A study of soil development on marine and stream terraces of Swanton Pacific Ranch, Davenport, CA

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Introduction

Purpose

The objectives of this study were to describe and classify five soils according to USDA Soil Taxonomy Standards, and to provide this information for the Professional Soil Scientists Association of California conference at Swanton Pacific Ranch, June 2010. The main focus was to provide an insight on the marine terrace and organic farm soil development at Swanton Pacific Ranch. A total of five soil pits were analyzed, three marine terraces of varying ages and a flood plain and stream terrace, both currently used for agricultural purposes. The marine terraces in our study offer a unique opportunity to evaluate rates of geochemical and pedogenic changes over time (Anderson et al., 1999). All soils sampled were located off of Highway 1, north of Davenport, CA, on the Swanton Pacific Ranch property.

Materials and Methods

Materials

- Backhoe
- Rounded shovel
- Flat shovel
- 150 cm cloth tape measure
- Nails
- Munsell color book
- No. 10 soil sieve
- Hand held clinometer
- Soil knife
- Rock hammer
- Garmin GPS receiver
- Water bottles with DI water
- 10% HCL
- Ziploc gallon size bags
- Sharpies
- NRCS field guide book
- Field sheets
- Keys to Soil Taxonomy 11th edition

Standard Methods

Soil classification interpretations followed those discussed in the Soil Survey Manual (Soil Survey Staff) and Keys to Soil Taxonomy, 11th edition (Soil Survey Staff, 2010). Digital maps were produced from the data collected and premade Swanton maps using ArcGIS software by Environmental Systems Research Institute.

Physical and chemical analysis of the soils sampled was performed to determine the cation exchange capacity in the soil with the Ammonium acetate method, soil concentration of carbon and nitrogen (%), electrical conductivity (E.C. measured in dS m^{-1}), and soil pH (Amedee, 1990).

Procedures

The Swanton Pacific Ranch soil survey was performed using five soil pits to document the soil morphological properties including soil depth to 150 centimeters, soil color, soil structure, and soil chemical characteristics and brought soils back to California Polytechnic State University, San Luis Obispo for further soil chemical analysis and to classify the soils using soil taxonomy into five different soil series. Chemical analysis of the soils was performed at California Polytechnic State University, San Luis Obispo.

Soil pH

Soil pH was determined using the two to one method of calcium chloride to soil by mass and measuring the soil mixture with a double junction electrode pH meter (Amedee, 1990).

Soil Electrical conductivity

Soil electrical conductivity (*desi-Siemens per* meter) was measured using a saturated paste of soil with deionized water (Amedee, 1990).

Soil percent carbon and percent nitrogen

Soil carbon and nitrogen were determined by use of the varioMAX CNS analyzer (Amedee, 1990).

Soil Cation Exchange Capacity

The soil cation concentration (parts per million) of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} was determined by ammonium acetate (NH_4OAc) method and measured with the atomic absorption spectrometer (Amedee, 1990).

Soil Particle Size Analysis

Particle size analyses were performed for a total of five soil horizons, one horizon of each of the soil pits. The percent sand silt and clay calculated from the particle size analysis was then compared to the soil texture that was determined by feel method to ensure accuracy (Amedee, 1990).

Swanton Pacific Ranch

Literature Review

A brief history of Swanton Pacific Ranch

The land that Swanton Pacific Ranch currently occupies was originally inhabited by the Ohlone Native American Tribe. Artifacts found near Waddell Creek and Scott Creek prove that the Ohlone visited these areas. The Ohlone remained in the area into the 1800's. In 1843 Ramon Rodriquez and Francisco Alviso were granted title to the land by the Mexican Governor of California. The Mexican Land Grant named Rancho Aqua Puerca Y Las Trancas (Hog Water and the Bars) was later sold to James Archibald in 1867. Archibald hired Ambrogio Gianone to manage the dairy. Gianone built the cheese house later that year and hired shipwrecked carpenters to build the barn in the 1880's. Both structures still stand today. The property was sold to Joseph Bloom after the death of James Archibald. Bloom continued using the land for farming purposes (Swanton Pacific Ranch, 2010).

In 1899, Fred Swanton, a former mayor of Santa Cruz, built powerhouses on Big Creek and Mill Creek, generating hydro-electric power for Central Coast Counties Gas and Electric company (now PG&E). Fred Swanton produced power well into the 1940's. He abandoned the powerhouse after a forest fire destroyed the flume (Swanton Pacific Ranch, 2010).

The San Vincente Lumber Company logged in the hills behind the current Swanton boundary from 1905 to 1923. Much of the redwood was used to rebuild San Francisco after the 1906 earthquake and fire. The Ocean Shore Railroad was constructed to assist with the logging operation. It ran along the coast from San Francisco to Santa Cruz. In 1922, the railroad shut down due to increasing wage demands by employees (Swanton Pacific Ranch, 2010).

During the 1920's the area became a prime region for artichokes and brussel sprouts. Scott's Creek was dammed, and the water was pumped to the upper marine terraces. The land was irrigated by this water through a system of gravity fed reservoirs on what is now the rangeland. In 1938, the Poletti and Morelli families bought the ranch and divided it into three sections: (1) a grade B dairy, (2) a beef cattle operation, and (3) row crops. A labor camp with mostly Filipino workers was established due to the additional labor needed for the intensification of row cropping. Remains of the labor camp still exist on the Swanton Pacific property and are considered a historic site. Later, John and Bob Musitelli took over the beef cattle operation and established a cow-calf operation, as well (Swanton Pacific Ranch, 2010).

In 1943, Albert B. Smith, a Cal Poly graduate and founder of Orchard Supply Hardware, purchased 412 acres of second growth forest. Smith's love of the land began when he was a Boy Scout and camped in the area. In 1978, Smith hired a cowboy to run a cow-calf and stocker cattle operation. Brussel sprouts and cut flowers were also grown on the land but both the cattle and cropping ventures turned out to be unprofitable and came to an end. A three year lease between Cal Poly and Al Smith was made in the 1980's, which was later extended to a five year lease. This in turn lead to the donation of land to Cal Poly in 1993. Over time, Al Smith had acquired 3,200 acres of land which is now known as Swanton Pacific Ranch(Swanton Pacific Ranch, 2010).

Marine Terrace Uplift

Marine terraces are a frequent manifestation of coastal uplift and global sea level changes. Terrace development begins when a wave cut platform is formed during global sea level high stands. The platform rises as a product of tectonic uplift and is above subsequent sea level high stands. When the process is repeated, a series of marine terraces is formed. These terraces are typically composed of beach sands, finer-grained near shore sediments or thin eolian deposits (White et al., 2009). The sediments are evidence of global warming and cooling sea levels rising and falling (Chernicoff and Whitney, 2007).

In the Santa Cruz area numerous faults influence the rate and angle of uplift of marine terraces; including the Loma Prieta, Coastways, Frijoles, San Andreas and San Gregorio faults (Stoffer and Goron, 2001). The San Gregorio fault is southeast dipping and the Loma Prieta fault is southwest dipping. The Frijoles and Coastways are a part of the San Gregorio fault zone and are northwesterly striking (Merritts et al., 2003). Uplift rates are highly disputed among scholars (Weber and Allwardt, 2001). California’s location between the North American plate and the Pacific plate is responsible for the tectonic activity occurring along the coast of California. The San Andreas Fault system is composed of northwest trending, right lateral, strike-slip faults. The slight variations in these fault movements create a small amount of compression, which is responsible for the continual uplift of the coastal ranges.

Marine Terrace Age

Marine terrace ages can be related to their elevation. The marine terrace with the greatest elevation in a series of terraces will be the oldest (Munster and Harden, 2002). In general, the oldest terrace will also have the most developed soil profiles given a stable environment. There is a series of six marine terraces that make up the Ben Lomond Mountain Santa Cruz Structural Block (Table 1) (Bradley and Griggs, 1976).

Table 1. Marine terrace formations on Ben Lomond Mountain with elevation and estimated ages (Bradley and Griggs, 1976).

Marine Terrace	Elevation (m)	Estimated Age (ka)
Santa Cruz/ Highway 1	32	105
Cement	58	125
Western	92	213
Wilder	140	320
Blackrock	190	430
Quarry	240	545

Geology of Marine Terraces

The two most prominent rock formations comprising the marine terrace series along the Santa Cruz coasts are the Santa Cruz Mudstone and the Santa Margarita Sandstone. The Santa Cruz Mudstone is composed of siliceous mudstone, non-siliceous mudstone, siltstone, and sandstone. The siliceous property of the mudstone reflects evidence of marine accumulation of organic matter in a calm deep-sea environment. The Santa Margarita Sandstone is comprised of arkosic sands thinly deposited in a bioturbating marine environment (Barnes et al., 2000).

