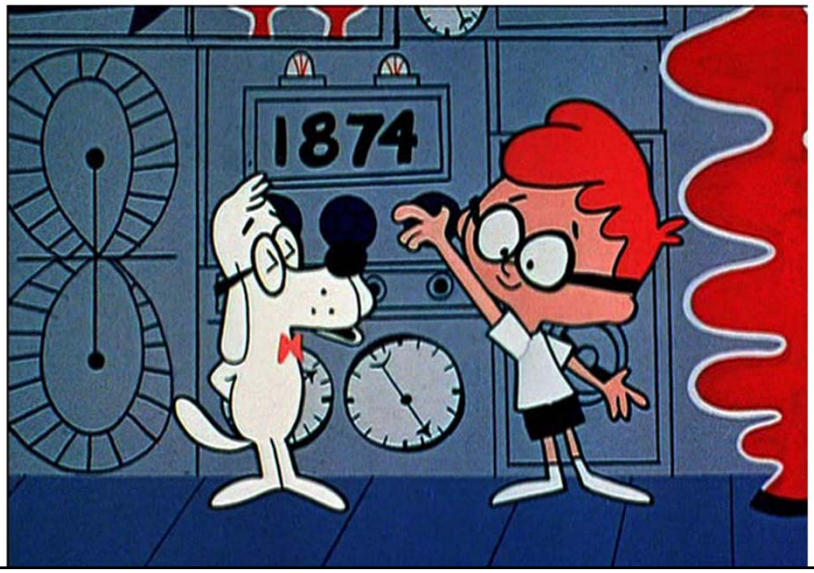
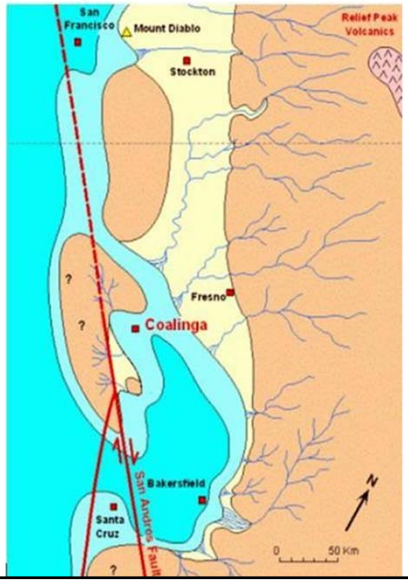
Mr. Peabody's Wayback Machine



- The climate of the San Joaquin Valley, and even the land under our feet, has been changing for a very long time.
- We are going to start our tour of the valley by going way back in time.

