation to plant chemical composition and characteristics of lakes. Canadian Journal of Zoology. 62:809-817.

Garcia-Bojalil, C., C. Ammerman, P. Henry, R. Littell, and W. Blue. 1988. Effects of dietary phosphorus, soil ingestion, and dietary intake level on performance, phosphorus utilization, and serum and alimentary tract mineral concentrations in lambs. Journal of Animal Science. 66:1508-1519.

Helalia, A.M., and J. Letey. 1988. Polymer type and water quality effects on soil dispersion. Soil Science Society of America Journal. 52:243-246.

Janzen, H.H. 1993. Soluble Salts., p. 161-167, *In* M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers,, Boca Raton, FL, USA.

Jones, R., and H. Hanson. 1985. Mineral licks, geophagy, and biogeochemistry of North American ungulates. The Iowa State University Press, Ames, Iowa, USA.

Lilley, J. 1982. Dryland salinity in Alberta. Edmonton: Environmental Council of Alberta.

Lima, L.A., M.E. Grismer, and D.R. Nielsen. 1990. Salinity effects on Yolo loam hydraulic properties. Soil Science. 150:451-458.

McIntyre, D.S. 1979. Exchangeable sodium, subplasticity, and hydraulic conductivity of some Australian soils. Australian Journal of Soil Research. 17:115-120.

Miller, B., and J. Litvaitis. 1992. Use of roadside salt licks by Moose, Alces alces, in northern New Hampshire. Canadian Field-Naturalist. 106:112-117.

Rengasamy, P., R.S.B. Green, G.W. Ford, and A.H. Mehanni. 1984. Identification of dispersive behaviour and the management of the red-brown earths. Australian Journal of Soil Research. 22:413-431.

Rhoades, J.D. 1996. Salinity: Electrical Conductivity and Total Dissolved Solids., p. 417-435, *In* D. L. Sparks., ed. Methods of Soil Analysis-Part 3 Chemical Methods. SSSA Book Series 5. American Society of Agronomy, Madison, WI, USA.

Richards, L.E. 1954. Diagnosis and Improvement of saline and alkali soils. Handbook 60. U. S. Salinity Laboratory, U. S. Department of Agriculture.

Rognrud, M. 1955. Evaluation of artificial salting and aerial salt distribution. Montana Fish and Game Commission Wildlife Restoration Division Quarterly Report. Project W-60-R-2 6(2).

Sandetto, E. 2000. Salt strategy. Unpublished Draft. USDA Forest Service, Teton Wilderness Buffalo Ranger District Bridger-Teton National Forest., Moran, WY, USA.

Terry, R.E., and S.D. Nelson. 1986. Effects of polyacrylamide and irrigation method on soil physical properties. Soil Science. 141:317-320.

Weeks, H. 1974. Physiological, morphological, and behavioral adaptations of wild herbivorous mammals to a sodium-deficient environment. Ph.D. dissertation, Purdue University, Lafayette, Indiana, USA.

Wilderness Act. 1964. 16 U.S.C. 1 1 21

Chapter 2. Properties of Salt-Affected Sites in the Teton Wilderness.

Abstract

Artificial salt licks in the Teton Wilderness have been created for hunting purposes and have caused areas of localized damage. The purpose of this study was to examine and characterize these sites. Physical and chemical properties of soils both inside and outside of salt sites were analyzed to compare differences. Bulk density, pH, electrical conductance, organic matter percentage, and analysis for concentrations of exchangeable sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}) were measured. It was found that compaction of the soils has the greatest effect on plant growth. Significantly higher levels of Na^+ were found inside of salt sites along with lower levels of Mg^{2+} and Ca^{2+}. Significantly lower percentages of organic material were also found in salt sites.

Introduction

Creation of salt licks in the Teton Wilderness has resulted in adverse impacts to vegetation and soils. The extent of these impacts were identified and studied.

The Wyoming Department of Game and Fish (WDGF) began salting in the Teton Wilderness in 1945. This salting was initiated to attract elk out of Yellowstone National Park into good habitat in the Teton Wilderness. The WDGF eventually discontinued salting but outfitters and private sportsmen in the area were allowed to continue salt placement until it was outlawed in 1990 (Sandetto, 2000).

The management of large ungulates by salt placement was a common practice historically. From the 1920's until the 1950's every western state except Nevada was using salt to some extent to try and control game movements. The main goals of these salting programs were to hold animals on summer range and conserve winter range (Dalke et al., 1965).

Although big game naturally seek salt, some authors feel a taste for salt is acquired when it is placed artificially (Rognrud, 1955). A study of salt consumption by deer in Oregon (Black, 1955) showed increased use of salt each year the study was in progress. Black (1955) suggested that salt consumption probably reflects the degree that deer have acquired the salt habit.

In studies of both natural and artificial salt licks, authors have found that sodium (Na^+) is the main draw for animal use (Dalke et al., 1965 and Jones and Hanson, 1985). High levels of potassium (K^+) in spring forage, particularly grasses, and the succulent condition of herbage at this season creates conditions for decreased efficiency of tubular resorption in the kidneys and a diarrheic condition that contributes to Na^+ loss and attracts ungulates to salt sites (Weeks, 1974).

Although aquatic plants contain higher amounts of Na^+ then terrestrial forage (Fraser et al., 1984), the use of licks is advantageous because they provide a more efficient means of obtaining Na^+ than aquatic plants. A moose at a lick ingests Na^+ 15 times faster than when feeding on aquatic plants (Belovsky, 1978). Also, aquatic plants have a lower energy content than terrestrial browse species. Therefore, when obtaining Na^+ from mineral licks, moose save time and energy allowing them to locate and feed on more nutritious forage (Miller and Litvaitis, 1992).

In simulated licks investigated by Jones and Hanson (1985), an estimated 22.7kg of common salt was spread on 9.3 m^2 annually from 1953 to 1976. This amount of salt evenly distributed through soil to a depth of 5 cm (assuming soil density = 1.3 g/cm^3) would create a concentration of 38,000 ppm Na^+ for a single addition. However, the actual concentration of 390 ppm found there indicates that much of the salt had been leached or consumed (Jones and Hanson, 1985).

Outfitters in the Teton Wilderness have that salt applications in excess of a ton of salt have been placed on individual sites yearly. This would imply concentrations much larger than the 38,000-ppm Na^+ hypothesized by Jones and Hanson (1985). However, just like Jones and Hanson (1985), concentrations were relatively low in the Teton salt sites, averaging 815 ppm Na^+.

One of the negative effects of salt placement on soil is the possibility of producing salinized soils. Soil salinity is quantified in terms of the total concentration of soluble salts. The diagnosis, assessment, management, and need for reclamation of saline soils are evaluated using information of soil and water salinity (Bresler et al., 1982; Lilley, 1982; Lima et al., 1990; and Rhoades, 1996). Soil salinity is a problem in the limitation of productivity from certain soil types throughout the world. The accumulation of soluble salts in the soil profile restricts plant growth through the increase of osmotic potential of the soil solution and inducing specific ion toxicities of nutrient imbalances (Bernstein, 1975 and Bresler et al., 1982).

The USDA developed indices of saline and sodic soils as guidelines for crop production (Richards, 1954). Although these guidelines have little relevance to natural systems, they provide a benchmark from which to judge the salinity and sodicity of Teton soils as they are affected by salting.

Using measures of electrical conductivity (EC), sodium absorption ratio (SAR), and soil pH, salt-affected soils are classified as saline, saline-sodic, or sodic. Electrical conductivity is a measure of the dissolved salts in soil solution and SAR is calculated from relative concentrations of Na^+, Ca^{2+}, and Mg^{2+} (Abrol et al., 1988; Rhoades, 1996; and Rhoades et al., 1999). A saline soil has an EC > 4 μmhos/cm, SAR < 13, and pH <8.5, a saline-sodic soil has an EC > 4 μmhos/cm, SAR > 13, and pH <8.5, and a sodic soil has an EC < 4 μmhos/cm, SAR > 13, and pH > 8.5 (Abrol et al., 1988; Rhoades, 1996; and Rhoades et al., 1999).

Even if a soil is not classified as sodic or saline under the traditional USDA standards, elevated levels of SAR cause several negative soil attributes including swelling, plugging of water conducting pores by dispersed clay, and slaking of large soil aggregates into smaller aggregates (Abu-Sharar et al., 1987; Barzegar et al., 1996; Cook and Nelson, 1986; Helalia and Letey, 1988; and Zahow and Amrhein, 1992). These processes in turn prevent root elongation, water infiltration, aeration and subsequent plant growth.

Traditionally, it has been accepted that an SAR of >13 affects structural and hydraulic properties of soil (Richards, 1954). However, authors have recently found that this value may need reconsideration. Crescimanno et al. (1995) found an almost linear relationship between SAR and negative soil properties such as clay swelling and dispersion, slaking of unstable aggregates, and hydraulic conductivity, leading them to conclude that there is no critical SAR threshold. They also reported that an effective hazard of soil quality degradation could be forecasted at an SAR of 2-5 in low cation concentrations (Crescimanno et al., 1995). Agassi et al. (1985), McIntyre (1979), and Rengasamy et al. (1984) all propose SAR values around >5 to be considered sodic.

Trampling of the soil is another concern for this study. Trampling by ungulates causes compaction, which adversely affects plant growth (Braunack and Walker, 1985; Greene et al., 1994 and Willatt and Pullar, 1984). Increased compaction is expected to occur on the Teton salt sites, decreasing water infiltration and root elongation and causing less vegetation to grow.

Along with compaction and Na^+ influences, organic matter levels will be negatively affected in salt enriched soils. Levels of organic materials are an important index for site reclamation. Higher levels of organic material can improve soil physical properties such as water infiltration, aggregation, and bulk density (Huang and Lu, 2000 and Logan, 1992). Lower organic matter percentage in salt sites is expected to adversely influence plant growth.

The objective of this study was to sample and assess damage to soil physical and chemical characteristics of salt affected areas. Measurements included bulk density, pH, electrical conductance, organic matter percentage, and analysis for concentrations of exchangeable Na^+, Ca^{2+}, K^+, and Mg^{2+} on both affected and adjacent non-affected areas (controls).

Study Area

Laboratory and field measurements were performed on soil samples collected from salt-affected sites in the Teton Wilderness of the Bridger-Teton National Forest.

These sites were located just south of the Yellowstone National Park boundary ranging in location from a few meters to several miles away from the boundary. Appendices 1 and 2 show location and UTM coordinates for all sites. The sites were located in the bottoms of the Washakie and Absaroka Ranges and in within the uplands of the Washakie Range. The bottomland sites were former glacial till deposits and the upland sites had residual volcanic conglomerate parent material. Elevation for salt sites ranged from 2393 to 2915 meters. Mean annual temperature is 2.4° C and precipitation is 20.7 cm.

Materials and Methods

Sites were located using a combination of maps provided by park rangers, prior knowledge of sites by rangers and outfitters, GPS coordination, and topographical maps. Initially total area (in meters) influenced by salt was determined. The zone bare of vegetation delineated the site. Next the depth of disturbance was measured by stretching a tape measure tight across the site then measuring the depth to the bottom of the pit. At each site, six sample points were identified. Three were located inside of the affected area while three were outside in an unaffected control. At all six of these points, samples were collected and measures of bulk density, electrical conductivity, and pH were taken.

Bulk density was determined in the field on the first 15 cm of mineral soil using the slide hammer core method (Culley, 1993). A 5 g representative sample was then diluted to 50mL soil solution with deionized water at each point. Electrical conductivity was measured on this solution with a CON 5 series Acorn Meter and recorded in μmhos per centimeter.

Using the method described by Thomas (1996), pH was measured on each sample. A 10-gram representative sample was diluted with 20 mL of 0.01 $M\,CaCl_2$, stirred for 30 seconds, left to stand for 5 minutes and then soil pH was measured.

Exchangeable Na^+, Ca^{2+}, K^+, and Mg^{2+} concentrations were determined on each sample. These elements are used in determining the extent of salinity and/or sodicity of soils (Bernstein, 1975; Janzen, 1993; and Rhoades, 1996). They have been the primary elements analyzed in several studies on both artificial and natural salt sites (Abrahams, 1999; Fraser, 1985; Klein and Thing, 1989; Miller and Litvaitis, 1992; and Schultz and Johnson, 1992).

Soils were first dried at 100° C then passed through a 2mm sieve. A 10-gram subsample was mixed with 35mL of 1.0 *M* NH_4Cl and shaken for an hour. The sample was filtered through a Whatmann-42 filter paper and brought to 100mL with 1.0 *M* NH_4Cl in a volumetric flask. Adding 1.0 *M* NH_4Cl to the soil sample acts to saturate the cation exchange sites with NH_4^+ and release all sorbed cations into solution. The extract was then stored in a refrigerator until cation analysis could be made on an atomic absorption spectrophotometer (AAS) (Rhoades, 1996).

The SAR was calculated using the following equation: $SAR=[Na^+]/[(Ca^{2+} + Mg^{2+})]^{0.5}$, where concentrations are in meq/L (Janzen, 1993). The SAR is used to determine sodicity or relative sodium status of soil solutions or aqueous extracts (Rhoades et al., 1999).

Soil organic matter was estimated by loss of mass on ignition at 440° C. About 5g of sieved soil sample was placed in a porcelain container and weighed. Next the samples were placed in the muffle furnace at 440° C and heated overnight (16 hours). They were then cooled in a desiccator and weighed again. The percentage of weight lost was determined to be organic matter (Kalra and Manyard, 1991).

Averages from the three control and center locations from each plot were calculated and paired. They were then tested for a normal distribution, meeting the assumptions of a t-test. A dependent t-test was ran to see if the average of the differences was zero. This is pseudo-pairing before and after treatment assuming the control and salt site center are of the same soil origin (Sokal and Rohlf, 1981).

Results

During the fall of 2000 (September 1- October 10), 29 salt sites were identified in the Thoroughfare and Fox Park areas of the Teton Wilderness. However, after reexamining the sites in the spring of 2001, nine of the sites were found not to be true salt sites but dried up marshes in the fall, which exhibited similar characteristics to salt sites.