Along the coast of California, from Ano Nuevo to the mouth of the Pajaro River, these six distinct marine terraces reflect the geologic history of the area (Valensise and Ward, 1991). These Tertiary sandstone and mudstone marine terraces offer a unique opportunity to study rates of geochemical and pedogenic changes over time (Anderson et al., 1999). Measurable geochemical and pedogenic accumulations and transformations include: organic carbon, soil pH, total mass of accumulated clay, crystalline and amorphous forms of iron, amorphous forms of aluminum, and the ratio of quartz to feldspars in the very fine sand fraction (Tsai et al., 2007; Jenny, 1973). Solum thickness is also a key indicator of soil development.

Factors most influential in the development of soils on marine terraces along the Santa Cruz coast of California are: climate, parent material, topography, and time. The large quantity of rainfall in the Santa Cruz area results in the highly developed soils found along the coast. The chemical weathering, spurred by rainfall, contributes to the formation of secondary clay minerals and their subsequent movement through the soil profile. The Santa Cruz marine terrace soils are formed from the Santa Cruz Mudstone and Santa Margarita Sandstone rock formations. These parent materials lend themselves to different attributes of the soil. For instance, soils derived from the sandstone have a greater quantity of fine sands than soils developed from the mudstone formations. Topography influences soil development largely, depending upon the site position on the landform. Soils formed on steep slopes are generally shallower and have a higher tendency towards erosion in comparison to soils on more stable landforms. Time is one of the most influential soil forming factors because it is the variable, while all other factors are constant (Singer and Munns, 2002).

The unique tectonic environment in Santa Cruz, CA produced to exceptionally developed marine terraces. This allows for the study of soil chronosequences because they formed with a slight degree of tilt (Jenny, 1973). These flat platforms, in combination with marine parent materials, produce highly acidic and nutrient deficient soils. The acidic properties are the result of the poor drainage at the platform-sand interface (Muhs et al., 2003).

The study of marine terrace chronosequences has provided scientists with information concerning the connection between organic carbon, soil pH, total mass of accumulated clay, crystalline and amorphous forms of iron, amorphous forms of aluminum, and the ratio of quartz to feldspars in the very fine sand fraction and soil formation (Bockheim et al., 1996; Merrits et al., 1991; Moody and Graham, 1995; Muhs, 1982; Tsai et al., 2007; Jenny, 1973). The previously referenced studies have produced information that is useful for scholars to assess and learn about geologic and soil morphologic processes.

Site Location Background

Land Use

All marine terraces analyzed were located in the Scotts Creek watershed and are currently used as rangeland for cattle. Cattle are managed using a “Planned Grazing” method which takes into account the health of the rangeland ecosystem and times cattle movement to minimize impact, promote native perennial grass diversity, and ensure pasture recovery. Soil pits located along Scotts Creek have been managed in an alternative way. Areas directly next to the Creak have remained vegetated in their natural form while soils on the flood plain of Scott’s Creek have been plowed and are used regularly for agricultural purposes.

Climate

The mean annual temperature of Santa Cruz County is 12°C to 14°C, (54°F to 58°F)(Figure 1). There is an average of 220 to 275 frost free days each year. Annual precipitation for the area ranges from 50 to 127 centimeters (20 to 50 inches) per year (Figure 2). Skies are overcast for 30 to 40 percent of the daylight hours annually. Average humidity is between 70 - 80 percent in the winter and slightly lower in the summer. Winds are usually light (USDA, 1980).

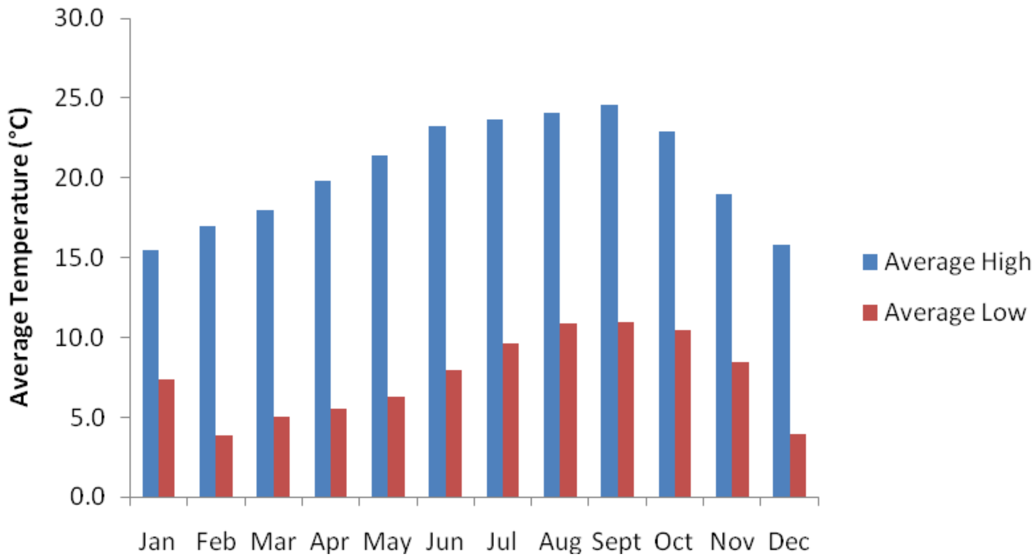

Figure 1. Average low temperatures (°C) by month of Santa Cruz, CA.

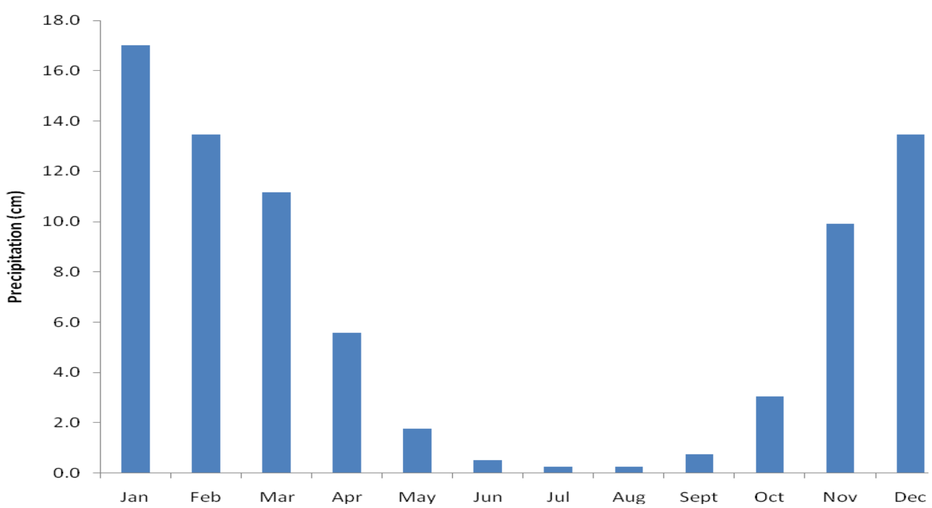

Figure 2. Average percipitation (cm) by month of Santa Cruz, CA.

Soil Pit Locations

The Bonnydoon, “Terrace,” and Botella series are located to the east of Highway 1, 1.5 miles north of the southern Swanton Road entrance. The Cole series is located adjacent to Jacob’s Farm, 1.4 miles northeast Swanton Road from Highway 1. The Pfieffer series is located on the west side of Swanton Road, 2 miles northeast from Highway 1 (Figure 1).