Temblor Sea

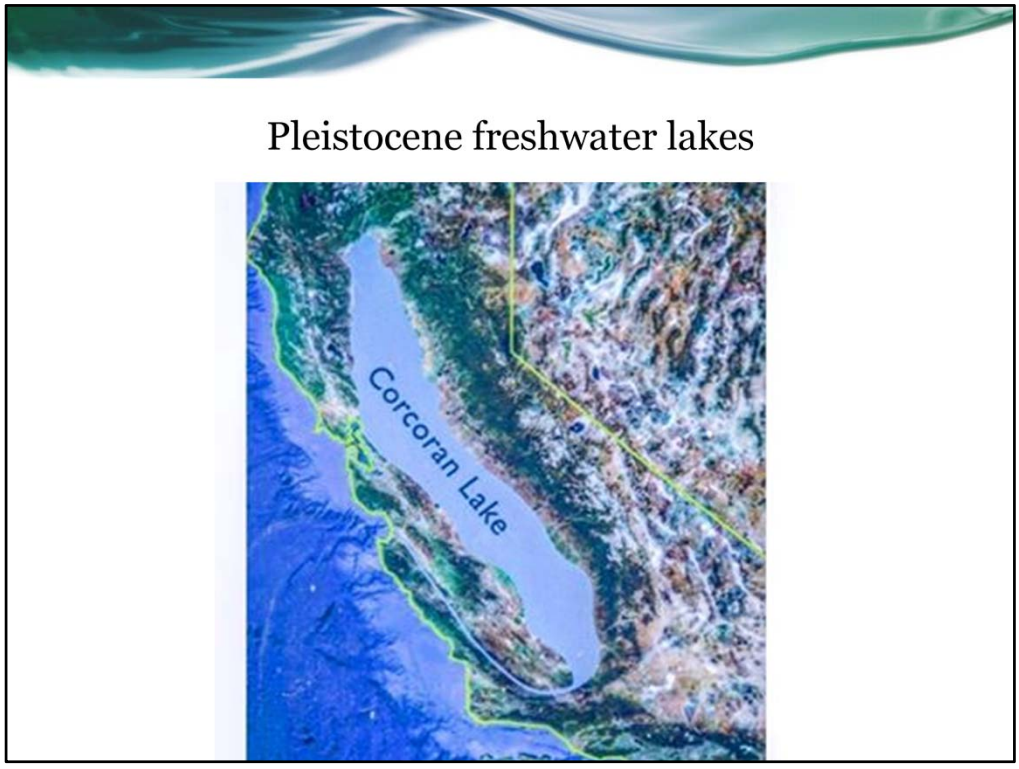


- Movement along the San Andreas Fault occurs at a pretty steady clip, just over an inch per year.
- Santa Cruz used to be 150 miles south of Coalinga, opposite Bakersfield.
- Now it is 150 miles north of Coalinga, on the north side of Monterey Bay.
- The Temblor Sea existed in the Kern County area about 15 million years ago.
- That was during the Miocene epoch, when the Earth was hot and the ocean was warm.
- Sharktooth Hill NE of Bakersfield dates from this period.
- The Buena Vista Museum of Natural History & Science on Chester Av in Bakersfield has nice exhibits of sperm whales, giant megalodon sharks, and huge sea lions that lived in the Temblor Sea.
- As the deep ocean connection closed off about 10 million years ago, a seaway opened connecting the San Joaquin marine basin near Coalinga with Elkhorn Slough via Warthan Canyon and Priest Valley.
- Think about that when you drive Highway 198 toward Pinnacles National Park.
- About 5 million years ago, the valley oceanic embayment began to fill with tremendous amounts of sediment.
- Several vertical miles of sediment accumulated in just a few million years.
- The sand dollar fossils in the Kettleman Hills date from this period.
- We are currently entering into a warmer time period than humans have ever experienced.
- The period that existed about 3 million years ago is the most recent time when temperatures were substantially warmer than the present for sustained periods.
- Sea level was 50 to 80 feet above present levels, primarily because temperatures resulted in less water being locked up in land-based ice sheets or glaciers.
- For comparison, Sacramento is elevation 30 feet.
- The Sacramento-San Joaquin Delta is forecast to rise by over 6 feet by 2100, higher than the intakes of the proposed twin tunnels.
- By 2 million years ago, the marine outlets were completely closed.
- The San Joaquin Valley Basin has accumulated up to 6 vertical miles of marine and continental sediment.
- That is twice the height of Mt. Whitney.
- For comparison, the Marianas Trench, the deepest spot on earth, is less than 7 miles deep.
- Sequoia logs are buried at various locations in the valley at depths of up to at least a couple hundred feet. None of these logs have been dated. They are probably all above the marine sediments.
- There have been multiple elevations of the Sierra Nevada batholith, the greatest being about 2.6 million

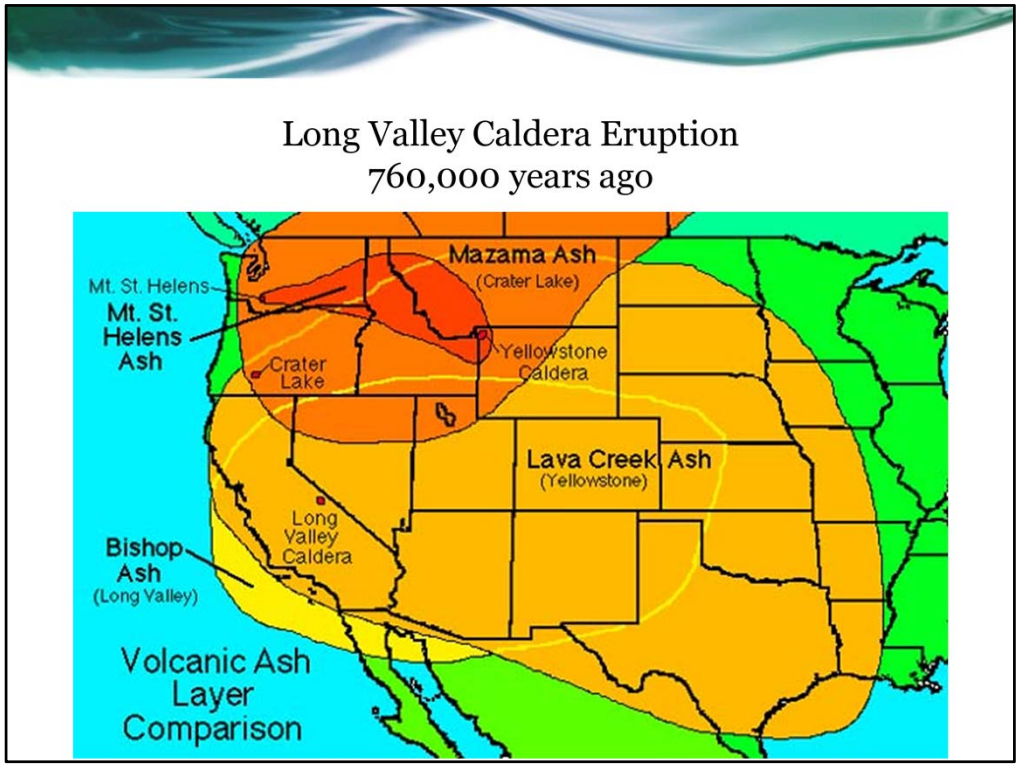
years ago, when the entire Sierra Nevada was uplifted and tilted to form the present range, and the present cycle of erosion was initiated.