The summer of 2001 was spent searching for additional salt sites and revisiting all except for two of the sites for further sampling, GPS coordination, and monitoring changes. In all, seven new sites were found. Table 2.1 shows elevation, aspect, slope, habitat, percentage sand silt and clay, and soil great group for all sites identified. Sites were from a variety of locations, ranging in elevation from 2393 to 2915 meters. There were five forested sites and the rest were all in open meadows. A majority of the sites were found in flat locations.

Table 2.1. General characteristics of salt affected sites in the Teton Wilderness.

Site	Elevation (m)	Aspect	% Slope	Habitat	% Sand/Clay/Silt	Great Group
1	2393	Flat	0	Meadow	2/42/56	Haplocryolls
2	2396	Flat	0	Meadow	20/30/50	Haplocryolls
3	2421	Flat	0	Meadow	10/54/36	Haplocryolls
4	2409	Flat	0	Meadow	64/16/20	Haplocryolls
5	2405	North	5	Meadow	62/16/22	Cryochrepts
6	2457	Southeast	20	Meadow	42/34/24	Haplocryolls
7	2409	Flat	0	Meadow	26/38/36	Haplocryolls
8	2409	Flat	0	Forest	42/20/38	Cryochrepts
9	2817	Southwest	5	Alpine Meadow	38/24/38	Cryochrepts
10	2817	Flat	0	Alpine Meadow	humic	Medisaprists
11	2561	Flat	0	Meadow	60/20/20	Cryochrepts
12	2436	South	10	Meadow	42/32/26	Haplocryolls
13	2424	Flat	0	Meadow	76/12/12	Haplocryolls
15	2482	Flat	0	Forest	44/28/28	Cryochrepts
17	2561	Flat	0	Forest	34/32/34	Cryochrepts
18	2555	West	15	Meadow	26/34/40	Cryochrepts
19	2710	East	15	Forest	18/44/38	Cryochrepts
22	2707	Flat	0	Meadow	32/28/40	Cryochrepts
25	2790	Northwest	25	Alpine Meadow	40/22/38	Cryochrepts
26	2790	Northwest	25	Alpine Meadow	50/16/34	Cryochrepts
30	2915	North	15	Forest	35/22/43	Cryochrepts
31	2768	Flat	0	Alpine Meadow	38/18/44	Cryochrepts
32	2805	Flat	0	Alpine Meadow	4/53/43	Cryochrepts
33	2671	Flat	0	Meadow	44/20/36	Cryochrepts
34	2683	Flat	0	Meadow	29/32/39	Cryochrepts
35	2823	West	5	Alpine Meadow	49/10/41	Cryochrepts
36	2820	Flat	0	Alpine Meadow	51/14/35	Cryochrepts

The length, width, average depth, and estimated area of each site are given in Table 2.2. The areas of the sites varied from 657 to 20 m^2 and from 65 cm deep to little or no depression.

Table 2.2. Length, width, depth, and estimated area of each salt site measured in the Teton Wilderness.

Site	Length N-S (m)	Width E-W (m)	Depth (cm)	Area (m^2)
1	24.9	19.0	0	473.1
2	13.8	14.8	0	204.2
3	19.8	12.4	65	245.5
4	10.8	10.6	23.5	114.5
5	11.3	19.0	53	214.7
6	13.4	9.5	51	127.3
7	9.1	9.6	56	87.4
8	2.2	9.2	11	20.2
9	10.0	8.4	27	84.0
10	15.5	42.4	11	657.2
11	7.4	6.4	28	47.4
12	7.7	3.5	22	27.0
13	9.0	10.9	32	98.1
15	10.5	18.4	0	193.2
17	20.4	26.4	0	538.6
18	18.4	11.6	23	213.4
19	13.6	30.0	20	408.0
22	12.8	23.0	32	294.4
25	16.7	28.7	44	479.3
26	16.1	15.6	32	251.2
30	21.3	12.2	15	259.9
31	11.7	7.1	26	83.1
32	8.6	4.4	29	37.8
33	12.9	17.4	24	224.5
34	12.4	8.8	24	109.1
35	9.1	5.9	11	53.7
36	10.7	7.8	0	83.5
Average	13.0	14.5	24.4	208.5

Table 2.3. Site center and control averages, standard error, and p-values for variables measured on salt-affected sites in the Teton Wilderness.

Variable	Site Center	Control	p-value
Electrical Conductance (µmhos/cm)	0.39 ± 0.08	0.10 ± 0.02	0.0032**
Soil pH	4.98 ± 0.09	4.81 ± 0.08	0.0184**
Organic Matter %	7.88 ± 2.25	12.5 ± 1.53	0.0015**
Bulk Density (g/cm^3)	1.16 ± 0.05	0.82 ± 0.04	0.0000***
Sodium Adsorption Ratio	10.4 ± 4.30	0.48 ± 0.13	0.0274*
Sodium Concentration (ppm)	756 ± 111	81.7 ± 10.6	0.0000***
Potassium Concentration (ppm)	425 ± 61.7	519 ± 82.1	0.2657^{ns}
Magnesium Concentration (ppm)	391 ± 91.3	587 ± 99.1	0.0005***
Calcium Concentration (ppm)	1212 ± 161	1894 ± 174	0.0000***

*** different from control, $\alpha<0.001$
** $\alpha=0.01$
* $\alpha=0.05$
ns=not significant

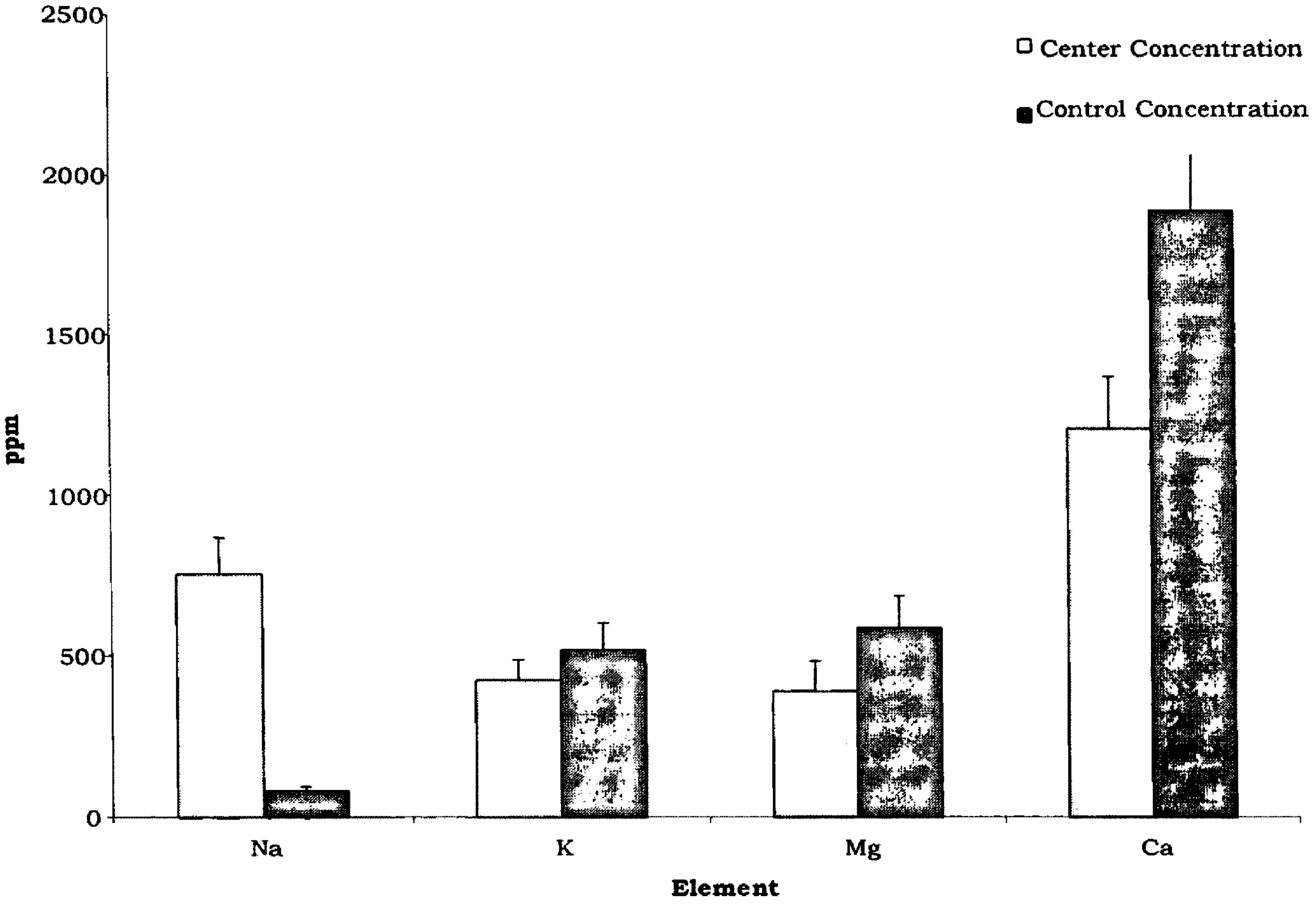


Figure 2.1. Average cation concentrations for all salt sites measured in the Teton Wilderness. Error bars represent standard errors for each measure.

A summary of average values for variables measured is given in Table 2.3. There was a significant difference between salt sites and controls for all measured variables except for K^+ concentration. The strongest associations were found for bulk density and concentrations of Na^+, Mg^{2+}, and Ca^{2+}. Figure 2.1 illustrates differences in cation concentrations between site centers and controls.

Figure 2.2 shows average EC values for each salt site in μmhos/cm. The standard error is represented on each error bar. Most values were relatively low, with EC > one at three sites.

Soil pH is given for each site in Figure 2.3. There was little variability in pH. Six of the controls had higher pH and all sites were somewhat acidic.

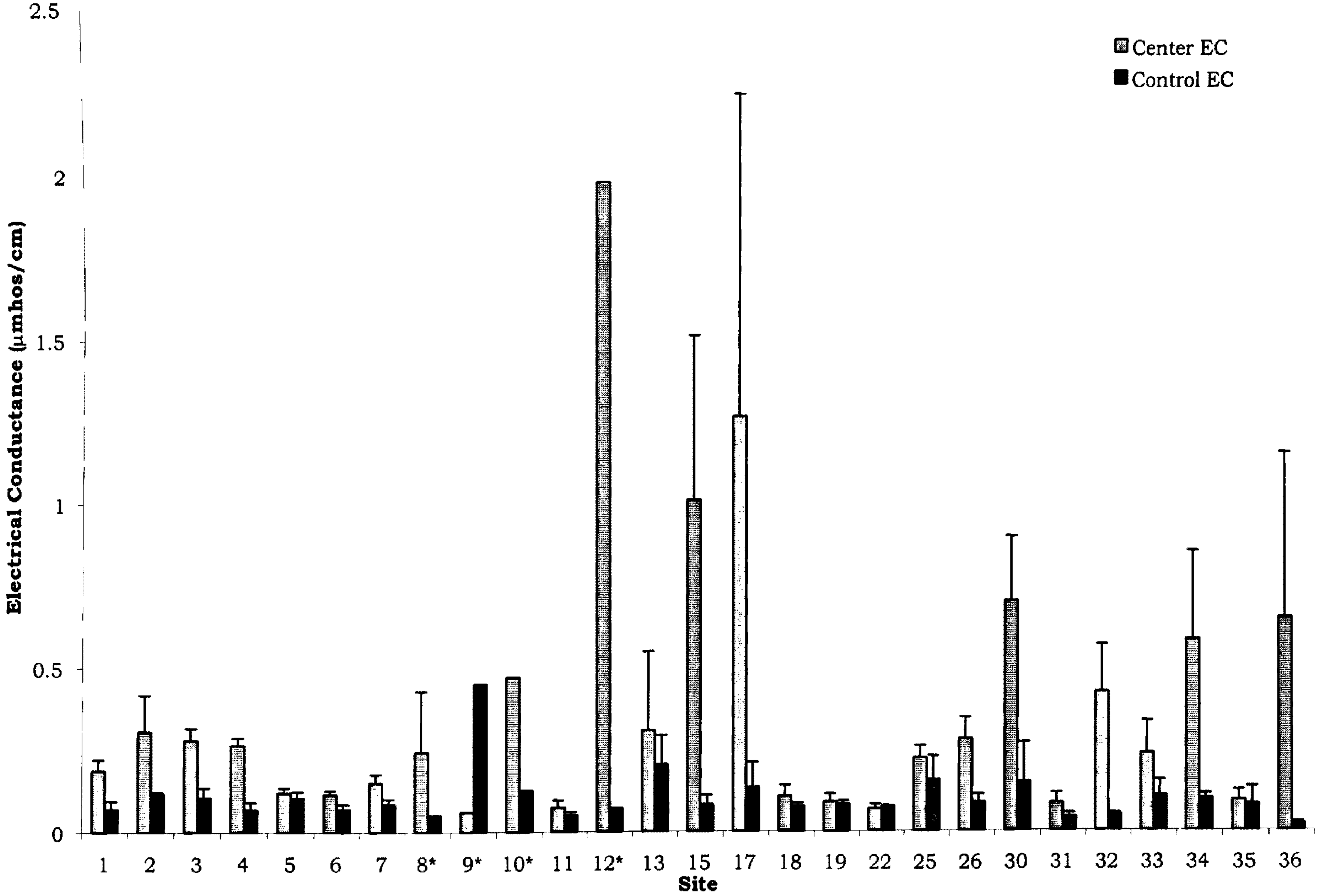


Figure 2.2. Mean Electrical Conductivity of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