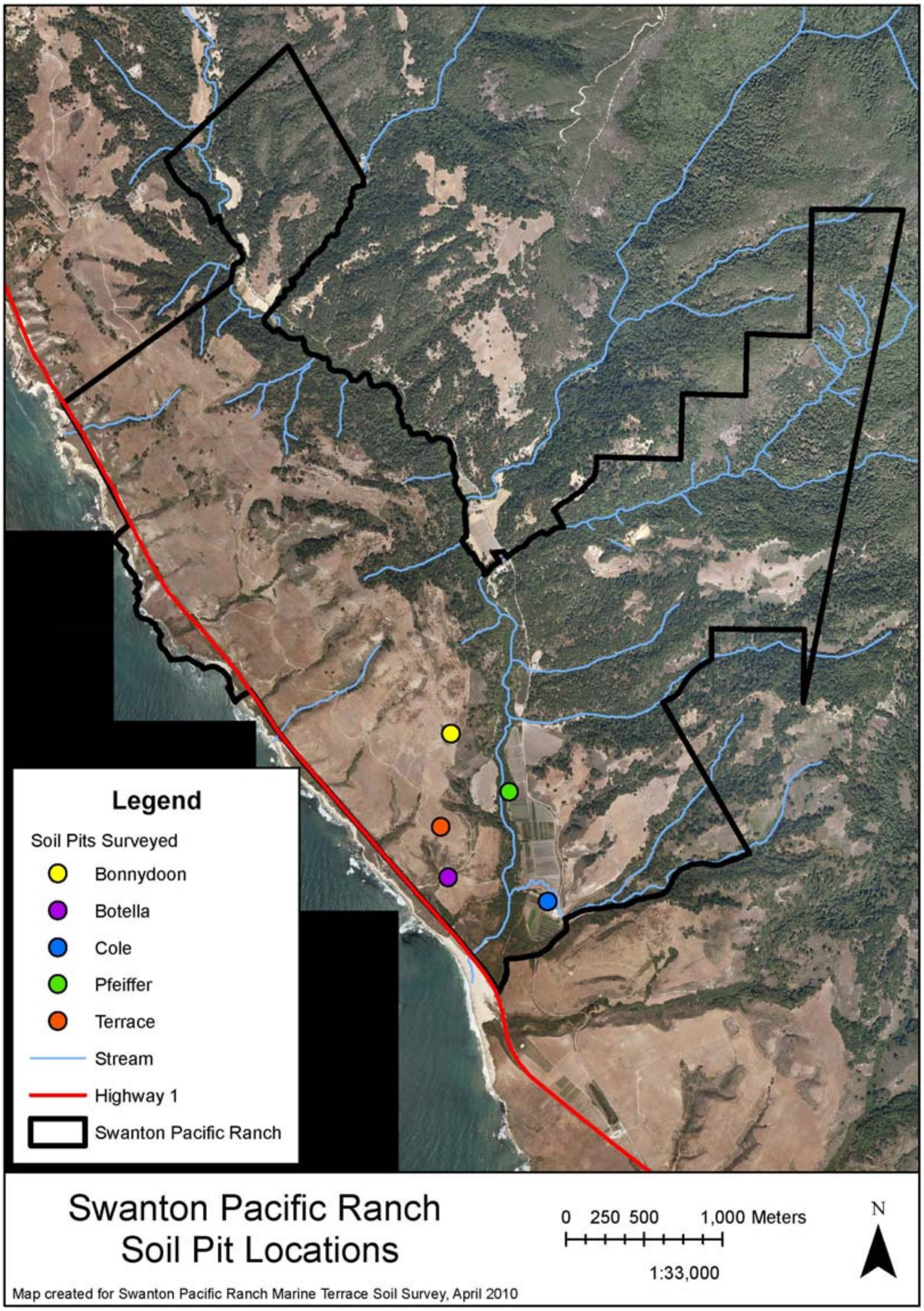

Figure 3. Arial view of Swanton Pacific Ranch soil survey area including soil pit locations (GIS Swanton Pacific Ranch database).

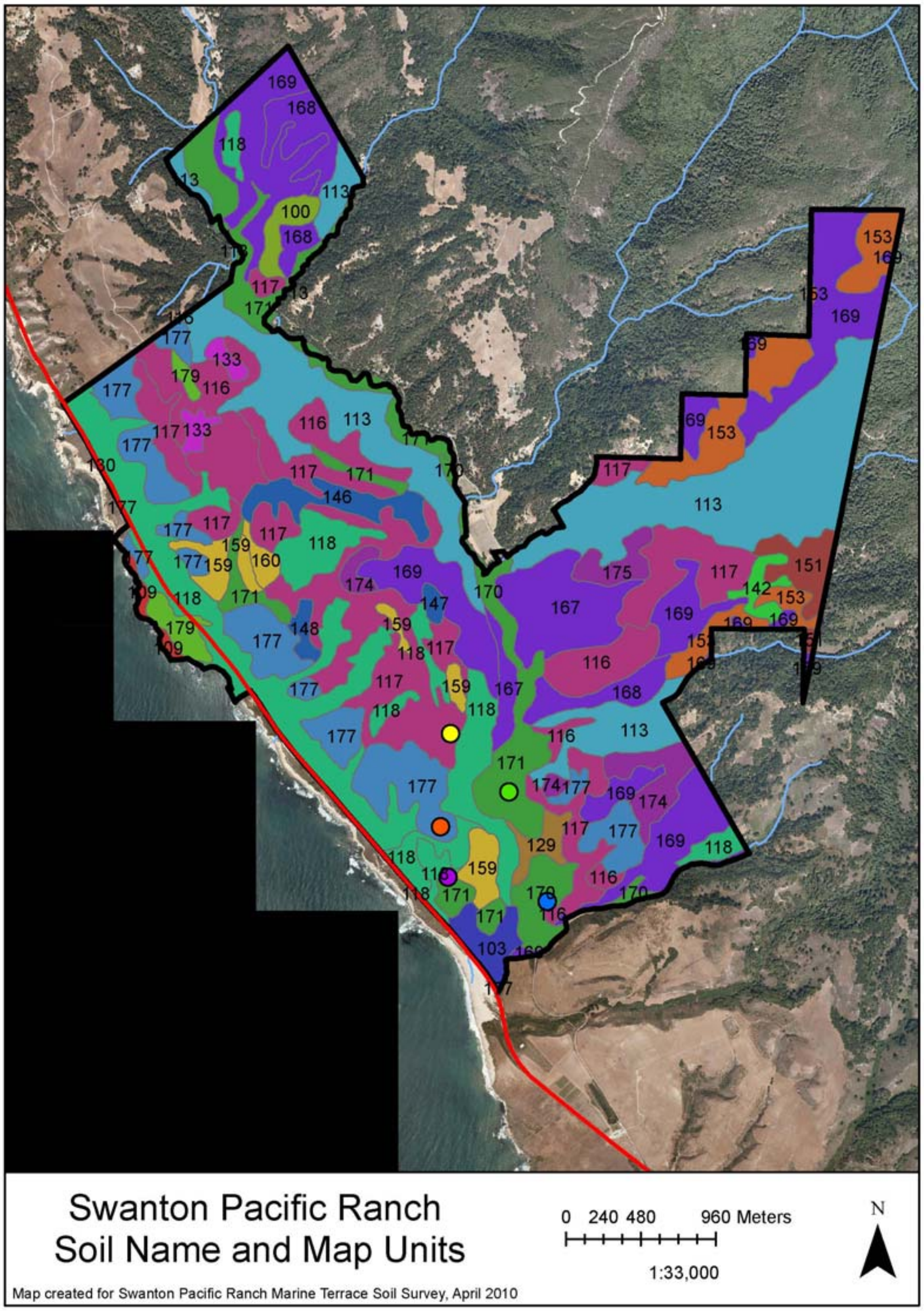

Figure 4A. Swanton Pacific Ranch soil pit locations with previously identified soil map units (GIS Swanton Pacific Ranch database).

Legend

Soil Pits Surveyed

- Bonnydoon
- Botella
- Cole
- Pfeiffer
- Terrace

Soil Series Name and Map Unit

- Aptos loam 100
- Aquents/flooded 103
- Beaches 109
- Ben Lomond-Catelli-Sur Complex 113
- Bonnydoon loam 116, 117
- Bonnydoon-Rock Outcrop Complex 118
- Elder sandy loam 129, 130
- Elkhorn sandy loam 133
- Lompico-Felton Complex 142
- Los Osos loam 146, 147
- Maymen stony loam 151
- Maymen-Rock Outcrop Complex 153
- Pfeiffer gravelly sandy loam 159, 160
- Santa Lucia Shaly Clay Loam 168, 169
- Soquel loam 170, 171
- Tierra-Watsonville Complex 174, 175
- Watsonville Loam 177
- Watsonville loam thick surface 179

Swanton Pacific Ranch

Stream

Highway 1

Figure 4B. Legend for Swanton Pacific Ranch and Soil Map Units Map.