Pleistocene Epoch — 2.6 million to 11,500 years ago

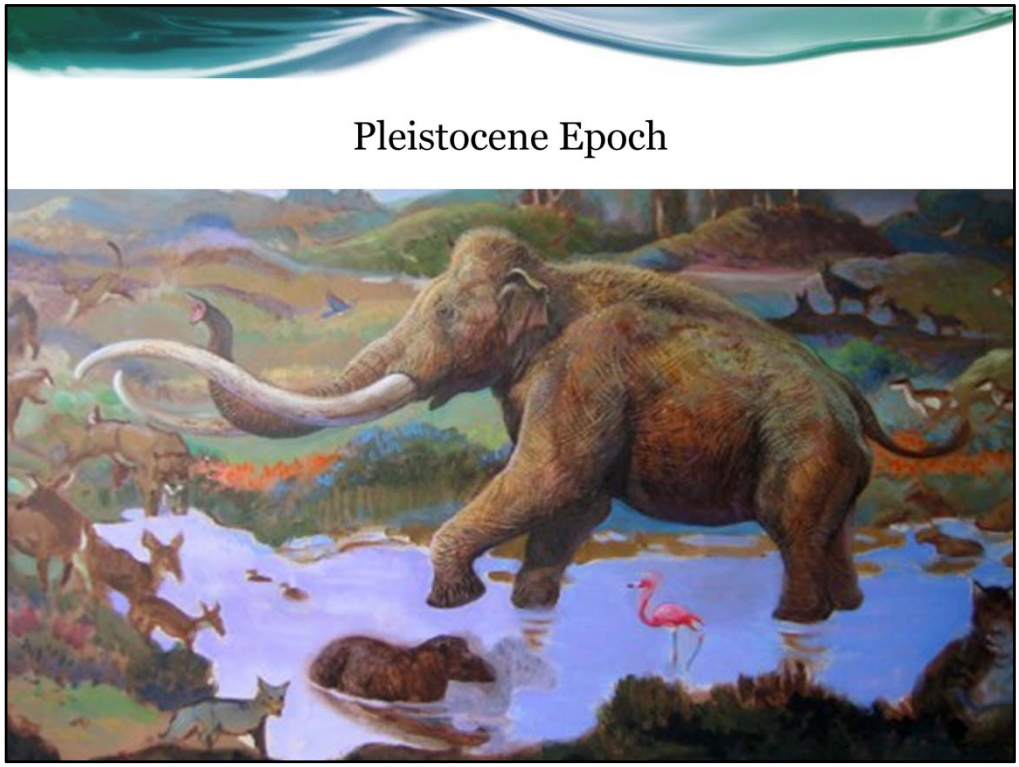
- The Pleistocene lasted from 2.6 million to about 11,500 years ago.
- This was a time of ice ages.
- Sea level was as much as 390 feet lower because so much water was locked up in ice sheets
- Much of North America was covered by thick sheets of ice.
- This is when Yosemite Valley and Kings Canyon were carved and the big delta fans were built.



- Great freshwater lakes formed in much of the western U.S. during the Pleistocene: Corcoran Lake, Lake Russel, and Bonneville Lake.
- Lake Corcoran extended about 250 miles from Bakersfield to Stockton.
- It was probably connected through the Bitterwater Valley to the Salinas River at King City, which then drained through Elkhorn Slough into Monterey Bay.
- The Corcoran Clay was deposited in Lake Corcoran. It underlies 6,600 square miles of the San Joaquin Valley.
- The top of the Corcoran Clay is up to 900 feet deep, and it is up to 200 feet thick.
- How to go about dating when the lake was present?
- We need a dating mechanism.