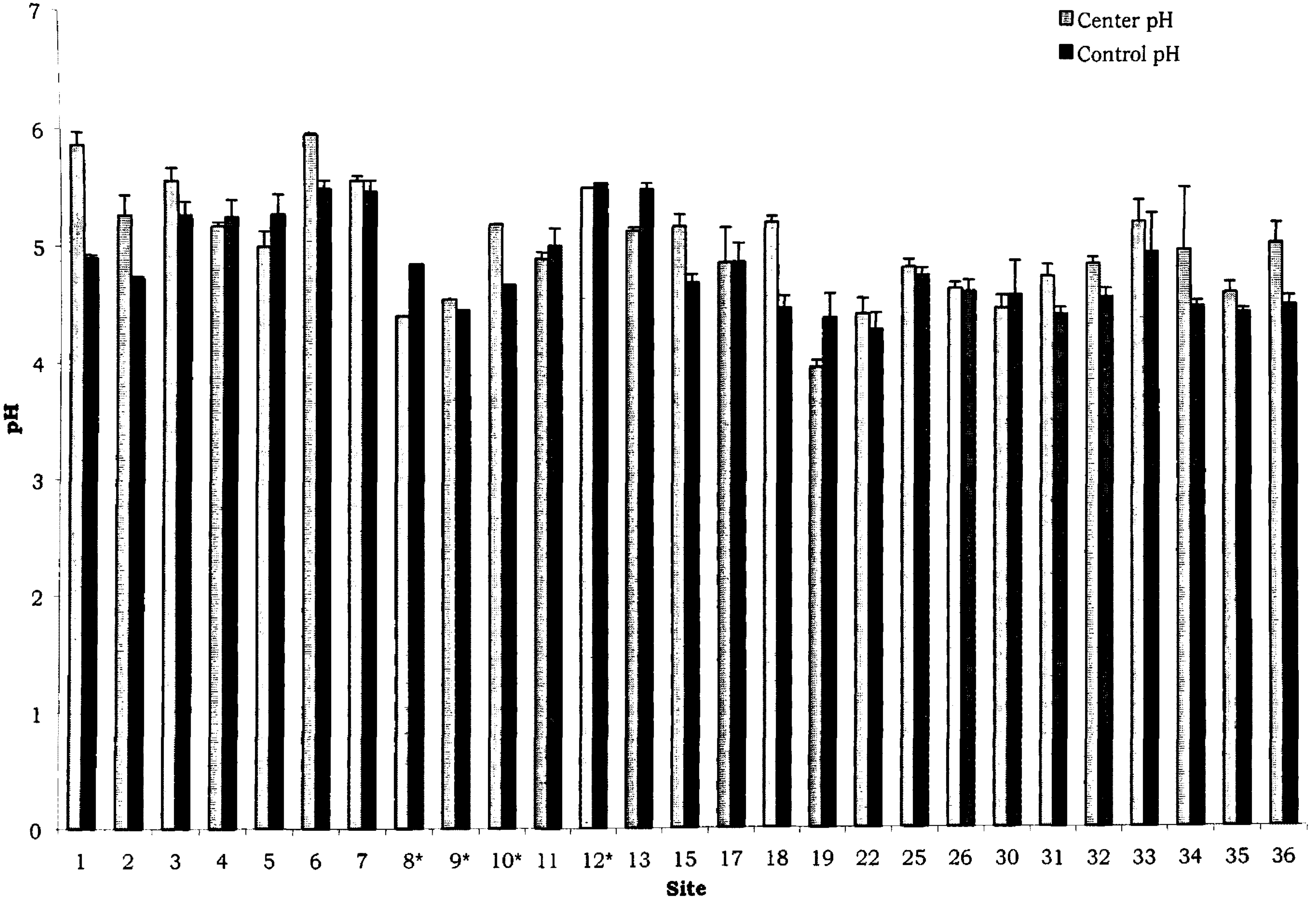


Figure 2.3. Mean soil pH of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

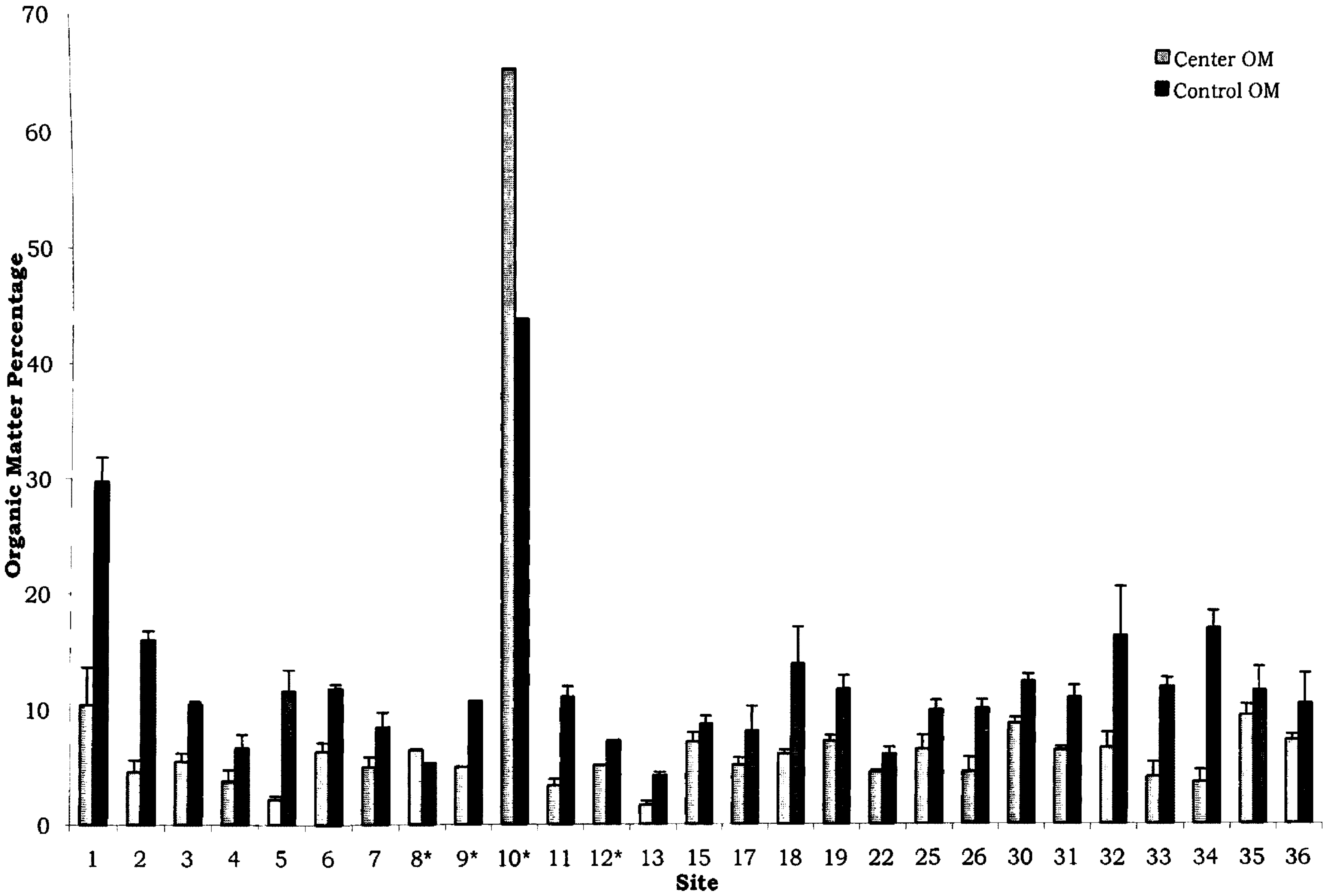


Figure 2.4. Mean organic matter percent of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

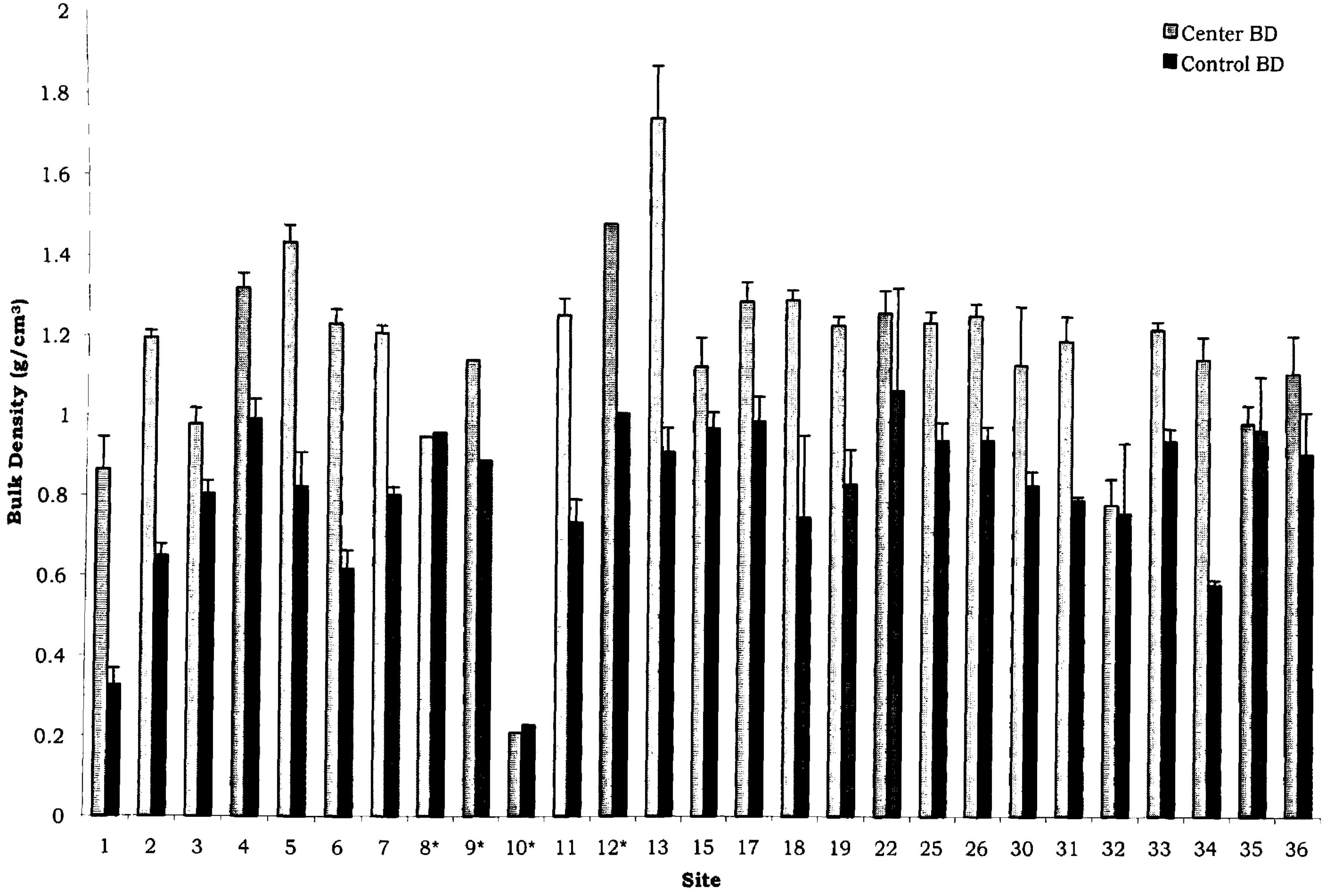


Figure 2.5. Mean bulk density of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

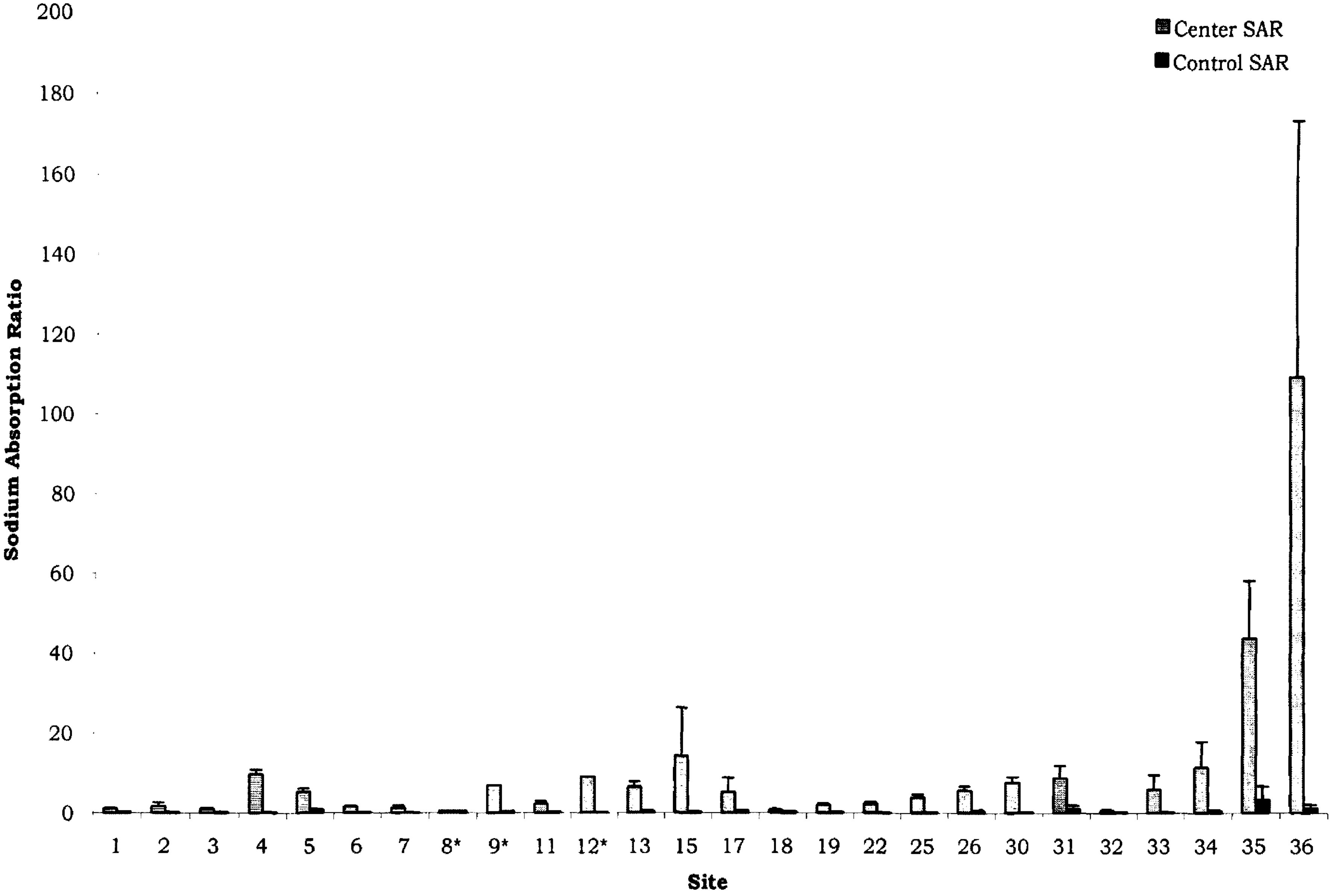


Figure 2.6. Mean sodium absorption ratio of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