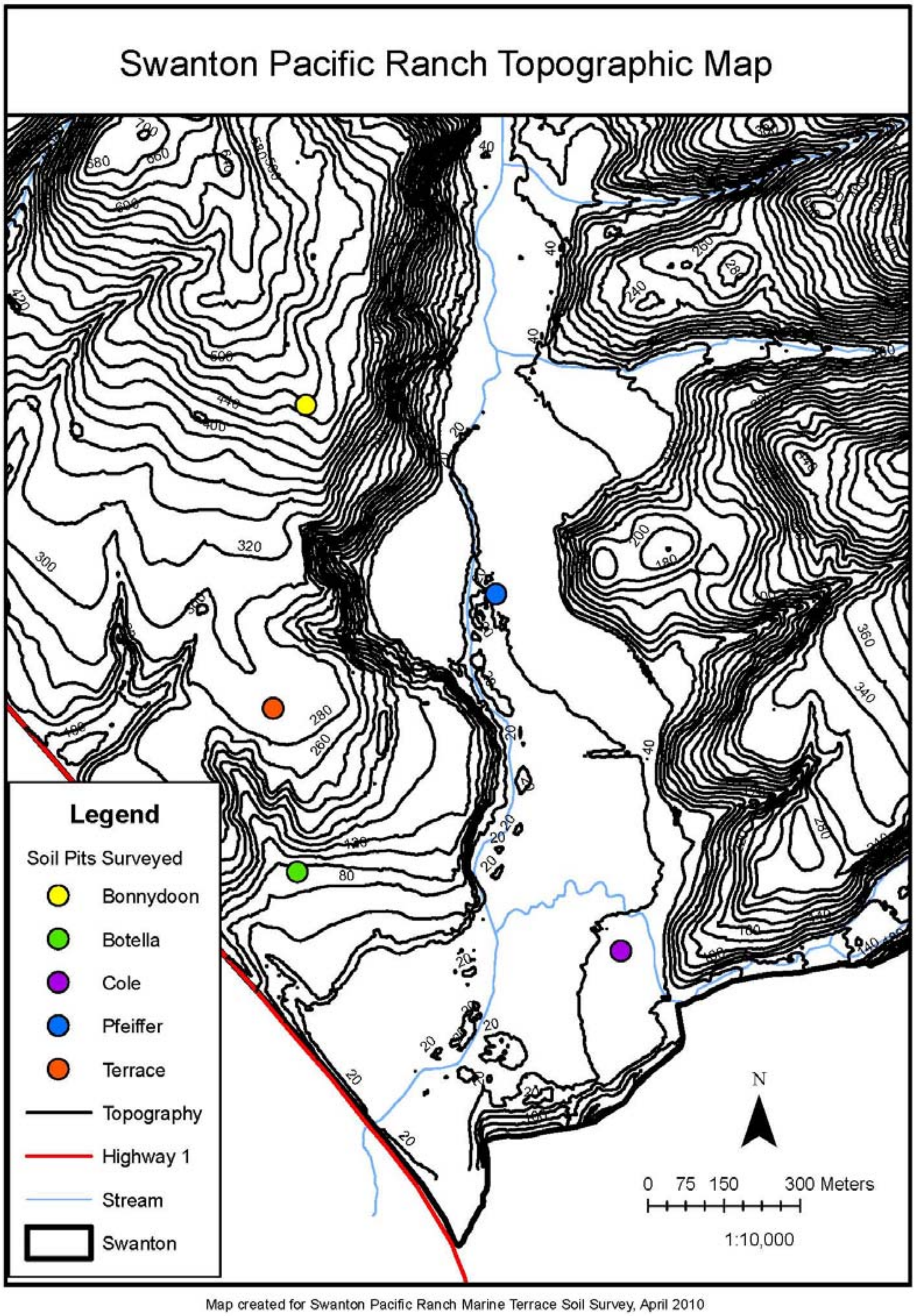

Figure 5. Topographic map of Swanton Pacific Ranch soil survey area including soil pit locations (GIS Swanton Pacific Ranch database).

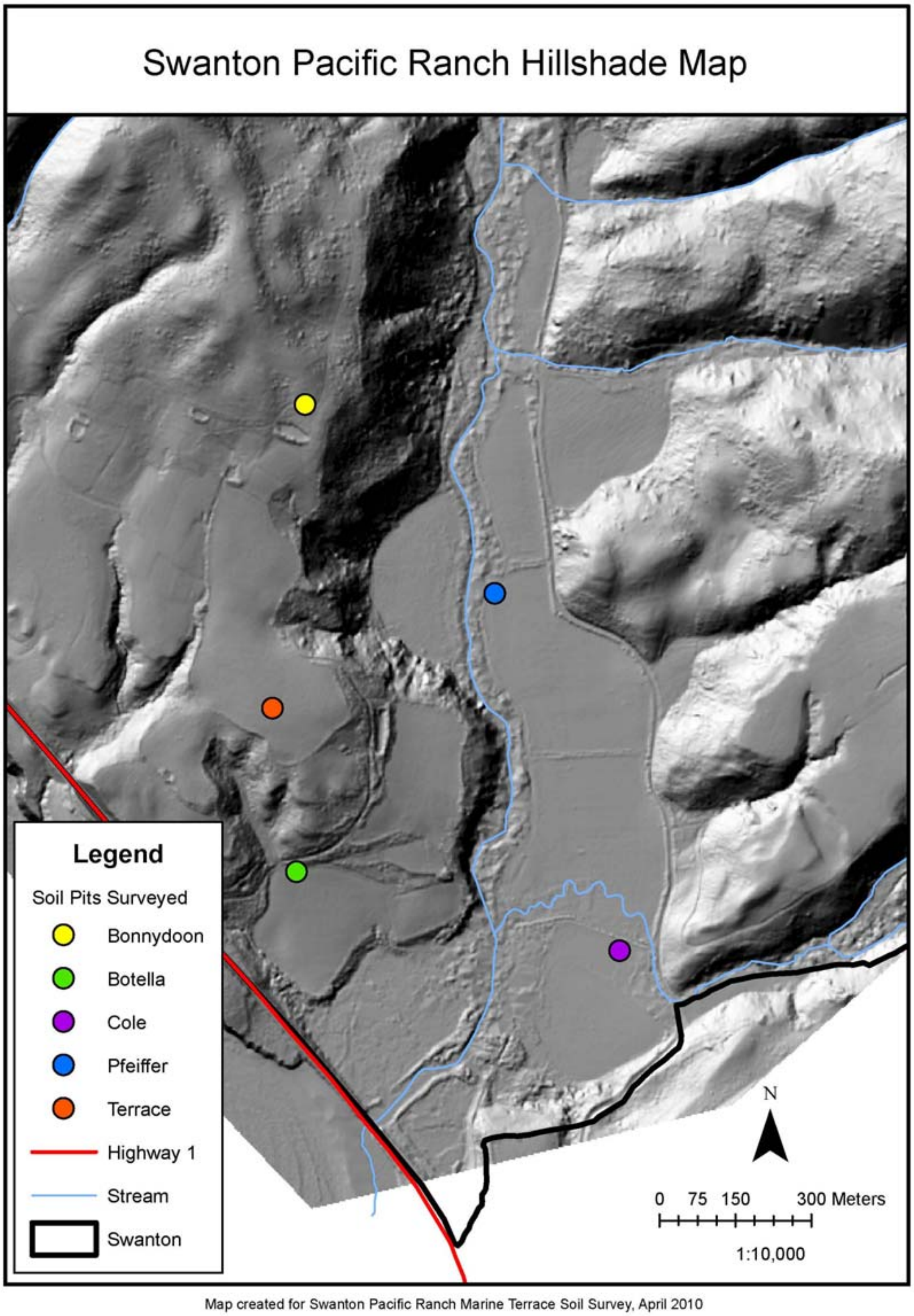

Figure 6. Hillshade map of Swanton Pacific Ranch soil survey area with soil pit locations (GIS Swanton Pacific Ranch database).

BONNYDOON SERIES

TAXONOMIC FAMILY NAME: Fine-loamy, mixed, superactive, thermic, shallow Entic Haploxeroll

The Bonnydoon series consists of shallow, somewhat excessively drained soils that formed in material weathered from sandstone and shale. Bonnydoon soils are on uplands and have slopes of 5 to 15 percent. The mean annual precipitation is about 76 cm (30 inches) and the mean annual air temperature is about 15°C (59°F).

REPRESENTATIVE PEDON: Bonnydoon loam with 5 to 15 percent slope, southwest facing formed on Santa Cruz mudstone formation at an elevation of 144 meters (474 feet). Latitude 37°3'12.84"N and Longitude W 122°13'49.997". (Colors are for dry soil unless otherwise stated. When described on January 17, 2010, the soil was moist throughout).

> A--0 to 34 cm (0 to 13 inches); dark gray (10YR 4/1) gravelly clay, very dark gray (10YR 3/1) moist; weak fine granular structure; moderately plastic, moderately sticky; many fine and very fine roots; 15 percent coarse gravel rock fragments; strongly acid (pH 5.17); gradual smooth boundary.
>
> AC--34 to 59.5 cm (13 to 23 inches); dark grayish brown (10YR 4/2) very channery clay, very dark gray (10YR 3/1) moist; weak fine subangular blocky structure breaking to fine granular structure; moderately plastic, moderately sticky; many fine roots; 40 percent channery platy rock fragments; strongly acid (pH 5.09); abrupt smooth boundary.
>
> Cr--59.5 to 150 cm (23 to 34 inches); light brownish gray (10YR 6/2) fractured weathered shale bedrock that breaks to clay, very dark brown (10YR 2/2) moist; rock structure; moderately plastic, moderately sticky; extremely acid (pH 3.98).