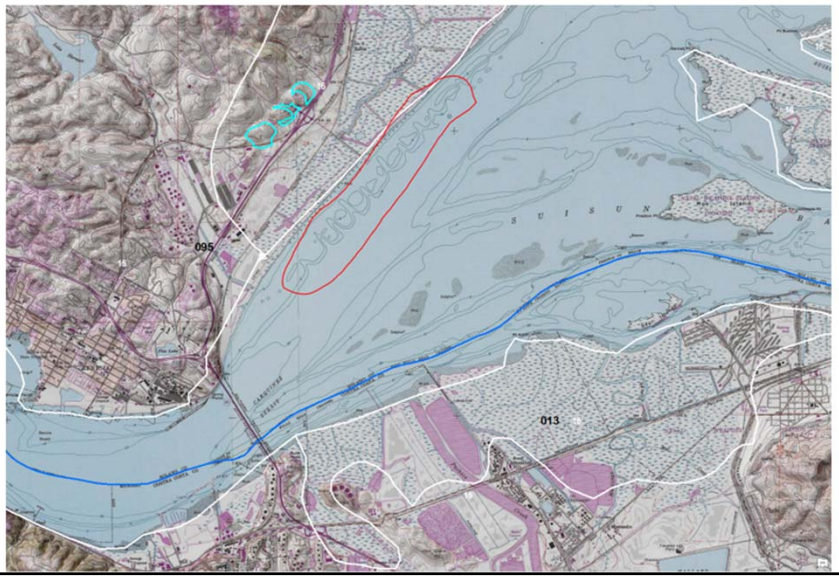


- Volcanic ash is easy to date.
- This map compares the ash deposits from four of our largest volcanic eruptions
- The Mount St. Helens eruption occurred in 1980. It was puny compared to the other three.
- Native Americans witnessed the Mount Mazama eruption in 4850 B.C. which created the 6-mile wide Crater Lake.
- Corcoran Lake filled the San Joaquin Valley from roughly 600,000-800,000 years ago.
- The most recent (and largest) explosion from the Yellowstone Caldera occurred 640,000 years ago and covered most of the western half of the U.S. No ash from this eruption has been found in San Joaquin Valley sediments.
- Long Valley Caldera is gigantic, 20 miles wide. Mammoth Mountain sits on the rim of the caldera.
- During the Pleistocene, the caldera held a lake that was 1,000 feet deep.
- US-395 cuts through the middle. Crowley Lake is in the southeast corner.
- We sometimes fly right over the remains of the caldera when we fly east out of Fresno.
- This supervolcano erupted 760,000 years ago.
- Ash from this eruption covers most of the southwestern quarter of the U.S. including in the deposits of Corcoran Lake.
- The latest period of caldera activity began Memorial Day Weekend, 1980 and has continued to this day.



- North America's climate was colder and wetter during the Pleistocene than at present.
- Cold-adapted animals such as mammoths and mastodons lived in California.
- The late-Pleistocene (30,000 years ago) animals are well represented at La Brea tar pits in Los Angeles.

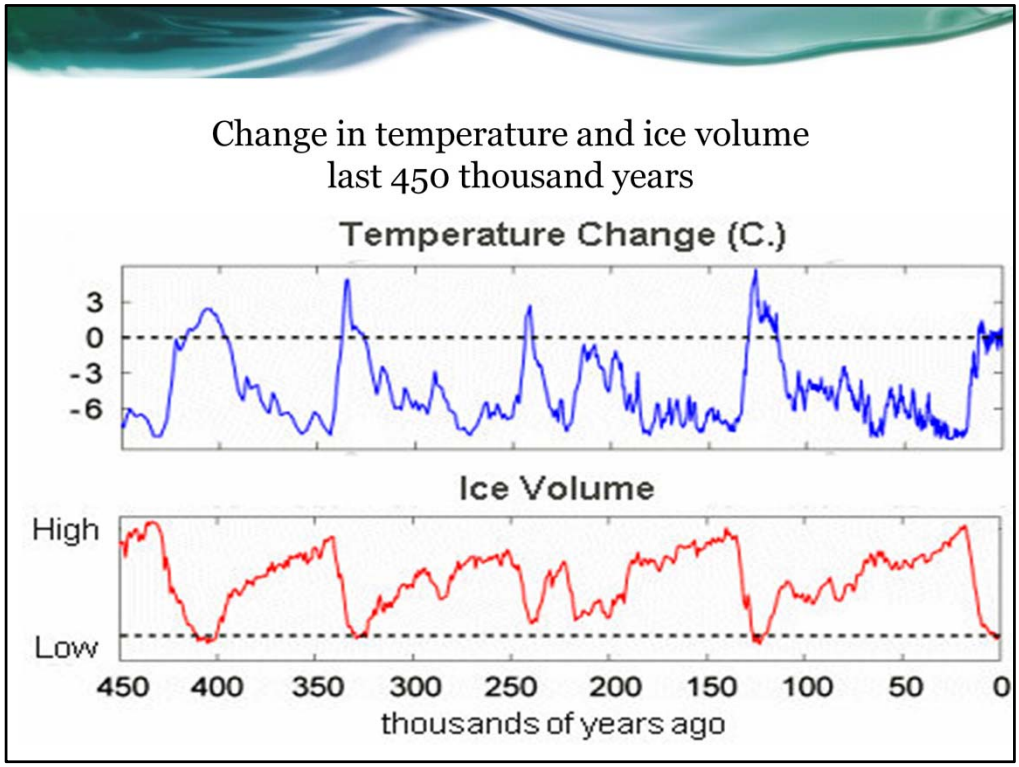
Submerged terraces — Carquinez Strait



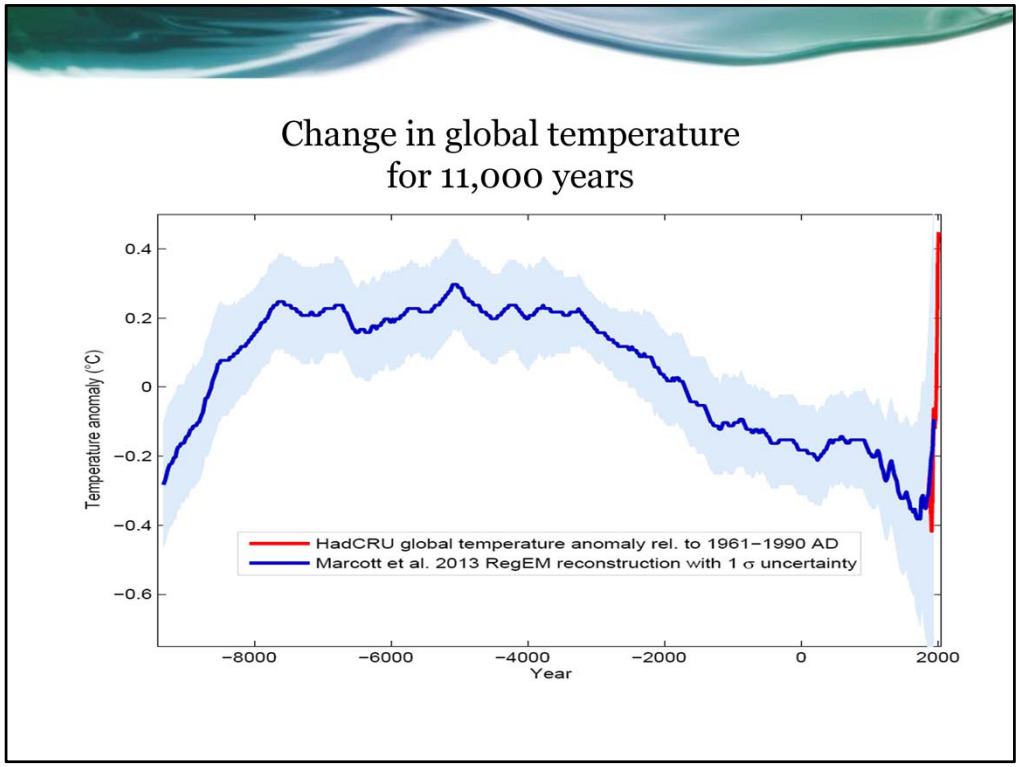
- This is the Benicia Bridge on the west side of Suisin Bay, the I-680 bridge.
- It connects Bernica and Napa on the north with Marinez and Antioch on the south.
- The Carquinez Strait is where the mothballed ships from WWII used to be kept.
- lower.