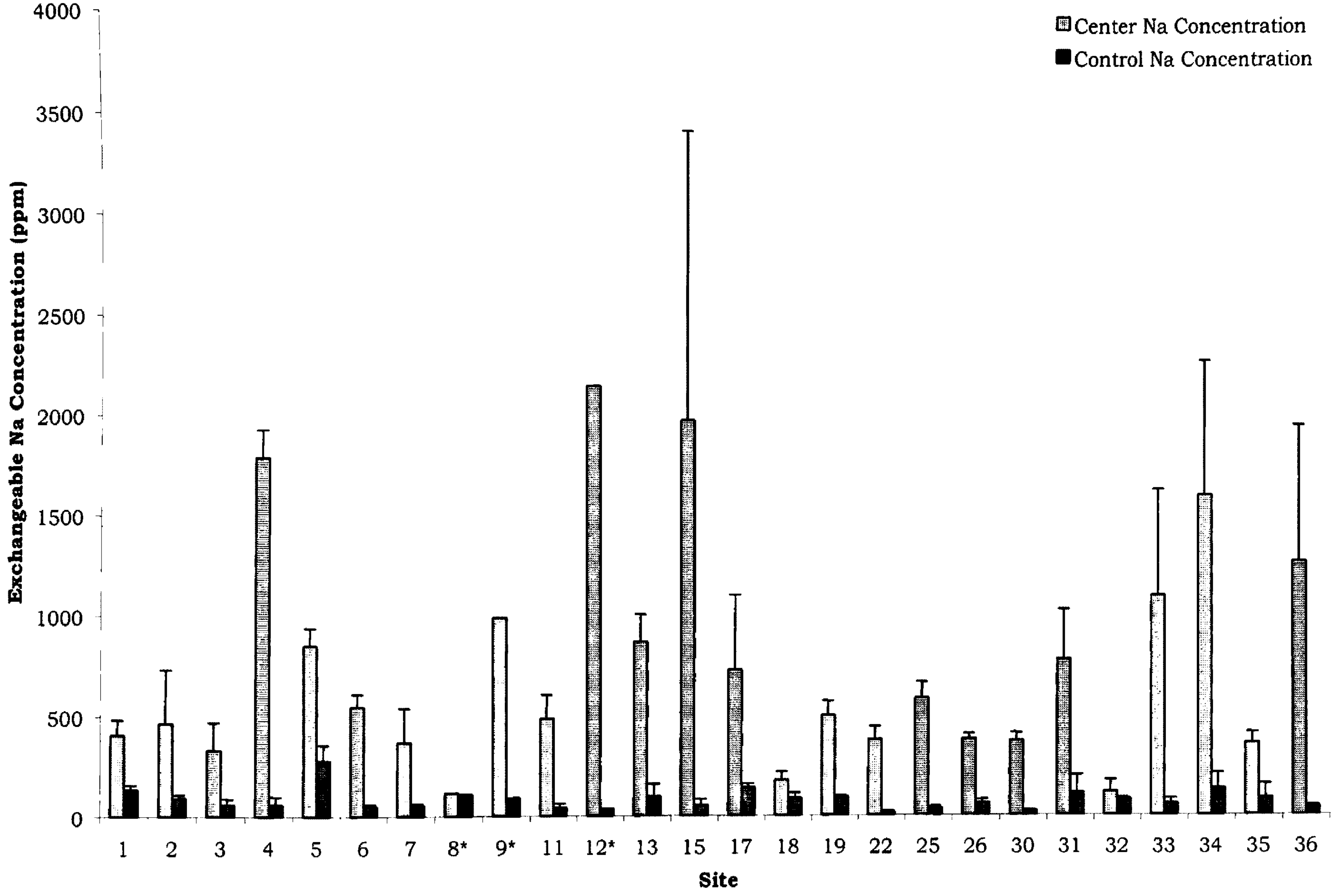


Figure 2.7. Mean exchangeable sodium concentration of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

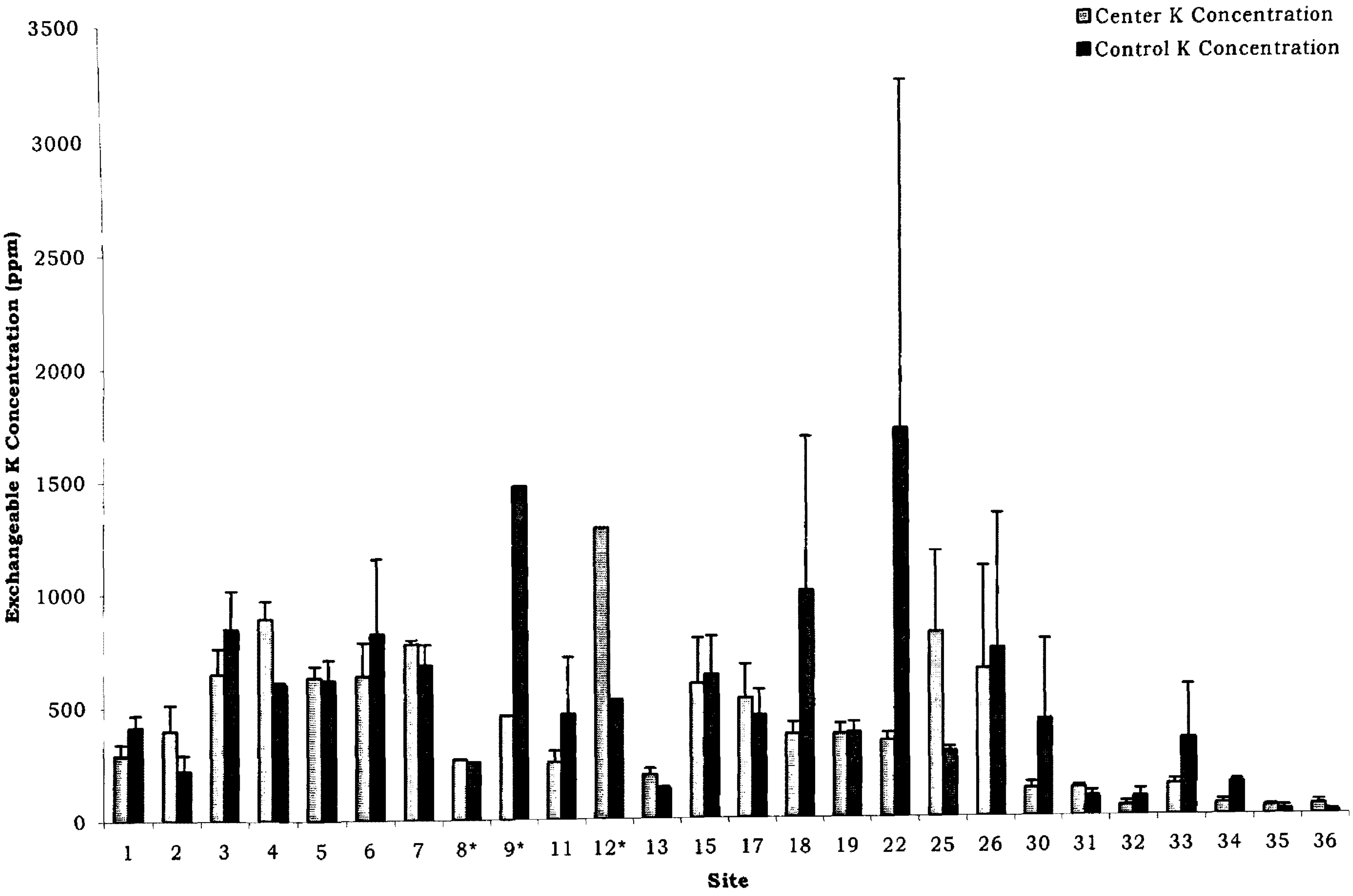


Figure 2.8. Mean exchangeable potassium concentration of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

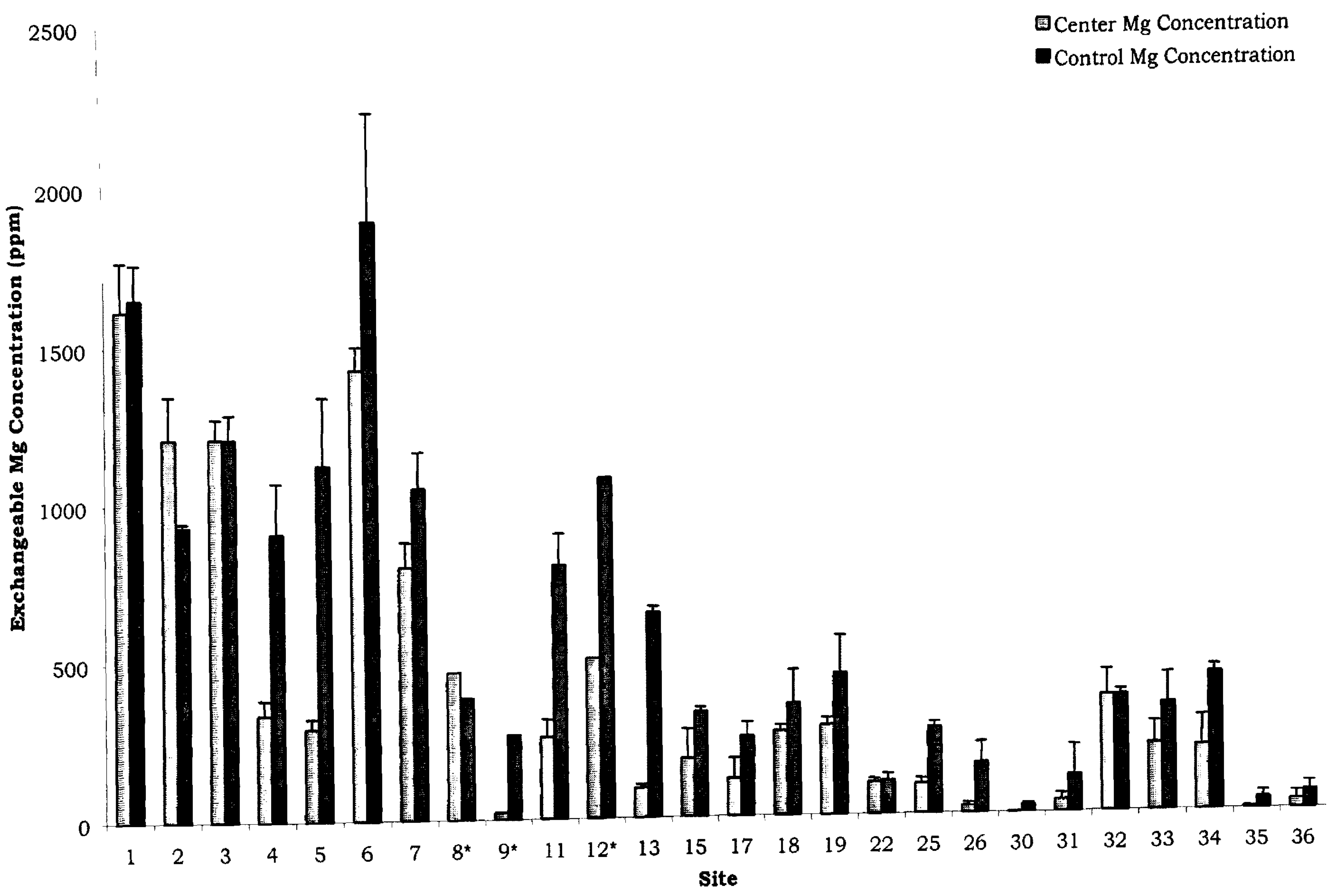


Figure 2.9. Mean exchangeable magnesium concentration of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