RANGE IN CHARACTERISTICS Depth to a paralithic contact is 34 to 60 cm. The soil between the depths of 15 cm to 48 cm or to the paralithic contact usually becomes moist in some parts in November or early December and remains moist until May. Mean annual soil temperature is about 59 degrees to 61 degrees F. The difference between mean summer and winter soil temperature is 15 degrees to 25 degrees F. Organic matter is more than one percent throughout the solum. The profile is heavy sandy loam, heavy fine sandy loam, loam, gravelly loam, sandy clay loam, or clay loam and has 18 to 30 percent clay. Pebbles range from 0 to 10 percent by volume. Reaction ranges from strongly acid to neutral. Base saturation is more than 75 percent throughout the profile (Bonnydoon official soil survey, 2001).

Photo 1. Representative pedon of the Bonnydoon Series (Photograph courtesy of Genevieve Widrig, Anna Tornincasa, and Kristine Johnson).

“TERRACE”

TAXONOMIC FAMILY NAME Fine-loamy, mixed, superactive, thermic Xeric Argialboll

The “Terrace” series consists of very deep, moderately drained soils formed in marine sediments. “Terrace” soils are on old coastal terraces and have slopes from 0 to 5 percent. The mean annual precipitation is about 76 cm (30 inches) and the mean annual air temperature is about 15°C (59°F).(This series name is used for the purpose of this survey performed and is not an official soil series.)

REPRESENTATIVE PEDON: “Terrace” loamy sand with 0 to 5 percent slope, southwest facing formed on Santa Cruz mudstone formation at an elevation of 106 meters (349 feet). Latitude 37°2' 53.686"N and Latitude 122°13' 51.342"W (Colors are for dry soil unless otherwise stated. When described on January 17, 2010, the soil was moist throughout).

Ap1--0 to 11 cm (0 to 4 inches); dark gray (7.5YR 4/1) loamy sand, very dark gray (10YR 3/1) moist; weak fine granular structure; non-plastic, non-sticky; many fine and very fine roots; strongly acid (pH 5.28); clear smooth boundary.

Ap2--11 to 41 cm (4 to 16 inches); dark gray (7.5YR 4/1) sandy loam, very dark gray (10YR 3/1), moist; weak fine and medium subangular blocky structure; non-plastic, non-sticky; common fine roots; strongly acid (pH 5.39); abrupt wavy boundary.

E--41 to 96 cm (16 to 38 inches); dark yellowish brown (10YR 4/6) sandy loam, dark yellowish brown (10YR 3/6), moist; weak fine and medium subangular blocky structure; moderately sticky, and moderately plastic; medium acid (pH 5.7); abrupt irregular boundary.

Btg--96 to 150 cm (38 to 59 inches); yellowish brown (10YR 5/6) sandy clay, red (10YR 4/6), moist; yellowish brown (10YR 5/6), dark yellowish brown (10YR 4/6) mottles, moist; yellowish brown (10YR 5/4), dark yellowish brown (10YR 5/4); weak medium subangular blocky structure breaking to singly grained structure; moderately plastic, moderately sticky; common very fine roots; many krotovinas; common clay films between sand grains; magnesium nodules, iron concentrations coating and cementing grains together, medium acid (pH 5.92).

Photo 2. Representative pedon of the “Terrace” Series (Photograph courtesy of Genevieve Widrig, Anna Tornincasa, and Kristine Johnson).

BOTELLA SERIES

TAXONOMIC FAMILY NAME: Fine-loamy, mixed, superactive, thermic Pachic Argixeroll The Botella series consists of very deep, well drained soils that formed in alluvial material from sedimentary rocks. Botella soils are in valley bottoms and on alluvial fans and have slopes of 0 to 5 percent. The mean annual precipitation is about 76 cm (30 inches) and the mean annual air temperature is about 15^{O}C (59^{O}F).

REPRESENTATIVE PEDON: Botella sandy clay loam with 0 to 5 percent slope, southwest facing, formed on the footslope on the Santa Cruz mudstone formation at an elevation of 21 meters (69 feet). Latitude 37°2'43.723"N and Latitude 122°13'51.816"W (Colors are for dry soil unless otherwise stated. When described on January 17, 2010, the soil was moist throughout). (Colors are for dry soil unless otherwise stated. When described on January 17, 2010, the soil was moist throughout).

Ap1--0 to 11 cm (0 to 4 inches); grayish brown (10YR 5/2) sandy clay loam, very dark gray (10YR 3/1) moist; weak fine granular structure; non-sticky, non-plastic; many very fine and common fine roots; many krotovinas and many worm casts; strongly acid (pH 5.29); abrupt wavy boundary.
Ap2--11 to 60 cm (4 to 22 inches); dark grayish brown (10YR 4/2) sandy clay loam, black (10YR 2/1) moist; weak fine and medium subangular blocky structure; non-sticky, non-plastic; common fine roots; common krotovina and many worm casts; medium acid (pH 5.79); gradual wavy boundary.

Bt1--60 to 90 cm (22 to 32 inches); dark grayish brown (10YR 4/2) sandy clay loam, very dark grayish brown (10YR 3/2) moist; brown (10YR 5/3), very dark grayish brown (10YR 3/2) concentrations, moist; weak fine and medium subangular blocky structure; slightly sticky, slightly plastic; few fine roots; common clay films on ped surfaces; slightly acid (pH 6.09); gradual wavy boundary.

Bt2--90 to 139 cm (32 to 54 inches); yellowish brown (10YR 5/6) sandy clay loam, dark yellowish brown (10YR 4/4) moist; light yellowish brown (10YR 6/4), dark yellowish brown (10YR 4/4) concentrations, moist; weak fine and medium subangular blocky structure; slightly sticky, slightly plastic; common clay films on ped surfaces; slightly acid (pH 6.08); gradual wavy boundary.

Bt3-- 139 to 150 cm (54 to 59 inches); yellowish brown (10YR 5/6) sandy clay loam, dark grayish brown (10YR 4/2) moist; light yellowish brown (10YR 6/4), dark yellowish brown (10YR 4/4) concentrations, moist; moderate fine and medium subangular blocky structure; slightly sticky, slightly plastic; common clay films on ped surfaces; 20 percent rock fragments by volume; medium acid (pH 5.98).

RANGE IN CHARACTERISTICS: The soil between depths of 10 cm and 30 cm becomes moist in some part in November or early December and remains moist until May. Mean annual soil temperature is 15 to 18°C. Shale fragments or other rock fragments generally make up less than 15 percent of the solum (Botella official soil survey, 2009).

Photo 3. Representative pedon of the Botella Series (Photograph courtesy of Genevieve Widrig, Anna Tornincasa, and Kristine Johnson).

COLE SERIES
TAXONOMIC FAMILY NAME: Fine, mixed, superactive, thermic Pachic Argixeroll

The Cole series consists of very deep, somewhat poorly drained soils that formed in alluvium from mixed sources. Cole soils are on river terraces, basins, flood plains, or on alluvial fans with slopes of 0 to 3 percent. The mean annual precipitation is about 76 cm (30 inches) and the mean annual air temperature is about 15°C (59°F).

REPRESENTATIVE PEDON: Cole clay loam with 0 to 5 percent slope, formed at an elevation of 7 meters (22 feet). Latitude 37°2'38.706"N and 122°13'24.66"W (Colors are for dry soil unless otherwise stated. When described on December 12, 2009, the soil was moist throughout).

Ap1--1 to 14 cm (0 to 6 inches); dark grayish brown (10YR 4/2) loam, black (10YR 2/1) moist; weak fine granular structure; slightly hard, very friable, non-sticky and non-plastic; few coarse and many fine roots; many krotovinas; medium acid (pH 5.86); abrupt smooth boundary.

Ap2--14 to 27 cm (6 to 11 inches); dark gray (10YR 4/1) clay loam, very dark gray (10YR 3/1) moist; moderate fine subangular blocky structure; moderately hard, friable, slightly sticky and slightly plastic; many fine roots; many krotovinas; medium acid (pH 5.79); gradual wavy boundary.

BA--27 to 51 cm (11 to 20 inches); very dark grayish brown (10YR 3/2) clay loam, black (10YR 2/1) moist; weak fine subangular blocky structure; moderately hard, friable, slightly sticky and slightly plastic; few fine and common very fine roots; common distinct clay films on ped faces; medium acid (pH 5.79); clear wavy boundary.

Bt1-- 51 to 68 cm (20 to 27 inches); dark grayish brown (10YR 4/2) Clay loam, very dark brown (10YR 2/2) moist; weak fine and moderate subangular blocky structure; moderately hard, friable, slightly sticky and slightly plastic; common fine and few very fine roots; few distinct clay films on ped faces; slightly acid (pH 6.07); clear wavy boundary.

Bt2--68 to 81 cm (27 to 32 inches);dark grayish brown (10YR 4/2) clay loam, very dark brown (10YR 2/2)moist; weak medium angular blocky structure; moderately hard, friable, moderately sticky and moderately plastic; few fine roots; many distinct clay films on ped faces; few distinct iron concentrations; medium acid (pH 5.99); clear wavy boundary.