Submerged terraces — Carquinez Strait

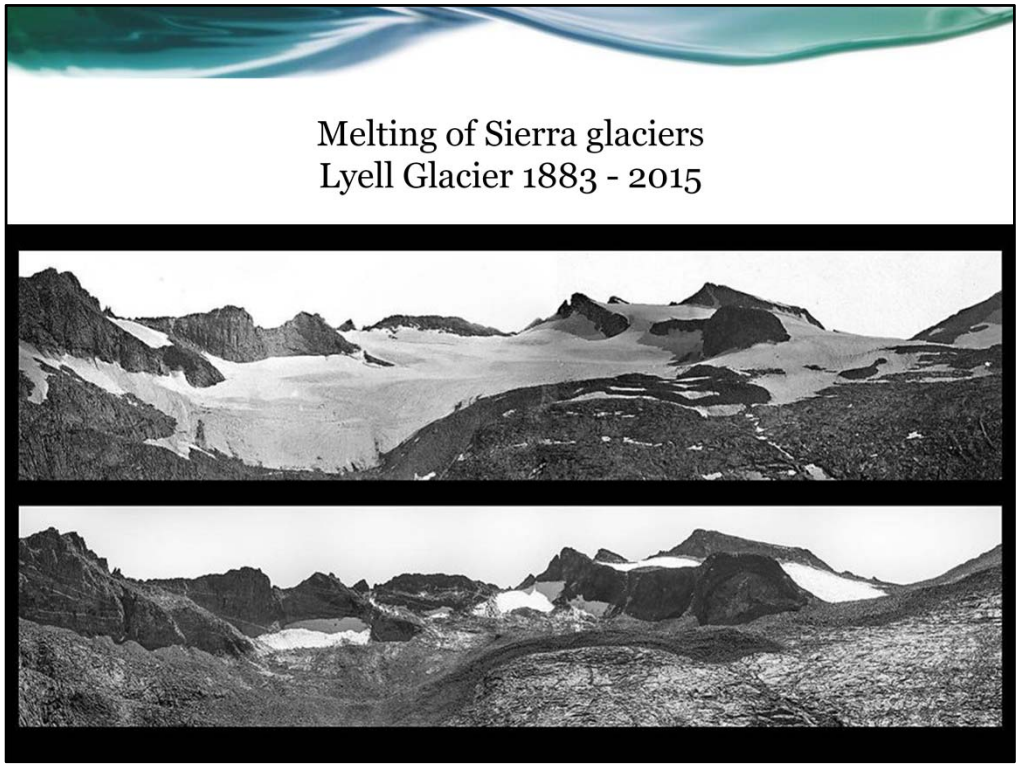
- We know from experience that when temperature changes, it affects how much water is stored as ice on land.
- That affects the level of the oceans.
- Sea level was as much as 390 feet lower during the Pleistocene because so much water was locked up in ice sheets
- There are submerged terraces on the north side of the Carquinez Strait just above the Benicia Bridge.
- They date from the Wisconsin glacial period when the Pacific Ocean was hundreds of feet lower.
- The Sacramento-San Joaquin Delta would have just been a river channel at that time.