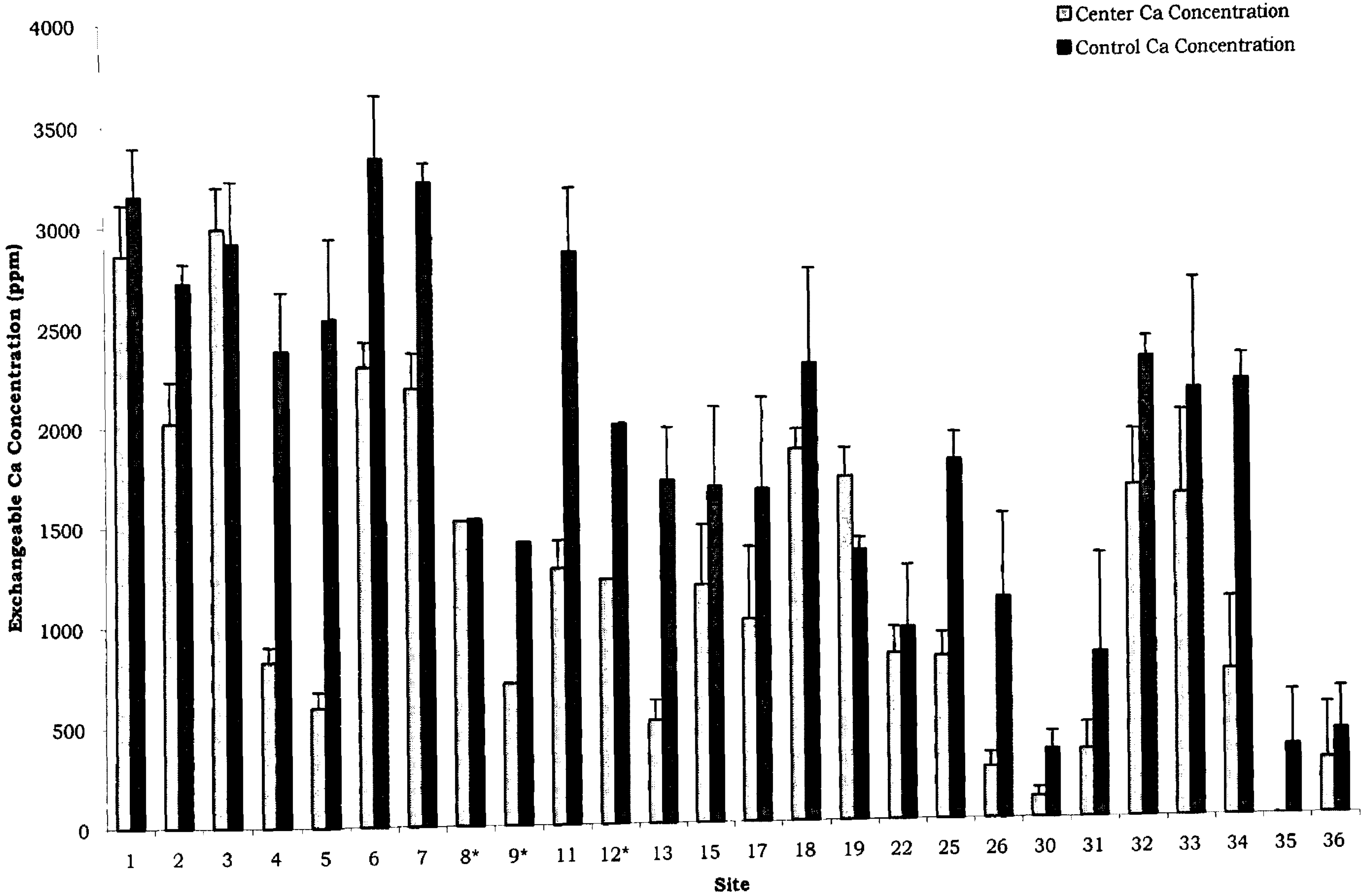


Figure 2.10. Mean exchangeable calcium concentration of each salt site identified in the Teton Wilderness. Sites with * are based on only one observation. Error bars represent standard error.

Organic matter percentage is displayed in Figure 2.4. There was little variation in OM% with only two of the values falling below 16%. All but two of the sites (10, 8) had higher OM% in controls than within sites.

Average bulk density (BD) in g/cm^3 for each site is shown in Figure 2.5. Again, sites 8 and 10 are the anomalies, being the only ones with higher BD in the controls. This may be a reflection of the single sampling at these sites.

Sodium absorption ratios (SAR) are shown in Figure 2.6. All within site values were higher than their respective controls for SAR. With the exception of sites 35 and 36, all SAR values were below 20. Only four sites had SAR values over 10, with 13 being considered the lower limit for sodicity status.

Exchangeable Na^+, K^+, Mg^{2+}, and Ca^{2+} concentrations are given in ppm in Figures 2.7-2.10. Sodium concentrations exhibited much variation from site to site. All site centers had higher Na^+ concentrations than their controls. Potassium concentrations also had variety on a per site basis. Eleven of the 29 sites had higher concentrations within sites while the other 18 had higher concentrations in controls. Magnesium values were heterogeneous from site to site. One trend was that all but four of the sites had higher Mg^{2+} concentrations in the controls than in site centers. Calcium concentrations showed variation from site to site but there was a strong treatment effect as all but two of the sites had lower Ca^{2+} concentrations in their plot centers than their controls.

Discussion

Upon finding each of the salt affected sites, it was apparent that several of them would display significantly different characteristics than their paired controls. This was due to the fact that visibly, most of the sites were large moon-crater appearing depressions in the ground where ungulates had been eating and trampling the soil.

Although cations measured were significantly different in site centers than controls for Na^+, Mg^{2+}, and Ca^{2+}, their altered concentrations are not out of the range for normal plant growth. No sites had EC values greater than 4 μmhos/cm, therefore eliminating all sites from classification as saline or saline-sodic as defined by the USDA for agricultural purposes (Abrol et al., 1988 and Rhoades et al., 1999). Only three of the 27 sites measured had SAR values greater than 13 and could be classified as sodic.

When examining sites as a combined whole, the average SAR value of 10.4 can be misleading considering the exceptionally high values for the final two sites were 43 and 109. With just the largest value excluded, the average becomes 6.43 and with both the outliers excluded, the mean value becomes 4.87. With the exception of a few sites, the SAR values are low. The reason for these relatively low SAR values considering the amount of salt added annually to the sites is leaching lower in the soil profile or consumption by animals (Jones and Hanson, 1985).

The three sites that met the sodic classification, sites 15, 35, and 36 were all visibly active and appeared newer than a majority of the sites. There were noticeable fresh scrapings on all three sites and there was found fresh salt blocks on site 36, which may explain it's abnormally large SAR value.

Although few sites had high enough SAR to be classified as sodic, lower SAR values than traditionally recognized as detrimental may have significant affects on soil properties (Agassi et al., 1985, Crescimanno et al., 1995, McIntyre 1979, and Rengasamy et al., 1984). Of the sites studied, over half (14) had SAR > 5, which has been suggested as a better threshold for sodicity (Agassi et al., 1985, Crescimanno et al., 1995, McIntyre 1979, and Rengasamy et al., 1984). However, most experiments have been carried out in a laboratory and dealt with soil characteristics and not plant growth. Therefore, SAR values and subsequent levels of exchangeable Na^+ alone cannot explain the lack of plant growth across all sites.

It should be stressed again that the USDA classification system for saline and sodic soils are traditionally used in agricultural systems. They may not necessarily apply to natural systems but serve as a tool for assessing the Na^+ status of salt sites. The observed SAR values demonstrate Na^+ concentrations far in excess of what is observed naturally. These concentrations (almost 10*x* greater) suggest that when vegetation is established, it may prove to be halophytes.

These SAR values suggest imbalances of base cations in salt-affected soils. The lower Ca^{2+} and Mg^{2+} levels are probably due to the introduction of excess Na^+ which displaces both cations off of the exchange sites through mass action and Ca^{2+} and Mg^{2+} are lost to leaching. Calcium in particular has been shown to promote flocculation of clays because it takes on less of a hydrated radius than Na^+ and therefore initiates rebuilding of soil structure.

Organic matter was significantly lower in sites compared to controls. The only sites in which OM % was higher within sites were 8 and 10, both of which only had one sample point, which may be a function of where the sample was taken and not the site itself. As salt is placed on the soil and reacts with the organic components, ungulates eat that reactive soil portion and expose the mineral layers underneath (Jones and Hanson, 1985).

Organic materials promote many positive soil characteristics such as increased cation exchange capacity, water holding capacity, and promote formation of stable structure (Logan, 1992). Increased levels of OM would additionally stimulate microbial activity and create binding sites for the added salts (Barker et al., 2000). However, decrease in organic components alone does not account for the lack of plant growth on salt sites.

The increase of soil bulk density on salt sites due to repeated trampling and compaction of affected soils by large ungulates is one of the main reasons for lack of plant growth. This causes soil aggregates to break down, lower water infiltration, and decreased root elongation. Under conditions without repeated trampling, plants would eventually reestablish themselves (Braunack and Walker, 1985; Greene et al., 1994; and Willatt and Pullar, 1984).

Trampling lessens the chances of plant reestablishment and therefore hinders accumulation of OM. Plant establishment would aerate the compacted portion of the soil, allowing water movement and leaching of excess salt on severely affected sites (Braunack and Walker, 1985; Greene et al., 1994; and Willatt and Pullar, 1984).

Conclusions

Artificial salt licks in the Teton Wilderness did not appear to be adversely affected by any specific toxicity from changed levels of exchangeable salt concentrations. The relatively low levels of exchangeable salt concentrations can be explained both by salt leaching into lower soil layers and ingestion by ungulates.

Repeated trampling by elk and other large ungulates appears to be the single most important factor inhibiting plant growth on the sites studied. Addition of Ca^{2+} and perhaps organic amendments will likely speed up recovery of these disturbed sites. Any attempts at rehabilitating these sites need to first eliminate salting and then take into consideration the use by animals, therefore fencing off sites to prohibit trampling would likely be a prerequisite.

Literature Cited

Abrahams, P.W. 1999. The chemistry and mineralogy of three savanna lick soils. Journal of Chemical Ecology. 25:2215-2228.

Abrol, I.P., J.S.P. Yadov, and F.I. Massoud. 1988. "Salt-affected soils and their management". FAO Soils Bulletin 39.

Abu-Sharar, T.M., F.T. Bingham, and J.D. Rhoades. 1987. Stability of soil aggregates as affected by electrolyte concentration and composition. Soil Science Society of America Journal. 51:309-314.

Agassi, M., J. Morin, and I. Shainberg. 1985. The effect of water drop impact energy and water salinity on the infiltration rates of sodic soils. Soil Science Society of America Journal. 49:186-190.

Barker, A.V., M.L. Stratton, and J.E. Rechcigl. 2000. Soil and by-product characteristics that impact the beneficial use of by products., p. Chapter 5, *In* J. F. Power and W. A. Dick, eds. Land Applications of Agricultural, Industrial, and Municipal By-Products., SSSA Book Series 6. Soil Science Society of America, Madison, WI, USA.

Barzegar, A.R., J.M. Oades, and P. Rengasamy. 1996. Soil structure degradation and mellowing of compacted soils by saline-sodic solutions. Soil Science Society of America Journal. 60:583-588.

Belovsky, G. 1978. Diet optimization in a generalist herbivore: the moose. Theoretical Population Biology. 5:105-134.

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Annual Review of Phytopathology. 13:295-312.

Black, H.C. 1955. Salt use by mule deer in the Dechutes National Forest of Central Oregon. Master's thesis, Oregon State College, Corvallis, OR, USA.

Braunack, M.V., and J. Walker. 1985. Recovery of some surface soil properties of ecological interest after sheep grazing in a semi-arid woodland. Australian Journal of Ecology. 10:451-460.

Bresler, E., B.L. McNeal, and D.L. Carter, (eds.). 1982. Saline and sodic soils: principals-dynamics-modeling. Springer-Verlag., New York, NY, USA.

Cook, D.F., and S.D. Nelson. 1986. Effect of polyacrylamide on seedling emergence in crust-forming soils. Soil Science. 141:328-333.

Crescimanno, G., M. Iovino, and G. Provenzano. 1995. Influence of salinity and sodicity on soil structural and hydraulic characteristics. Soil Science Society of America Journal. 59:1701-1708.

Culley, J.L.B. 1993. Density and Compressibility. p. 529-541, *In* M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL, USA.

Dalke, P., R. Beeman, F. Kindel, R. Robel, and T. Williams. 1965. Use of salt by elk in Idaho. Journal of Wildlife Management. 29:319-332.

Fraser, D. 1985. Mammals, birds, and butterflies at sodium sources in Northern Ontario forests. The Canadian Field-Naturalist. 99:365-367.

Fraser, D., E. Chavez, and J. Paloheimo. 1984. Aquatic feeding by moose: selection of plant species and feeding areas in relation to plant chemical composition and characteristics of lakes. Canadian Journal of Zoology. 62:809-817.

Greene, R.S.B., P.I.A. Kinnell, and J.T. Wood. 1994. Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangelands. Australian Journal of Soil Resources. 32:953-973.

Helalia, A.M., and J. Letey. 1988. Polymer type and water quality effects on soil dispersion. Soil Science Society of America Journal. 52:243-246.

Huang, W., and Y. Lu. 2000. Estimating the benefits of agricultural use by municipal, animal, and industrial byproducts. Chapter 12, *In* J. F. Power and W. A. Dick, eds. Land Applications of Agricultural, Industrial, and Municipal By-Products., SSSA Book Series 6. Soil Science Society of America, Madison, WI, USA.

Janzen, H.H. 1993. Soluble Salts. p. 161-167, *In* M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL, USA.

Jones, R., and H. Hanson. 1985. Mineral licks, geophagy, and biogeochemistry of North American ungulates. The Iowa State University Press, Ames, Iowa, USA.

Kalra, Y.P., and D.G. Manynard. 1991. Methods manual for forest soil and plant analysis. Information Report NOR-X-319. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta, Canada.

Klein, D.R., and H. Thing. 1989. Chemical elements in mineral licks and associated muskoxen feces in Jameson Land, northeast Greenland. Canadian Journal of Zoology. 67:1092-1095.

Lilley, J. 1982. Dryland salinity in Alberta. Edmonton: Environmental Council of Alberta.

Lima, L.A., M.E. Grismer, and D.R. Nielsen. 1990. Salinity effects on Yolo loam hydraulic properties. Soil Science 150:451-458.

Logan, T.J. 1992. Reclamation of chemically degraded soils., p. 13-31, *In* Rattan Lal and B. A. Stewart, eds. Advances in Soil Science., Vol. 17 Soil Restoration. Springer-Verlag, New York, New York, USA.

McIntyre, D.S. 1979. Exchangeable sodium, subplasticity, and hydraulic conductivity of some Australian soils. Australian Journal of Soil Research. 17:115-120.

Miller, B., and J. Litvaitis. 1992. Use of roadside salt licks by Moose, Alces alces, in northern New Hampshire. Canadian Field-Naturalist. 106:112-117.

Rengasamy, P., R.S.B. Green, G.W. Ford, and A.H. Mehanni. 1984. Identification of dispersive behaviour and the management of the red-brown earths. Australian Journal of Soil Research. 22:413-431.