Bt3--81 to 105 cm (32 to 41 inches; brown (10YR 4/3) clay loam, very dark brown (10YR 2/2) moist; weak medium angular blocky structure; moderately hard, friable, slightly sticky and slightly plastic; few very fine roots; medium acid (pH 6.00); clear wavy boundary.

Bt4--105 to 127 cm (41 to 50 inches); very dark grayish brown (10YR 3/2) sandy clay loam, very dark brown (10YR 2/2) moist; weak medium angular blocky structure;

moderately hard, friable, slightly sticky and slightly plastic; few very fine roots; slightly acid (pH 6.09); gradual smooth boundary.

C--127 to 150 cm (50 to 59 inches); dark grayish brown (10YR 4/2) sandy loam, very dark grayish brown (10YR 3/2) moist; weak medium angular blocky structure; moderately hard, friable, slightly sticky and slightly plastic; few fine roots; medium acid (pH 6.00).

RANGE IN CHARACTERISTICS: The mean annual soil temperature is 15 to 18° C. The soil between depths of 10 cm and 30 cm is usually dry from July 1 to October 1 and is moist in all parts from December 1 to April 30. The particle-size control section has 35 to 45 percent clay. Organic carbon is 1 to 2 percent to a depth of 50 to 89 cm. Gravel content ranges from 0 to 15 percent throughout. Soil is slightly acid to medium acid throughout (Cole official soil survey, 2003 A).

Photo 4. Representative pedon of the Cole Series (Photograph courtesy of Genevieve Widrig, Anna Tornincasa, and Kristine Johnson).

PFEIFFER SERIES

TAXONOMIC FAMILY NAME: Coarse-loamy, mixed superactive, thermic Typic Haploxeroll

The Pfeiffer series consists of deep, well drained soils that formed in material weathered from sandstone, schist, gneiss and granitic rocks. Pfeiffer soils are on uplands and have slopes of 2 to 85 percent. The mean annual precipitation is about 76 cm (30 inches) and the mean annual air temperature is about 15°C (59°F).

REPRESENTATIVE PEDON: Pfeiffer sandy loam with 0 to 5 percent slope, formed on northwest aspect at an elevation of 5 meters (16 feet). Latitude 122°13'35.124"W and Longitude W 37°3'0.512"N (Colors are for dry soil unless otherwise stated. When described on December 12, 2009, the soil was moist throughout).

Ap--0 to 29 cm (0 to 11 inches); dark grayish brown (2.5Y 4/2) loam, black (10YR 2/1) moist; moderate fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; many fine, common medium and few coarse roots; slightly acid (pH 6.14); gradual smooth boundary.

Ap2--29 to 45 cm (11 to 18 inches); dark grayish brown (2.5Y 4/2) loam, black (10YR 2/1) moist; weak fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; common fine and few very fine roots; medium acid (pH 5.93); clear smooth boundary.

Bw1--45 to 67 cm (18 to 26 inches); dark grayish brown (2.5Y 4/2) sandy loam, black (10YR 2/1) moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; medium acid (pH 5.90); clear smooth boundary.

Bw2--67 to 85 cm (26 to 33 inches); brown (10YR 4/3) sandy loam, very dark gray (10YR 3/1) moist; moderate fine subangular blocky structure; slightly hard, friable, non-sticky and non-plastic; few very fine roots; slightly acid (pH 6.12); clear smooth boundary.

BC--85 to 108 cm (33 to 43 inches); dark yellowish brown (10YR 4/4) loamy sand, brown (10YR 4/3) moist; weak and moderate medium angular and subangular blocky structure; slightly hard, friable, non-sticky and non-plastic; few very fine roots; slightly acid (pH 6.31); clear smooth boundary.

CB--108 to 135 cm (43 to 53 inches); dark yellowish brown (10YR 4/4) loamy sand, very dark brown (10YR 2/2) moist; weak fine subangular blocky structure; soft, very friable, non-sticky and non-plastic; few very fine roots; slightly acid (pH 6.51); abrupt smooth boundary.

2C--135 to 150 cm (53 to 59 inches); dark yellowish brown (10YR 4/6) sand, dark yellowish brown (10YR 4/4) moist; single grained structure; loose, loose, non-sticky and non-plastic; iron oxide coatings on sand grains; slightly acid (pH 6.18).

RANGE IN CHARACTERISTICS: Depth to a paralithic contact is 100 to 178 cm. The mean annual soil temperature at a depth of 50 cm inches is 15 to 18° C. The soil between the depths of about 23 to 69 cm is usually moist all of the time from about the middle of October until about the middle of May and is dry all the rest of the time. Rock fragments average 10 to 35 percent in the 25 to 100 cm control section. Most of these fragments are less than 2 cm in diameter. The amount and size of rock fragments increase with depth and most pedons have more than 35 percent rock fragments below a depth of 100 cm. Organic matter is 1.5 to 2.5 percent in the upper 25 cm and decreases gradually to less than 1 percent at a depth of 50 cm. The soils are sandy loam or coarse sandy loam throughout and are medium acid or slightly acid throughout. Some pedons have a few thin clay films.

The A horizon is brown, dark brown, or dark yellowish brown (10YR 5/3, 4/3, 4/4) dry and dark brown or very dark grayish brown (10YR 3/3, 3/2; 7.5YR 3/2) moist (Pfeiffer official soil survey, 2003 B).

Photo 5. Representative pedon of the Pfeiffer Series (Photograph courtesy of Genevieve Widrig, Anna Tornincasa, and Kristine Johnson).

Summary Description

Chemical Properties

The sodium concentration ranged from 0.11 to 0.64 ppm throughout the soils analyzed and no trend was seen with increasing depth in any of the studied soils. Results for potassium showed that as depth increased the amount of measured potassium decrease in concentration. Magnesium concentrations appeared to be highest in the Bonnydoon series and Cole series surface soils with 4.11 ppm and 3.49 ppm, respectively. The Pfeiffer series had an irregular decrease in calcium concentrations going from 4.69 to 10.63 ppm and back down to 3.11 ppm at depth. This trend was also seen in the Cole series concentration of calcium increasing and then decreasing at depth. These irregular decreases in calcium could indicate a possible buried horizon in these soil series surveyed. The soil electrical conductivity tended to decrease with depth.

The percent of total carbon and nitrogen decreased with increasing depth in all soils sampled. The carbon to nitrogen ratio remained about 10:1 throughout surface soils. The three soil series located on the terraces analyzed showed a decrease in carbon to nitrogen ratio with increasing depth. The carbon to nitrogen ratio had an irregular increase with depth, which is characteristic of stratified alluvial soils.

All soils sampled were classified as slightly acidic to extremely acid (Fig. A2). Due to the high amounts of precipitation and proximity to the ocean, the area has a constant marine layer, which limits the amount of evapotranspiration.

Bonnydoon Series

The Bonnydoon series was classified as a shallow, excessively drained Mollisol. The lack of soil horizonation with little development is why this Mollisol is classified as entic (young). The Bonnydoon series lies over stratified layers of platy weathered sandstone and blocky weathered sandstone. Of the marine terraces surveyed, this terrace is known to be oldest due to site position and elevation relative to the other terraces and is assumed to be from the Wilder Formation (Bradley and Griggs, 1976). The lack of soil development is most likely due to slope and hillslope shoulder site position, which increases erosion and surface runoff.

"Terrace" series

The "Terrace" series consists of a very deep, moderately drained Mollisol. The development of argillic and albic horizons are characteristic of a highly weathered, well developed soil. The "Terrace" series is known to be the second oldest terrace based on its site position and elevation relative to the other marine terraces and is assumed to be from the Western Formation (Bradley and Griggs, 1976). Dark yellowish brown mottles were observed, indicating periods of oxidation and reduction.

Botella series

The Botella series consists of a very deep, well drained Mollisol. This soil has an argillic horizon, indicating that this soil is well developed. The deep pachic A horizon is indicative of high amounts of organic matter deposition. Many krotovinas and worm castings were observed in the surface horizons, which mixed the soil and help with the formation of the thick mollic horizon. Concentrations of dark yellowish brown iron nodules were found throughout the soil and on ped faces. The Botella series was formed from the Santa Cruz/Highway 1 Formation and is the youngest marine terrace that we studied (Bradley and Griggs, 1976).

Cole series

The Cole series consists of a very deep, somewhat poorly drained Mollisol formed from various periods of alluvial deposits. This soil has multiple argillic horizons, typical of flood plains. The area where this soil was studied is currently used as agricultural land, so the surface horizons have frequently been disturbed by plowing.

Pfeiffer series

The Pfeiffer series consists of a very deep, well drained Mollisol formed from various periods of alluvial deposition. A lithologic discontinuity is located at 135 cm where texture changes from loamy sand to coarse sand. This soil displayed signs indicating a lack of development due to by the absence of illuvial clay deposits in the B horizons. Due the proximity to Scott's Creek, this soil is subject to erosion and deposition, which limits internal soil development.