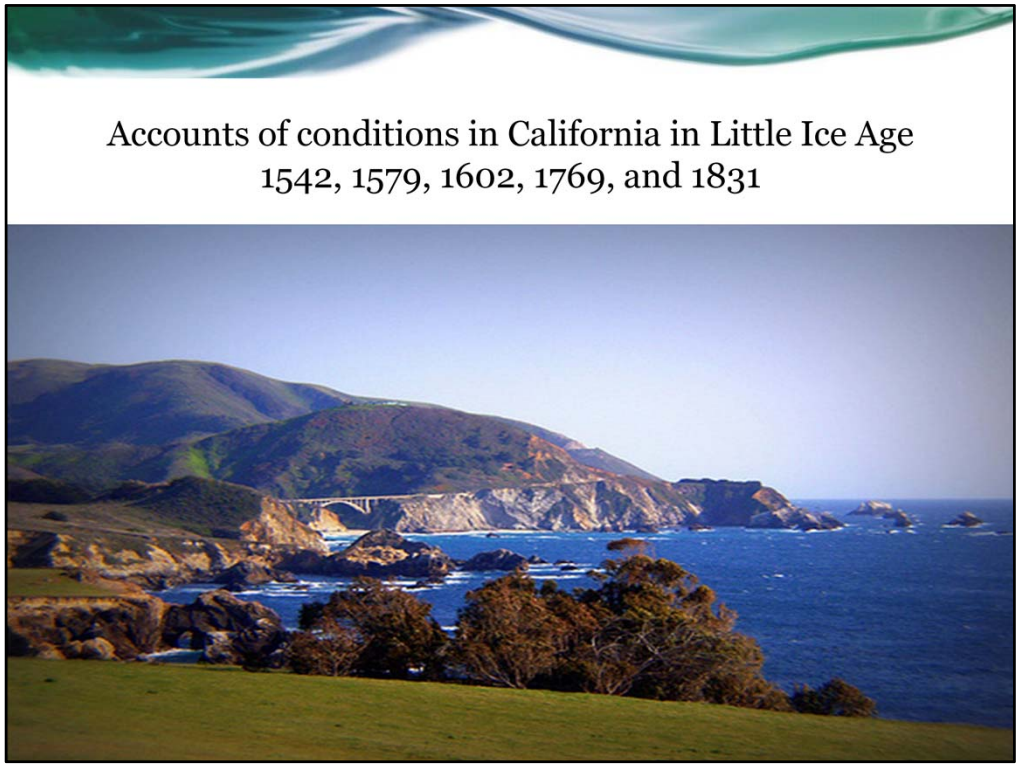
- Yosemite Valley and Kings Canyon were carved out by glaciers between 1 million and 250 thousand years ago.
- For context, the most recent common ancestors of all living humans lived between roughly 100,000 and 160,000 thousand years ago. This is where all of our lineages converge.
- Our ancestors emerged from Africa between 50,000 and 80,000 years ago.
- The earliest ancestors of Native Americans were thought to have arrived in North America less than 15,000 years ago.
- But now it appears that humans were living near San Diego about 130,000 years ago, eating mastodon.
- The last glacial period, the Wisconsin, occurred from about 110,000 to 11,700 years ago.
- Glacial moraines from this period are very visible in Giant Forest around Lodgepole.
- Vast ice sheets covered much of the Northern Hemisphere and Antarctica during the Wisconsin.
- The maximum ice extent occurred about 21,000 years ago.
- At that point, sea level was about 410 feet lower than it is today.
- Deglaciation gradually began in the Northern Hemisphere between about 17,000 to 18,000 years ago.
- Sea level began rising abruptly about 12,500 years ago when deglaciation began in Antarctica.
- The Mount Toba supervolcano eruption in Indonesia occurred about 75,000 years ago.
- It is the largest known eruption on Earth in at least the last 25 million years.
- The eruption spewed a huge amount of ash and sulfur dioxide into the atmosphere.
- The eruption would likely have caused a global volcanic winter of 6–10 years.



- This graph covers average temperature for the entire Holocene period, just over 11,000 years.
- A group of researchers from Harvard and Oregon State created this graph by combining 73 different reconstructions of temperatures from around the world.
  - From 11,000–7,000 years ago, the vegetation of the Tulare Lake Basin resembled that of the Great Basin, pinyon–juniper–oak woodland in the foothills, with greasewood on the salt flats near the lake. The upper watersheds consisted of open pine forests and dry meadows with very few sequoias.
  - A very dry period set in at the end of this warming period; it covered all North America. For example, from 7900 to 7500 years ago, the lake levels in the Great Lakes dropped dramatically, up to 66 feet below their outlets, so that they became disconnected from each other. Each lake became a closed basin, like the Tulare Lake Basin. Their overflow rivers, including the Niagara River, ran dry during this period.
  - From 7,000–4,500 years ago, the Tulare Lake basin was drier, and there was widespread increase in fire frequency. Great Basin-like vegetation (both woodland and greasewood) was generally replaced by drought-tolerant grassland and flowering plants.
  - A cooling (and moister) period began about 3,000-4,500 years ago. This is when the sequoia groves, the mixed conifer forest, and the wet Sierra meadows began developing. Fire was relatively infrequent in the upper watersheds prior to 4,500 years ago, apparently due to low fuel levels.
  - The Medieval Warm Period or Medieval Climatic Anomaly lasted from about 950–1250 A.D. The western Sierra was droughty and often fiery during the Medieval Warm Period; it had the most frequent fires of any period during the last 3,000 years. During that period, extensive fires burned through parts of Giant Forest at intervals of about 3–10 years.
- Then the cooling trend resumed.
- The Little Ice Age lasted from approximately 1275–1850.
- The 5000-year cooling trend ended abruptly with the rapid warming of the 20th Century.
- American settlement in the San Joaquin Valley began in 1850, right at the end of Little Ice Age.