Rhoades, J.D. 1996. Salinity: Electrical Conductivity and Total Dissolved Solids., p. 417-435, *In* D. L. Sparks, ed. Methods of Soil Analysis-Part 3 Chemical Methods. SSSA Book Series 5. American Society of Agronomy, Madison, WI, USA.

Rhoades, J.D., F. Chanduvi, and S. Leech. 1999. Soil salinity assessment methods and interpretation of electrical conductivity measurements. FAO Irrigation and Drainage Paper 57. Food and Agriculture Organization of the United Nations, Rome, Italy.

Richards, L.E. 1954. Diagnosis and Improvement of saline and alkali soils. Handbook 60. U. S. Salinity Laboratory, U. S. Department of Agriculture.

Rognrud, M. 1955. Evaluation of artificial salting and aerial salt distribution. Montana Fish and Game Commission Wildlife Restoration Division Quarterly Report. Project W-60-R-2 6(2).

Sandetto, E. 2000. Salt strategy. Unpublished Draft. USDA Forest Service, Teton Wilderness Buffalo Ranger District Bridger-Teton National Forest, Moran, WY, USA.

Schultz, S. and M. Johnson. 1992. Use of artificial mineral licks by white-tailed deer in Louisiana. Journal of Range Management 45:546-548.

Sokal, R. and F. Rohlf. 1981. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Company, New York, New York, USA.

Thomas, G.W. 1996. Soil pH and Soil Acidity., p. 475-490 (Chapter 16), *In* D. L. Sparks, ed. Methods of Soil Analysis-Part 3 Chemical Methods. SSSA Book Series 5. American Society of Agronomy, Madison, WI, USA.

Weeks, H. 1974. Physiological, morphological, and behavioral adaptations of wild herbivorous mammals to a sodium-deficient environment. Ph.D. dissertation, Purdue University, Lafayette, Indiana, USA.

Willatt, S.T., and D.M. Pullar. 1984. Changes in soil physical properties under grazed pastures. Australian Journal of Soil Resources. 22:343-348.

Zahow, M.F., and C. Amrhein. 1992. Reclamation of saline sodic soil using synthetic polymers and gypsum. Soil Science Society of America Journal. 56:1257-1260.

Chapter 3. Rehabilitation Study of Salt-Affected Sites in the Teton Wilderness.

Abstract

Artificial salt licks in the Teton Wilderness have been created for hunting purposes and have caused large areas of localized damage. The purpose of this study was to test the potential for reclamation of salt affected soils. Experimental plots were created on salt sites using a 2x2 factorial combination of a control, aeration, and gypsum amendment. Sites were seeded with bunchgrass and an organic mulch was placed on the surface of all plots. At the end of one growing season, plots were revisited and analyzed for bulk density, pH, electrical conductance (EC), exchangeable sodium (Na^+) and calcium (Ca^{2+}) concentrations, and water stable aggregates. No significant quantity of vegetation was established on the plots, possibly due to the short duration of the study or the extent of compaction of affected sites. Significant increases were observed in Ca^{2+} concentrations and EC on plots with gypsum amendments.

Introduction

Creation of artificial salt licks in the Teton Wilderness has created adverse impacts to vegetation and soils. The extent of these impacts were identified and studied. The following document presents potential reclamation approaches.

The Wyoming Department of Game and Fish began salting in the Teton Wilderness in 1945. This salting was first started to attract elk out of Yellowstone National Park into seemingly good habitat in the Teton Wilderness. The Game and Fish Department eventually discontinued salting but outfitters and private sportsmen in the area were allowed to continue salt placement until it was outlawed in 1990 (Sandetto, 2000).

The management of large wild game by placement of salt has historically been common. From the 1920's until the 1950's every western state except Nevada was using salt to some extent to try and control game movements. The main goals of these salting programs were to hold animals on summer range and conserve winter range (Dalke et al., 1965).

In studies of both natural and artificial salt licks, authors have found that sodium (Na^+) is the main draw for animal use (Dalke et al., 1965 and Jones and Hanson, 1985). High levels of potassium in spring forage, particularly grasses, and the succulent condition of herbage at this season creates conditions for decreased efficiency of tubular resorption in the kidneys and a diarrheic condition that contributes to Na^+ loss and attracts ungulates to salt sites (Weeks, 1974).

Creating artificial salt sites requires introducing Na^+ into the soil solum. When Na^+ is first introduced into soil solution, it will occupy the cation exchange sites where other nutrients may have previously been available for plant uptake. As Na^+ becomes a predominant cation in the soil, deflocculation, or clay dispersion occurs, which results in poor physical properties such as low permeability, resistance to root penetration, and poor aeration. The lack of permeability further reduces the amount of salts that can be leached into lower soil layers from above (Bernstein, 1975).

Deflocculation along with trampling by ungulates results in heavily compacted areas with minimal plant growth. Compaction has been shown to be a problem in many areas where stock trampling occurs. Repeated trampling by large ungulates causes further compaction and breakdown of soil physical properties beyond what is caused by sodium in the soil (Greene et al., 1994 and Willatt and Pullar, 1984).

Compaction will further exacerbate salt site impacts and make rehabilitation difficult. Negative effects of compaction have been shown to be evident for 16 years after removal of grazing sheep (Braunack and Walker, 1985). In forest soils where logging has occurred, plant regrowth following compaction can take anywhere from 5-15 years, depending on soil type and compaction severity (Blake et al., 1976 and Greacen and Sands, 1980). Some measurable adverse signs of compaction have been reported over fifty years after logging operations ceased (Greacen and Sands, 1980). Without repeated use on heavily compacted salt sites, it is likely that plant reestablishment would take several years. However, repeated trampling of soil will cause vegetative regeneration to take considerably longer.

An important management consideration for mitigating compaction effects is applying and/or reducing the amount of organic matter lost from soil. This is especially important in sandy soils which are almost entirely dependent upon organic matter for nutrients, cation exchange capacity, water retention, and resistance to compaction. After soils have already been compacted, mechanical loosening is an important practice (Greacen and Sands, 1980).

Some chemical amendments have been added to compacted soils to improve their physical properties. Water soluble, synthetic polymers have been applied to compacted and clay-dispersed soils and have had promising results in stabilizing aggregates and improving desirable soil characteristics (Cook and Nelson, 1986 and Zahow and Amrhein, 1992). These polymers have not been used commercially for aggregate stabilization due to their high cost and the difficulty applying them properly (Helalia and Letey, 1988 and Terry and Nelson, 1986).

Gypsum is another chemical amendment used in reclaiming compacted and sodic soils (Sansom et al., 1998 and Schuman et al., 1994). In a study by Zahow and Amrein (1992), effectiveness of gypsum and synthetic polymers were compared for the reclamation of saline-sodic soils. They found that in soils with sodium absorption ratios (SAR) levels less than 13, the polymers were the most effective and in soils with SAR > 13 gypsum was more effective (Zahow and Amrein, 1992). These results were attributed to the ability of synthetic polymers to reduce slaking of clay particles at low SAR values and gypsum's ability to displace Na^+ and reduce clay swelling at higher SAR values (Zahow and Amrein, 1992).

Gypsum, or calcium sulfate ($CaSO_4 \bullet 2H_2O$) replaces exchangeable Na^+ on cation exchange sites in sodic soils. The Ca^{2+} in the gypsum replaces Na^+ as it leaches further into the soil substrate and the Ca^{2+} is available for plant uptake. This also helps the physical properties of sodium-saturated soils by promoting flocculation and increasing the amounts of aggregates present (Richards, 1954).

Materials and Methods

Seven of the previously identified salt sites were selected for establishment of experimental seeding plots to determine the best methods for plant growth. The sites were selected based on their high Na^+ content and if they contained standing water during the spring of 2001.

At each of the seven sites, four experimental plots were established. These plots were arranged in a large 4*x*4 meter square subdivided into four 2*x*2 meter quadrants. The plots were arranged such that the dividing lines between them pointed in the four cardinal directions. In this way, the four plots could be identified as being NW, SW, NE, and SE. In each of the four plots, two sampling points were established and field measures of bulk density and electrical conductance (EC) were taken with samples returned to the lab for analysis.

One of four treatments was assigned to each plot. The treatments were as follows: 1) control, 2) aeration, 3) gypsum amendment, and 4) gypsum amendment with aeration. Aeration was done using a pulaski, simulating what backcountry rangers would be able to use. On aerated plots, the top 10-15 cm of soil was loosened and turned over. Next gypsum was evenly distributed over gypsum-amended plots. Control plots had no treatment done but were seeded and mulched.

Treatments were randomly assigned to each plot. After the treatments were applied, all plots were seeded with a mixture of native slender wheatgrass and mountain brome at an application rate of 20 seeds per square foot. Finally, a mulch treatment of one gallon-sized Ziploc bag full of surrounding vegetation was applied to each plot. Plot establishment was done in the spring (June 19-23) of 2001 and sampling was done in the fall (September 14-16) of 2001.

Gypsum was used because of its cost and availability. The amount of gypsum applied to each plot was determined using calculations given by Richards (1954). For every 10% exchangeable sodium percentage (ESP) needed lowered, 1.7 tons gypsum was added per acre-ft^2. ESP was calculated from SAR using the following formula: ESP=[100(-0.0126+0.01475*SAR)]/[1+(-0.0126+0.01475*SAR)] (Richards, 1954). Sufficient gypsum was applied to lower the ESP to a value of ten.

Bulk density was determined in the field on the first 15cm of mineral soil using the slide hammer core method (Culley, 1993). A 5-gram representative sample was then diluted to 50mL soil solution with deionized water at each point. Electrical conductivity was measured on this solution with a CON 5 series Acorn Meter and recorded in µmhos per centimeter.

Using the method described by Thomas (1996), pH was measured on each sample. A 10-gram representative sample was diluted with 20 mL of 0.01 *M* $CaCl_2$, stirred for 30 seconds, left to stand for 5 minutes and then soil pH was measured.

Exchangeable Na^+ and Ca^{2+} concentrations were determined on each sample. These were the only cations measured because the addition of gypsum is expected to result in a rise in Ca^{2+} and a drop in Na^+.

Soils were first dried at 100° C then passed through a 2mm sieve. A 10-gram subsample was mixed with 35mL of 1.0 *M* NH_4Cl and shaken for an hour. The sample was filtered through a whatmann-42 filter paper and brought to 100mL with 1.0 *M* NH_4Cl in a volumetric flask. Adding 1.0 *M* NH_4Cl to the soil sample acts to saturate the cation exchange sites with NH_4^+ and release all sorbed cations into solution. The extract was then stored in a refrigerator until cation analysis could be made on an atomic absorption spectrophotometer (AAS) (Rhoades, 1996).

Water stable aggregate (WSA) percent was determined on all samples from experimental plots. The wet sieving method described by Kemper and Rosenau (1986) was used. Dry samples were first sieved to obtain particles between one and two millimeters. A subsample was then placed in a 0.25 mm sieve and wetted by capillary action. After sitting for 5 minutes, the sieves were then ran through deionized water in the wet-sieving apparatus for 15 minutes. Samples were then dried and weighed and aggregates remaining were destroyed followed by a final weighing to measure coarse fragments (Kemper and Rosenau, 1986).

Experimental plots were treated as a 2x2 factorial design with gypsum and aeration being the main factors. All data was first tested for a normal distribution and homogeneity of variance. Data was then analyzed using a univariate analysis of variance (Sokal and Rohlf, 1981).

Results

Initial plot treatments were applied in June 2001 and left the entire growing season for seedling growth and incorporation of gypsum into the soil. The plots were then sampled in September 2001. It was found that one of the experimental plots had been destroyed during the season as someone had placed several large logs over the entire site.

Table 3.1. Treatment averages and mean standard error for all variables measured on experimental seeding plots on salt-affected sites in the Teton Wilderness (n=6).

	Treatment				
Response Variable	**Control**	**Aerate**	**Gypsum**	**Aerate and Gypsum**	**Treatment p-value**
Bulk Density (g/cm^3)	1.26 ± 0.05	1.33 ± 0.04	1.22 ± 0.04	1.27 ± 0.05	0.1760^{ns}
EC (μmhos/cm)	0.14 ± 0.04	0.15 ± 0.04	0.97 ± 0.37	0.35 ± 0.09	0.0058*
Soil pH	4.88 ± 0.13	4.86 ± 0.14	5.00 ± 0.14	4.94 ± 0.13	0.4990^{ns}
Water Stable Aggregate %	53.4 ± 9.66	49.3 ± 8.45	53.2 ± 9.55	49.5 ± 9.27	0.4564^{ns}
Exchangeable Na^+ (ppm)	788 ± 221	584 ± 215	684 ± 195	596 ± 180	0.0257^{ns}
Exchangeable Ca^{2+} (ppm)	1197 ± 236	1179 ± 273	2542 ± 459	1820 ± 328	0.0000**

EC=Electrical Conductance
ns= not significant
* different from control, $\alpha<0.001$
** $\alpha=0.01$

There was no significant increase in vegetation growth at any of the experimental plots after one growing season. Averages for measured variables across all sites and treatments are given in Table 3.1. Significant treatment effects were found for Ca^{2+} concentrations and EC on plots that received an amendment of gypsum.

Average bulk density values are given in Figure 3.1. The treatments that received aeration had larger bulk density values than those without treatment; however, there was no significant treatment effect.