Conclusion

Based on the results from our observations in the field and the laboratory analyses of soil samples, we have concluded that the upper two marine terraces analyzed, the Bonnydoon and "Terrace" series, were formed from sandstone and mudstone residuum parent material. In the field, we saw no evidence of alluvial or colluvial deposits, or lithologic discontinuities, which led us to believe that these soils were formed from residuum. Lab analyses confirmed our assumptions in that carbon followed the trend typical to soils formed from residuum, decreasing with depth.

Soil argillic horizons within the Botella series of the lower terrace indicates the occurrence of water infiltration of soil clay particles. With increased water infiltration and movement of clay particles through the soil solum the formation of horizons with clay films and increased clay percentage takes place.

Soils formed on the flood plain (Cole series) and stream terrace (Pfeiffer series) had irregular changes in carbon with depth, pointing to the depositional environment typical of a stream terrace or floodplain. In these environments, parent material is often deposited over developing soils during flood events.

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Appendix 1. Soil Chemical Data and figures.

Table A1. Cation concentrations, pH, percent nirtogen, percent carbon, carbon to nitrogen ratio, and electrical conductivity of soil.

Depth (cm)	K^{+1}	Na^{+1}	Ca^{+2}	Mg^{+2}	pH	%N	%C	C/N ratio	EC
	----------mg/kg soil----------								(dS/m)
Bonnydoon 0 - 34	1.44	0.45	5.72	4.11	5.17	0.36	3.65	10.19	0.10
34 - 85	0.83	0.46	5.47	6.24	5.09	0.24	2.32	9.54	0.12
85 - 150	0.58	0.55	5.23	10.25	3.98	0.13	0.98	7.76	0.23
"Terrace" 0 - 11	0.49	0.20	0.87	0.07	5.28	0.16	1.60	10.15	0.19
11-41	0.25	0.22	2.94	0.70	5.39	0.09	0.80	8.53	0.23
41-96	0.31	0.11	2.38	0.38	5.70	0.06	0.40	6.22	0.03
96-150	0.30	0.15	4.10	1.24	5.92	0.03	0.17	6.74	0.17
Botella 0 - 11	0.61	0.44	5.41	2.27	5.29	0.18	1.70	9.37	0.15
11-60	0.36	0.42	6.47	2.43	5.79	0.16	1.47	9.47	0.18
60-90	0.16	0.15	5.05	0.89	6.09	0.11	0.81	7.57	0.07
90-139	0.12	0.31	4.73	1.61	6.01	0.07	0.30	4.48	0.14
139-150	0.08	0.40	4.04	2.72	5.98	0.07	0.27	3.94	0.16
Pfeiffer 0 - 28	0.95	0.30	4.69	1.19	6.14	0.23	2.51	11.01	0.23
28 - 44	0.62	0.28	9.05	1.59	5.93	0.20	2.23	11.23	0.20
44 - 65	0.30	0.26	2.91	0.51	5.90	0.15	1.76	11.84	0.18
65 - 82	0.28	0.35	7.32	2.43	6.12	0.11	1.38	12.97	0.18
82 - 105	0.20	0.48	10.63	2.92	6.31	0.10	1.37	13.42	0.17
105 - 135	0.16	0.41	8.01	2.21	6.51	0.07	0.88	13.33	0.16
135-150	0.05	0.22	3.11	0.73	6.18	0.01	0.12	10.79	0.16
Cole 0 - 14	1.10	0.40	7.44	3.49	5.86	0.23	2.29	10.06	0.26
14 - 27	1.01	0.42	6.14	3.40	5.97	0.18	1.80	10.07	0.26
27 - 51	0.94	0.47	7.11	3.34	5.97	0.17	1.74	10.52	0.24
51 - 68	0.80	0.42	8.46	2.60	6.07	0.10	1.09	10.85	0.20
68 - 81	0.61	0.64	8.03	2.91	5.99	0.17	1.90	11.01	0.20
81 - 105	0.88	0.59	10.34	3.21	6.00	0.10	1.61	15.59	0.12
105 - 127	0.76	0.53	7.74	3.45	6.09	0.10	1.18	11.95	0.12
128 -150	0.68	0.51	5.94	2.99	6.00	0.09	1.01	11.51	0.15

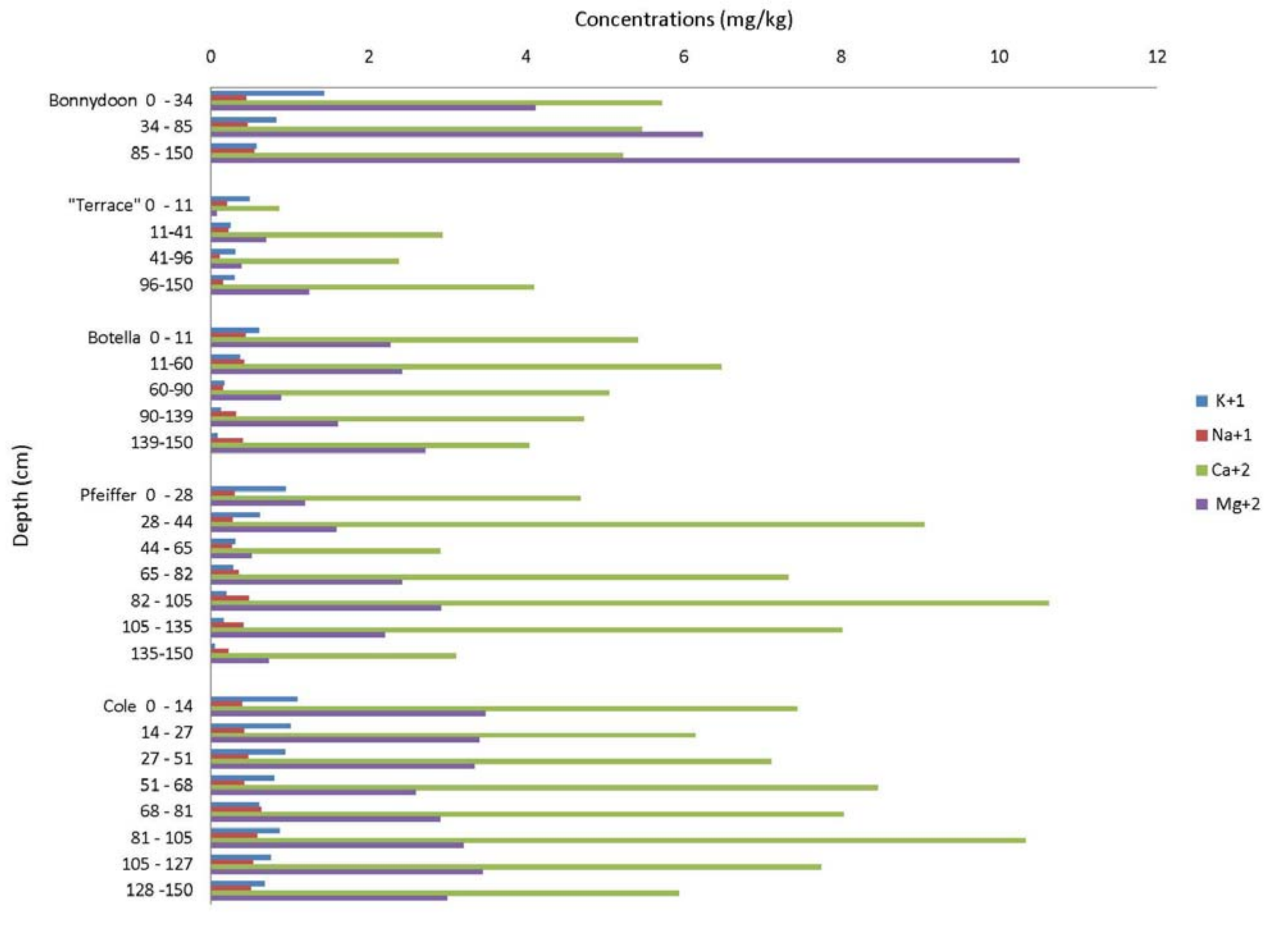

Figure A1. Concentrations of K,Na, Ca, and Mg cations in soils by horizon.

Figure A1. Soil concentrations of K^{+}, Na^{+}, Ca^{+2}, and Mg^{+2} cations of Swanton Pacific Ranch soils.