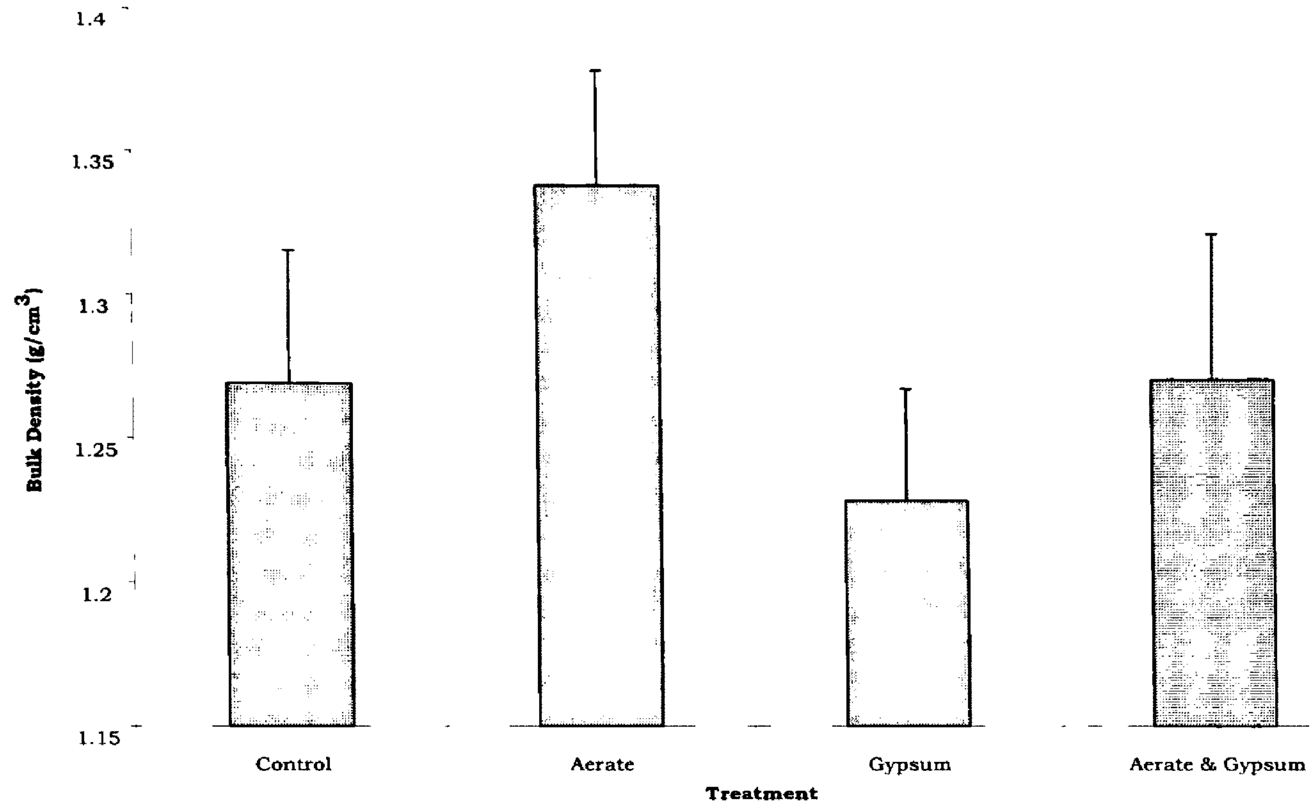


Figure 3.1. Mean bulk density for treatments on experimental seeding plots on salt-affected sites in the Teton Wilderness. Error bars represent mean standard error (n=6).

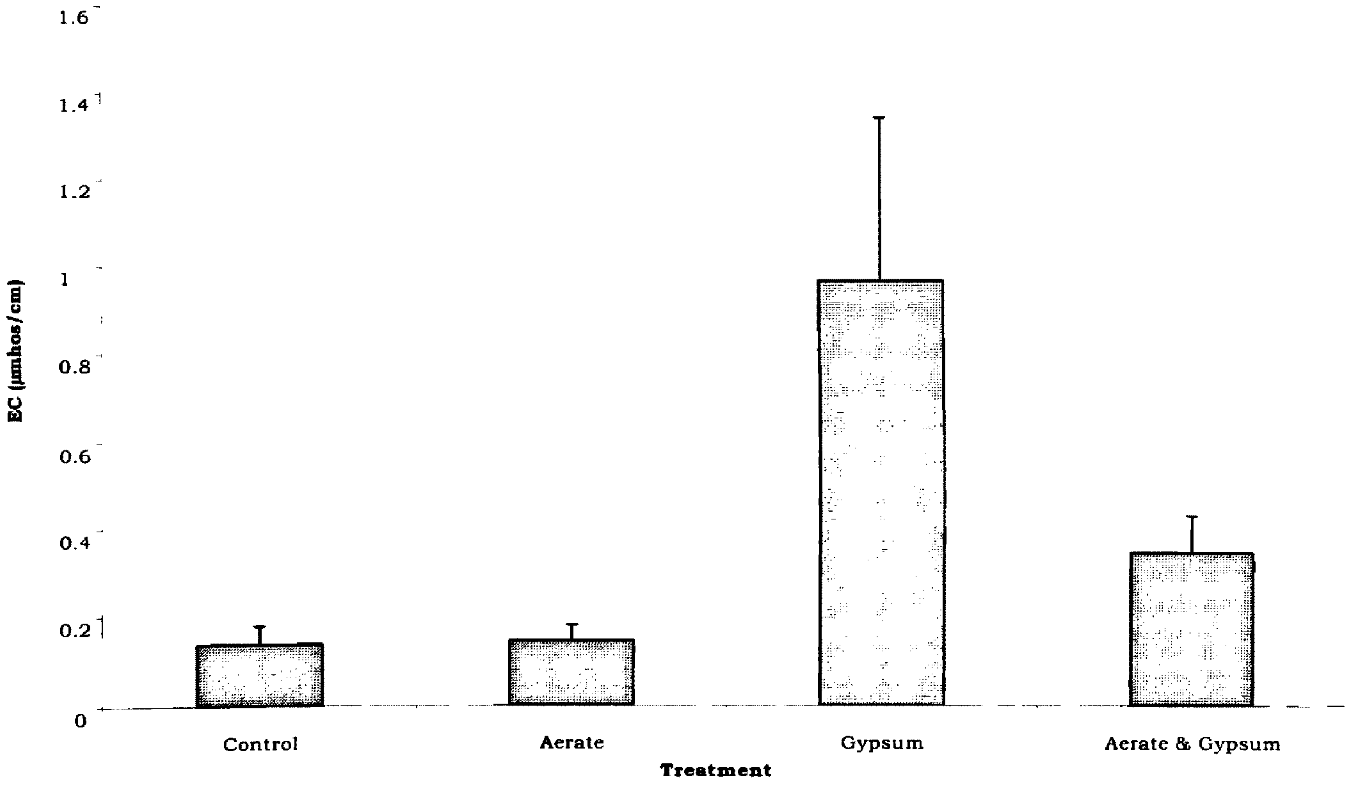


Figure 3.2. Mean electrical conductance for treatments on experimental seeding plots on salt-affected sites in the Teton Wilderness. Error bars represent mean standard error (n=6).

Aeration plus gypsum and gypsum alone resulted in significantly greater EC values than the control or aeration treatments (Figure 3.2). The gypsum only treatment also had much higher EC than gypsum plus aeration.

Soil pH for experimental seeding plots were found to not differ significantly with treatment (Figure 3.3). Water stable aggregate percentage also did not change with treatments (Figure 3.4). Concentrations of exchangeable Na^+ went down slightly in the gypsum-amended plots. Calcium concentrations were significantly increased ($p < 0.05$) in the gypsum-amended plots (Figure 3.5).

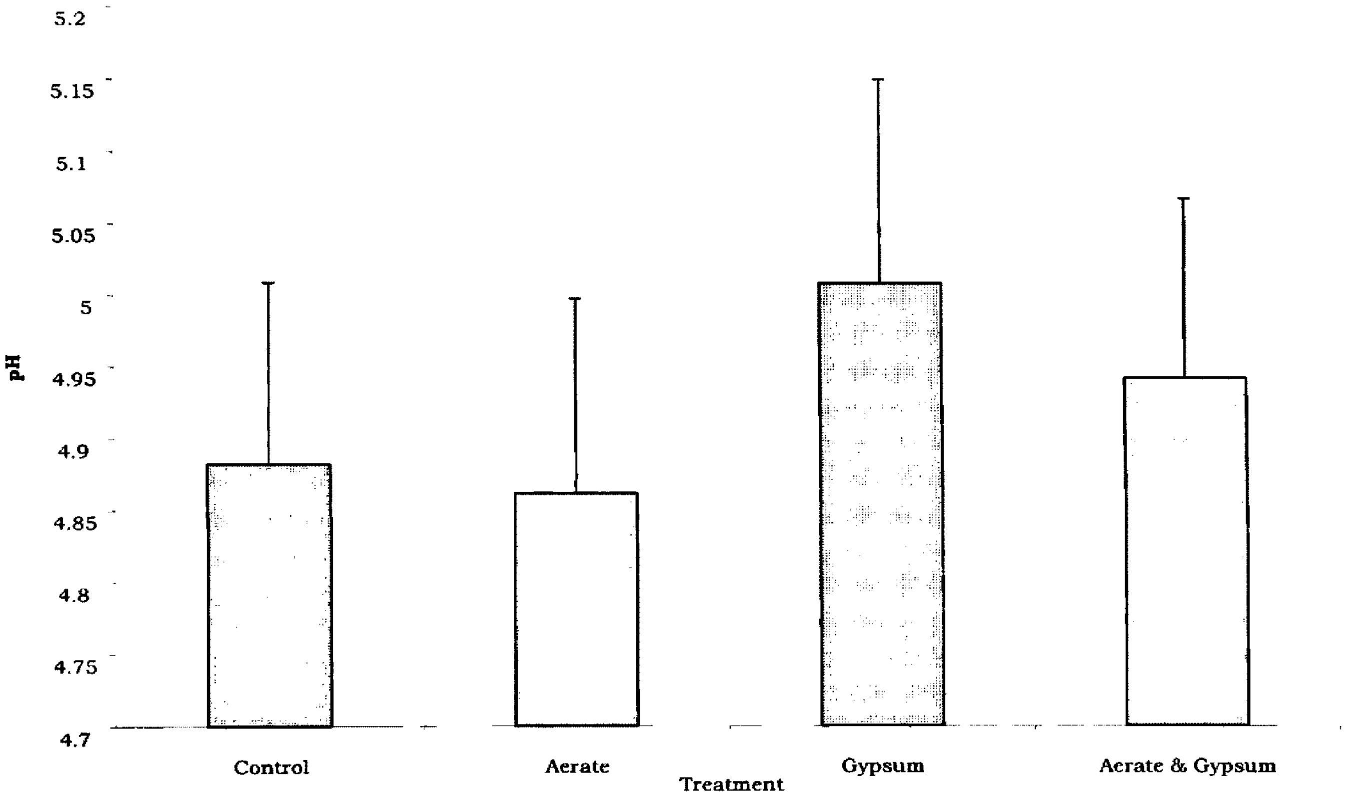


Figure 3.3. Mean soil pH for treatments on experimental seeding plots on salt-affected sites in the Teton Wilderness. Error bars represent mean standard error (n=6).

Discussion

Treatment plots showed a negligible amount of vegetative growth. The main reason for this is probably due to the short amount of time between plot establishment and sampling. Another reason may be that three of the sites had fresh animal scrapings in the fall. Some animals had came back during the growing season and disturbed the sites.

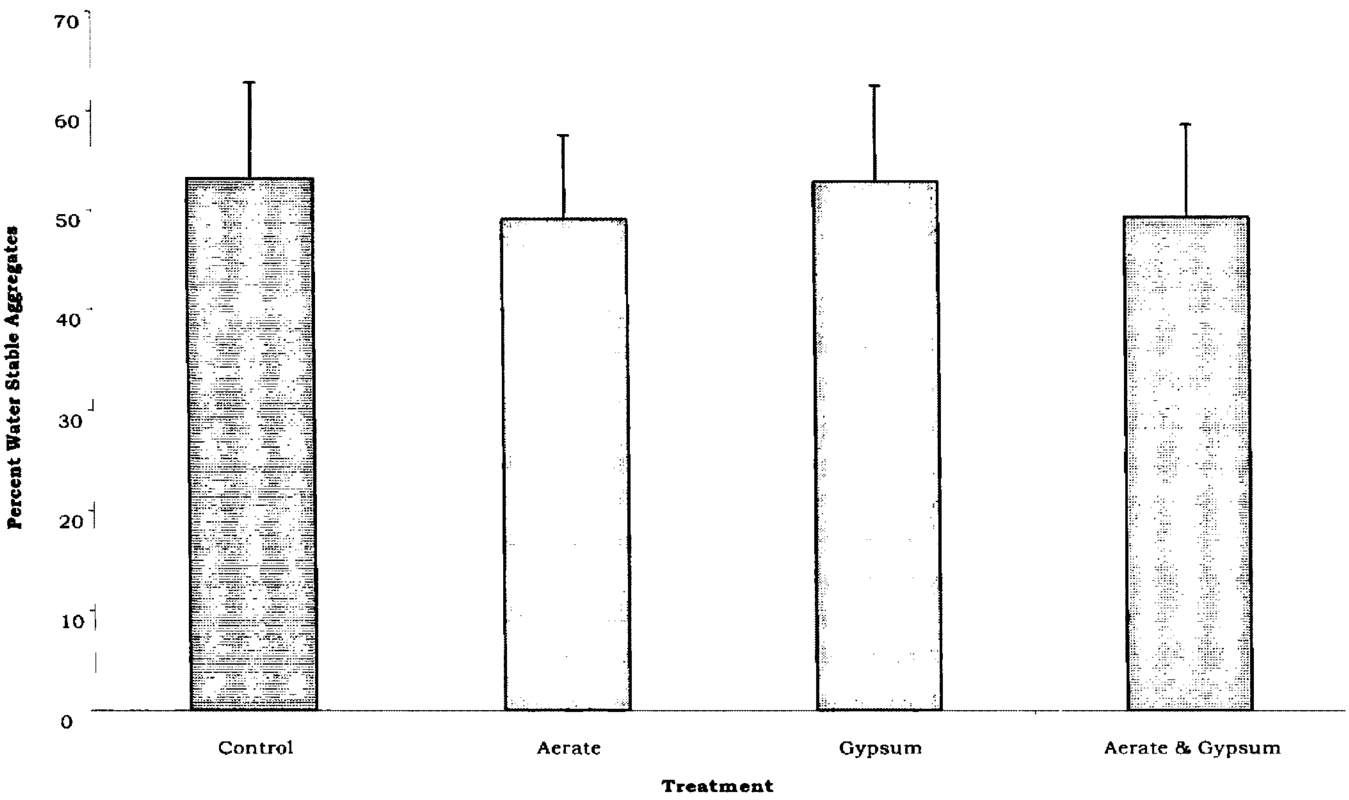


Figure 3.4. Mean water stable aggregate percentages for treatments on experimental seeding plots on salt-affected sites in the Teton Wilderness. Error bars represent mean standard error.

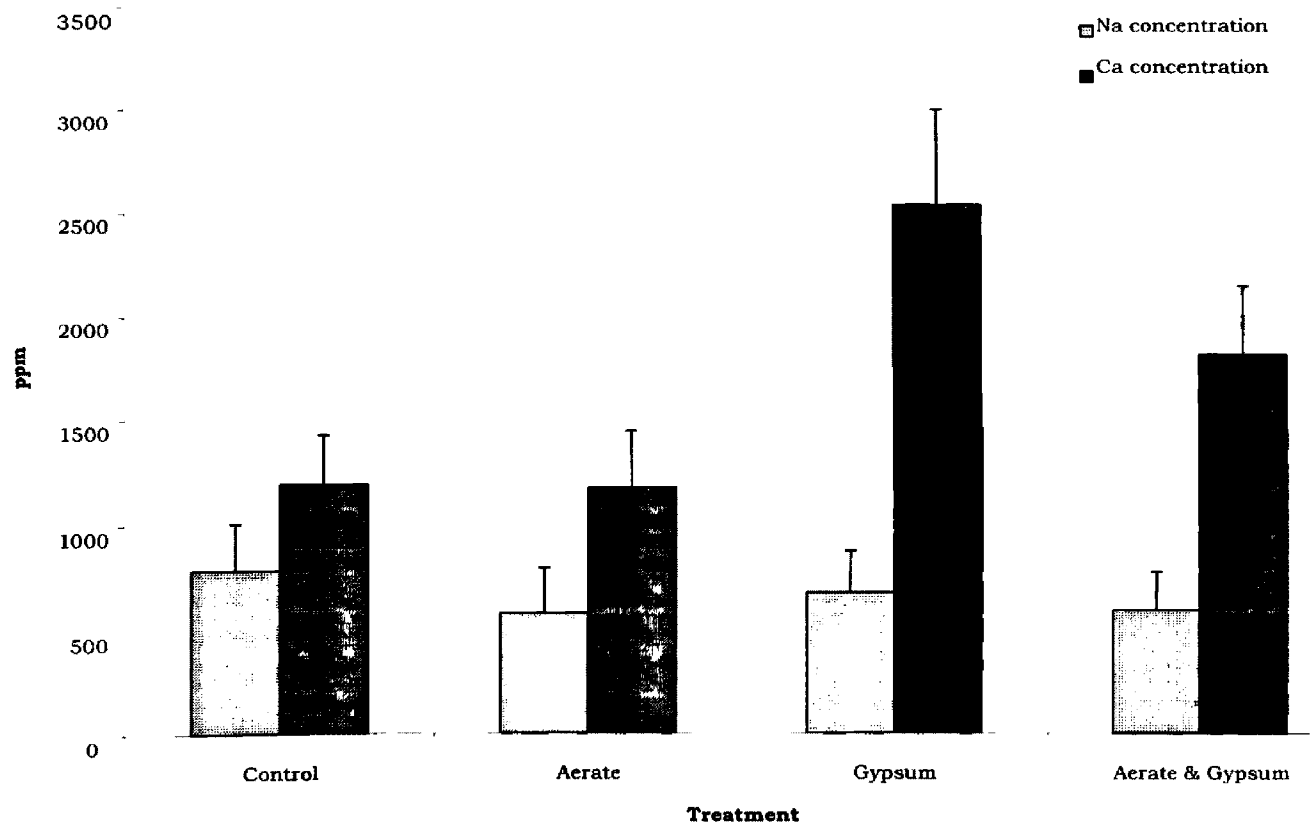


Figure 3.5. Mean exchangeable calcium and sodium concentrations for treatments on experimental seeding plots on salt-affected sites in the Teton Wilderness. Error bars represent mean standard error.

Electrical conductance increased significantly in both treatments receiving a gypsum amendment. This is due primarily to the addition of cations. It is interesting to note that the non-aerated gypsum treatment is much higher than the aerated one. This is probably due to Ca^{2+} being incorporated into the soil solution and leaching in the aerated treatment. It is interesting that the treatments not receiving aeration had higher WSA %. This may be due to the exposure and subsequent breakdown of organic materials (Stevenson and Cole, 1999).

It was expected for water stable aggregate percentage to increase with gypsum amendment (Sansom et al., 1994 and Zahow and Amrhein, 1992) however, no significant differences were observed. One of the reasons for this may have been the time frame involved. Given another growing season, the Ca^{2+} from the gypsum may have incorporated into the soil solution and caused flocculation to occur and aggregates to reform.

The significant increase in concentration of exchangeable Ca^{2+} is attributable to the addition of Ca^{2+} cations into the soil. The amount of Ca^{2+} in the gypsum only treatment was significantly higher than the gypsum plus aerate treatment. This is probably due to the Ca^{2+} being incorporated into the soil solution and leaching more readily in the aerated treatment.

Given another growing season, the Ca^{2+} cations in solution may have worked to remove a significant amount of Na^+ cations from exchange sites. The concentration of exchangeable Na^+ is lower than the control in both the gypsum amended sites, however not enough to make any definite conclusions.

Conclusions

The results of this study proved to be inconclusive, as experimental seeding plots failed to yield a significant amount of vegetative regrowth. It is important to note that aeration in the manner that was attempted had no positive effect on bulk density. The remoteness of the sites makes it unfeasible to attempt any other type of aeration. Therefore, aerating sites may not be the best treatment.

Given more time, there may have been more positive results to report. In the long run, incorporation of some form of Ca^{2+} amendment is recommended because of it's proven ability to improve soil structural characteristics. Additional mulching or incorporation of humified organic matter into the soil solum seems like a logical amendment. Finally, fencing off of salt sites in the Teton Wilderness will be essential for rehabilitation as ungulates act to repeatedly use and trample any rehabilitating sites.

Literature Cited

Bernstein, L. 1975. Effects of salinity and sodicity on plant growth. Annual Review of Phytopathology. 13:295-312.

Blake, G.R., W.W. Nelson, and R.R. Allmaras. 1976. Persistence of soil compaction in a mollisol. Soil Science Society of America Journal. 40:943-948.

Braunack, M.V., and J. Walker. 1985. Recovery of some surface soil properties of ecological interest after sheep grazing in a semi-arid woodland. Australian Journal of Ecology. 10:451-460.

Cook, D.F., and S.D. Nelson. 1986. Effect of polyacrylamide on seedling emergence in crust-forming soils. Soil Science. 141:328-333.

Culley, J.L.B. 1993. Density and Compressibility, p. 529-541, *In* M. R. Carter, ed. Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL, USA.

Dalke, P., R. Beeman, F. Kindel, R. Robel, and T. Williams. 1965. Use of salt by elk in Idaho. Journal of Wildlife Management. 29:319-332.

Greacen, E.L., and R. Sands. 1980. Compaction of forest soils-a review. Australian Journal of Soil Resources. 18:163-189.

Greene, R.S.B., P.I.A. Kinnell, and J.T. Wood. 1994. Role of plant cover and stock trampling on runoff and soil erosion from semi-arid wooded rangelands. Australian Journal of Soil Resources. 32:953-973.

Helalia, A.M., and J. Letey. 1988. Polymer type and water quality effects on soil dispersion. Soil Science Society of America Journal. 52:243-246.

Jones, R., and H. Hanson. 1985. Mineral licks, geophagy, and biogeochemistry of North American ungulates. The Iowa State University Press, Ames, Iowa, USA.

Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution, Chapter 17 (425-442), *In* A. Klute, ed. Methods of Soil Analysis-Part I Physical and Mineralogical Methods, 2nd Edition, American Society of Agronomy., Madison, WI, USA.

Rhoades, J.D. 1996. Salinity: Electrical Conductivity and Total Dissolved Solids, p. 417-435, *In* D. L. Sparks, ed. Methods of Soil Analysis-Part 3 Chemical Methods. SSSA Book Series 5. American Society of Agronomy, Madison, WI, USA.

Richards, L.E. 1954. Diagnosis and Improvement of saline and alkali soils. Handbook 60. U. S. Salinity Laboratory, U. S. Department of Agriculture.

Sandetto, E. 2000. Salt strategy. Unpublished Draft. USDA Forest Service, Teton Wilderness Buffalo Ranger District Bridger-Teton National Forest, Moran, WY, USA.

Sansom, J.J., M.A. Naeth, D.S. Chanasyk, and J.C. Bateman. 1998. In situ amelioration of sodic minespoil with chemical amendments and crop management. I. Soil chemical properties. Canadian Journal of Soil Science. 78:359-365.

Schuman, G.E., E.J. Depuit, and K.M. Roadifer. 1994. Plant responses to gypsum amendements of sodic bentonite mine spoil. Journal of Range Management. 47:206-209.

Sokal, R. and F. Rohlf. 1981. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Company, New York, New York, USA.

Stevenson, F.J., and M.A. Cole. 1999. Soil carbon budgets and role of organic matter in soil fertility, p. 56-64 (Chapter 2) Cycles of Soil. Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. 2nd ed. John Wiley and Sons, New York, New York, USA.

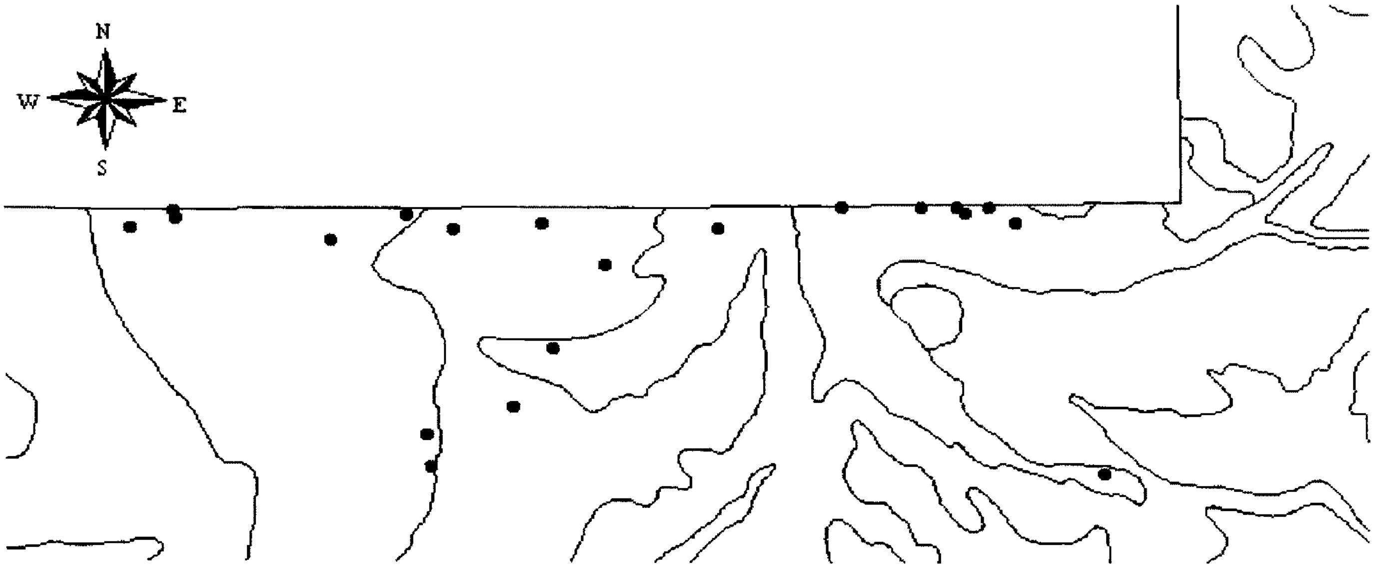
Terry, R.E., and S.D. Nelson. 1986. Effects of polyacrylamide and irrigation method on soil physical properties. Soil Science. 141:317-320.

Thomas, G.W. 1996. Soil pH and Soil Acidity, Chapter 16, *In* D. L. Sparks, ed. Methods of Soil Analysis-Part 3 Chemical Methods. SSSA Book Series 5. American Society of Agronomy., Madison, WI, USA.

Weeks, H. 1974. Physiological, morphological, and behavioral adaptations of wild herbivorous mammals to a sodium-deficient environment. Ph.D. dissertation, Purdue University, Lafayette, Indiana, USA.

Willatt, S.T., and D.M. Pullar. 1984. Changes in soil physical properties under grazed pastures. Australian Journal of Soil Resources. 22:343-348.

Zahow, M.F., and C. Amrhein. 1992. Reclamation of saline sodic soil using synthetic polymers and gypsum. Soil Science Society of America Journal. 56:1257-1260.



Appendix 1. Map of salt-affected sites in the Teton Wilderness. Map area is Teton Wilderness, Northern non-map area is Yellowstone National Park.

SITE	EASTING	NORTHING
2	12T 0571282	4886693
3	12T 0575036	4886723
4	12T 0574245	4886710
5	12T 0573299	4886714
6	12T 0575764	4886829
7	12T 0574437	4886549
8	12T 0573399	4556540
11	12T 0568049	4886096
12	12T 0575782	4886295
13	12T 0578030	4879117
15	12T 0558103	4885756
17	12T 0554134	4886340
18	12T 0554130	4886527
22	12T 0553015	4886064
25	12T 0560030	4886684
26	12T 0560058	4886449
30	12T 0563532	4886208
31	12T 0565171	4885067
32	12T 0563798	4882693
33	12T 0561238	4886065
34	12T 0560565	4880212
35	12T 0562748	4881024
36	12T 0560634	4879309

Appendix 2. UTM coordinates for all salt-affected sites in the Teton Wilderness. Coordinates are all in NAD CONUS 27.