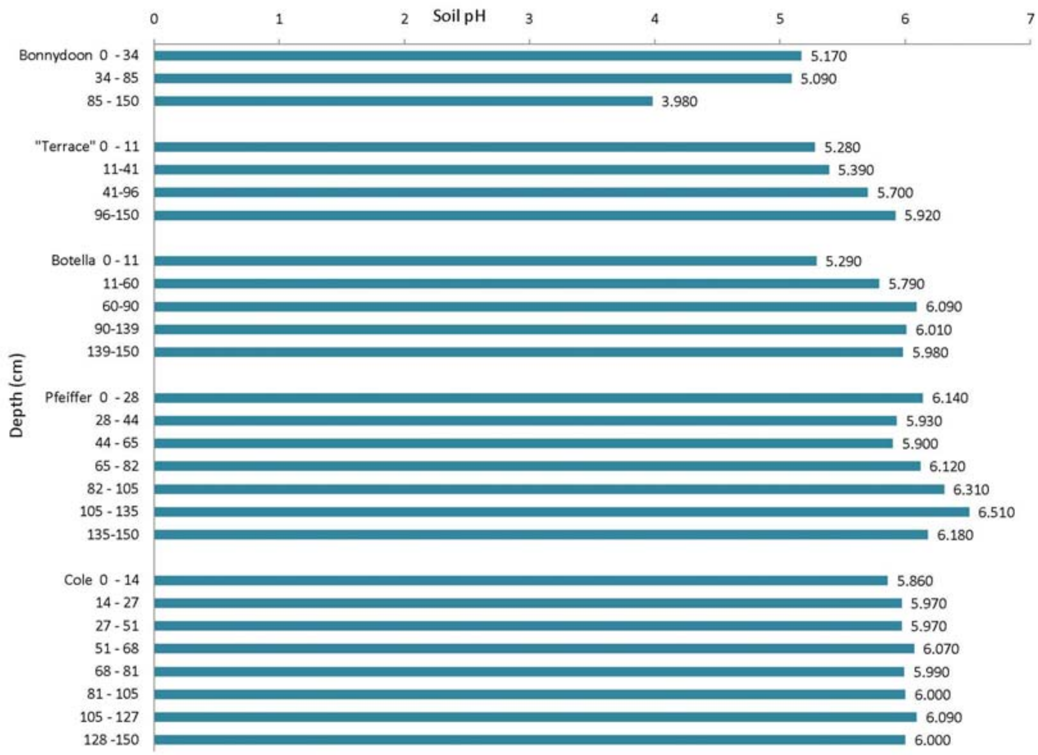

Figure A2. Soil pH of Swanton Pacific Ranch soils.

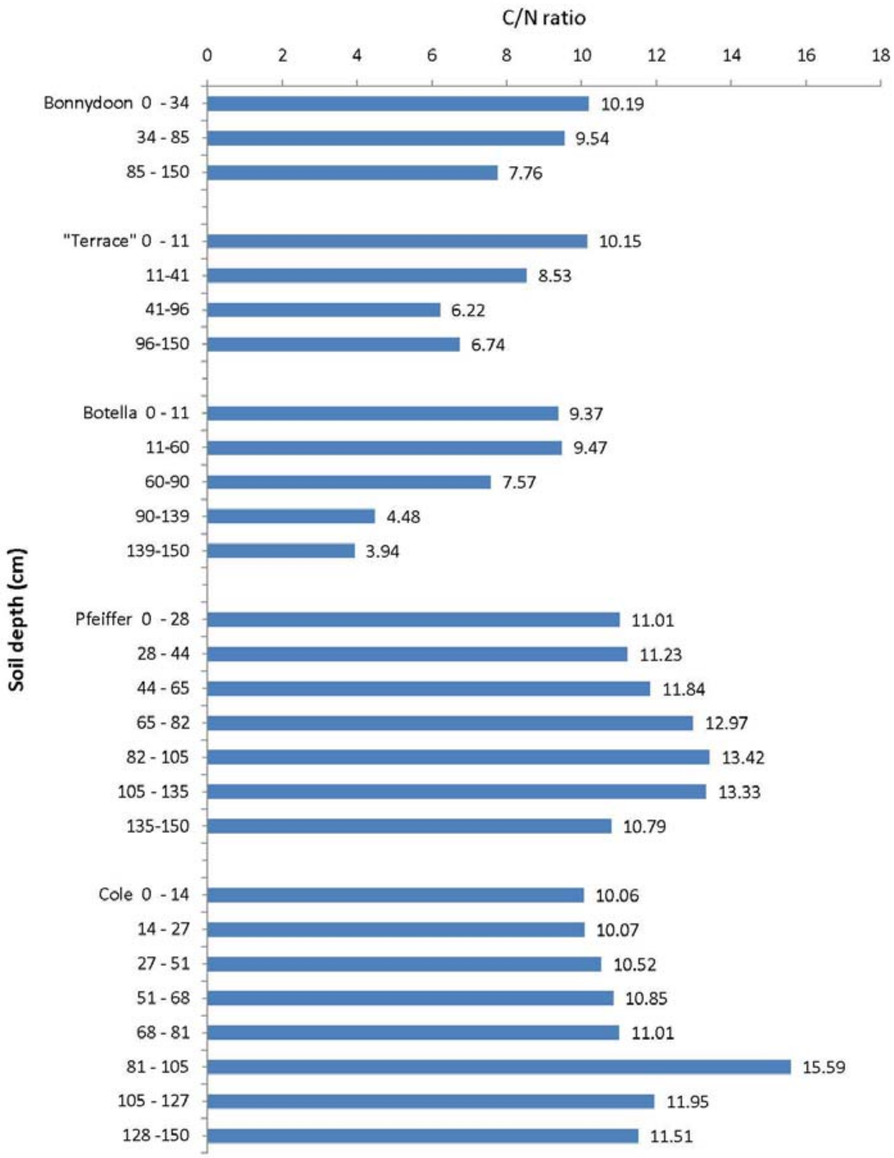

Figure A3. Soil Carbon/nitrogen ratio of Swanton Pacific Ranch soils.

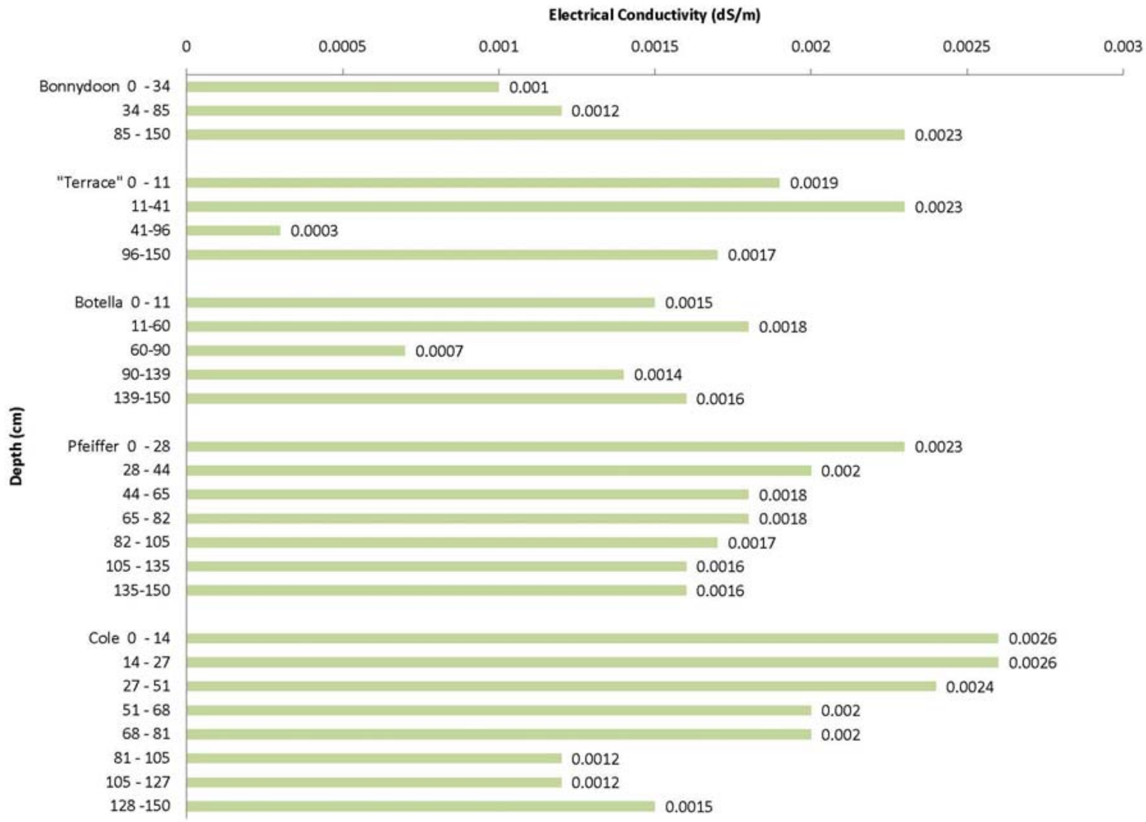

Figure A4. Soil electrical conductivity of Swanton Pacific Ranch soils.