- Visalia was founded in 1852, right at the end of the Little Ice Age.
- The glaciers in the Sierra have advanced and retreated with each of the various ice ages.
- The Sierran glaciers reached their maximum extent during the Little Ice Age about 1850.
- Lyell Glacier was discovered by John Muir in 1871, and was the largest glacier in Yosemite National Park.



We have five firsthand accounts of what conditions were like in California during the Little Ice Age.

1542. The Cabrillo expedition sailing out of Guatemala was the first European expedition to explore what is now the West Coast of the U.S. Returning south on November 18, 1542, Cabrillo noted the snow-capped Santa Lucia Mountains along the Big Sur Coast.

1579. Sir Francis Drake sailed up the up the western coast of North America in 1579, searching for a possible northeast passage back to the Atlantic.
- Drake found the northern California coast so cold in early June that his men had difficulty bearing it. Six men could hardly do the work of three, so stiff was the rigging from ice. Meat was frozen shortly after it came out of the fire. He came ashore briefly, possibly at Oregon Dunes near Coos Bay.
- Discouraged by the extreme cold, Drake then went down the coast. He found that the coastal hills along Northern California were snow-covered, even in June.
- Drake sought a good harbor, and eventually came into what he is thought to be Drakes Bay at Point Reyes National Seashore.
- He stayed there for five weeks from June 17 until July 23. They found the harbor extremely cold, even in June and July. If they had not had outside work to do, they would have been content to keep their winter clothes on or to stay in their beds. The natives seemed to treat this cold weather as being normal.

1602. Sebastian Vizcaino led an expedition sailing out of Acapulco that discovered Monterey Bay on December 14, 1602. He recorded that on Christmas Day, the mountains near the port were covered with snow and that on New Year's morning the water holes were frozen to the depth of a palm.
- The expedition encountered no American Indians, but did find a deserted village. Vizcaino speculated that the inhabitants had taken refuge in the interior to escape the biting cold.
- Today, the average low temperature in Monterey in December and January is a much more pleasant 43°.
- Vizcaino wanted to attract colonists to his new bay. So although he was numb with cold, he wrote a glowing report in which he said the area's climate was like that of Seville's.

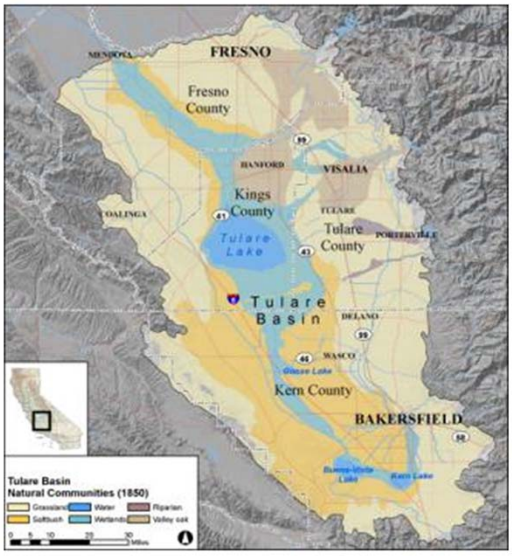
1769. So untrue was the picture that Vizcaino painted, that when the colonizing party arrived 167 years later, they failed to recognize the fabled port.
- Food was so scarce that they were reduced to eating seagulls and pelicans.
- After snow began to cover the hills on November 30, 1769, the survivors decided to return to San Diego.

1831. Captain Bonneville sent the Walker Party from the Great Salt Lake in search of the Pacific Ocean.
- They succeeded in their mission, coming out in the vicinity of Half Moon Bay on November 20, 1833.
- In the process, they were surprised to encounter the Sierra Nevada.
- They crossed the Sierra in October 1833. Their probable route was over Ebbetts Pass, and generally along the route of present-day Highway 4.
- In any case, Leonard described encountering a lot of old and consolidated snow as they crossed the Sierra in October 1833:

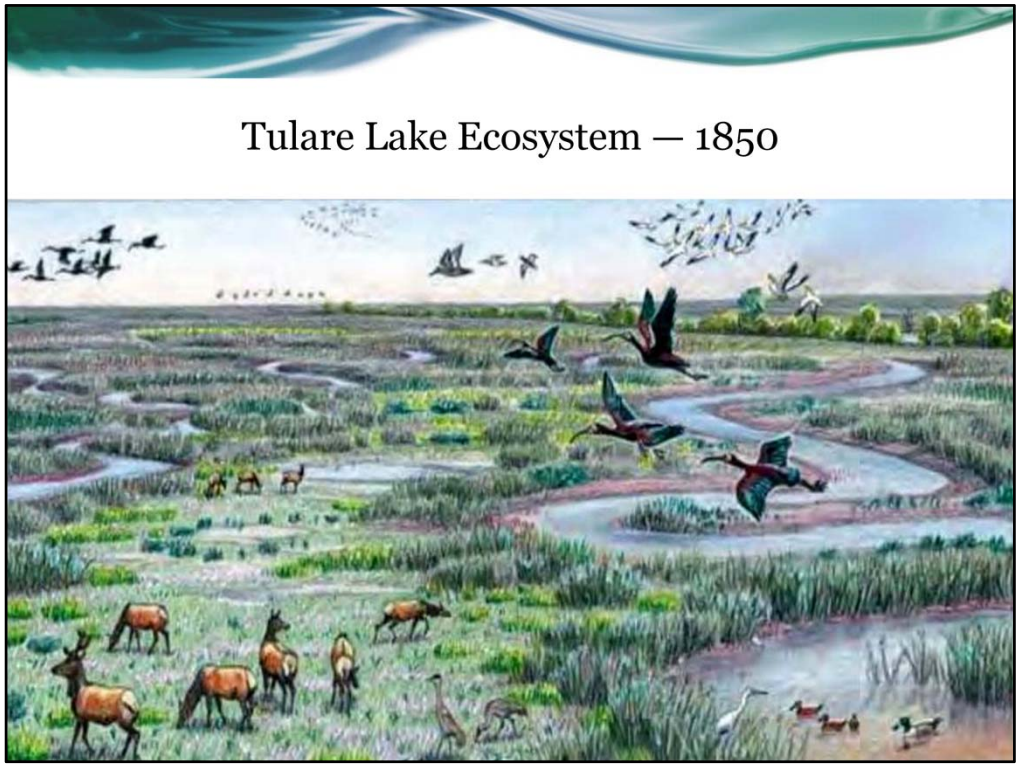
In some of these ravines where the snow is drifted from the peaks, it never entirely melts, and may be found at this season of the year, from ten to one hundred feet deep. From appearance it never melts on the top, but in warm weather the heap sinks by that part melting which lays next the ground. This day's travel was very severe on our horses, as they had not a particle to eat…but the most of the distance we this day traveled, we had to encounter hills, rocks and deep snows. The snow in most of the hollows we this day passed through, looks as if it had remained here all summer, as eight or ten inches from the top it was packed close and firm — the top being loose and light, having fell only a day or two previous.

The Walker Party encountered snow that was persisting from year to year. They were crossing the Sierra near the end of the Little Ice Age. There is no longer persistent snow in that area; conditions have changed dramatically in the last 180 years.

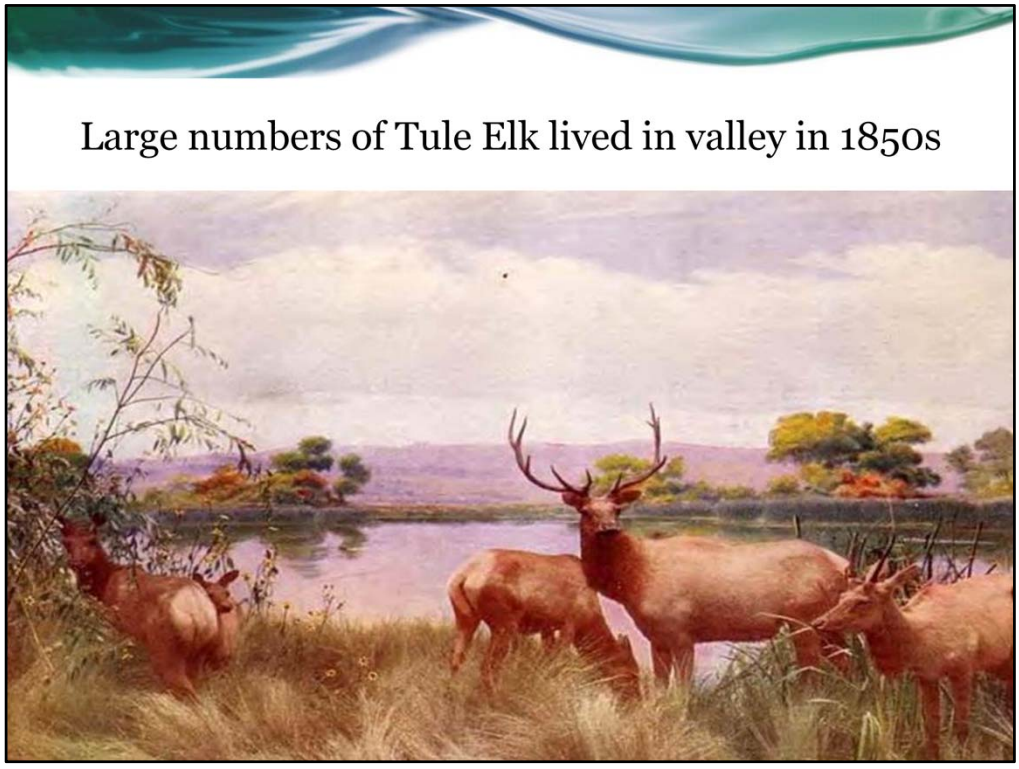
Tulare Lake Basin natural communities
Wetland connections



- This presentation is about the fish and wildlife of the Tulare Lake Ecosystem, and what happened when that ecosystem crashed.
- This map shows what the Tulare Lake Basin was like in 1850 at the time of settlement.
- The middle of the basin was a wetland complex of over 400,000 acres; not a single river. Imagine the Everglades.
- It was essentially a desert on either side of the wetland. The San Joaquin Valley Desert.
- The Kaweah Delta was an oasis of oaks and sycamores.



- Tulare Lake was the largest of the 5 natural lakes in the valley.
- These lakes were the anchors of a wetland complex of over 400,000 acres
- This illustration is from Laura Cunningham's book A State of Change.
- That book captures and explores the biology of our state at the time of settlement.

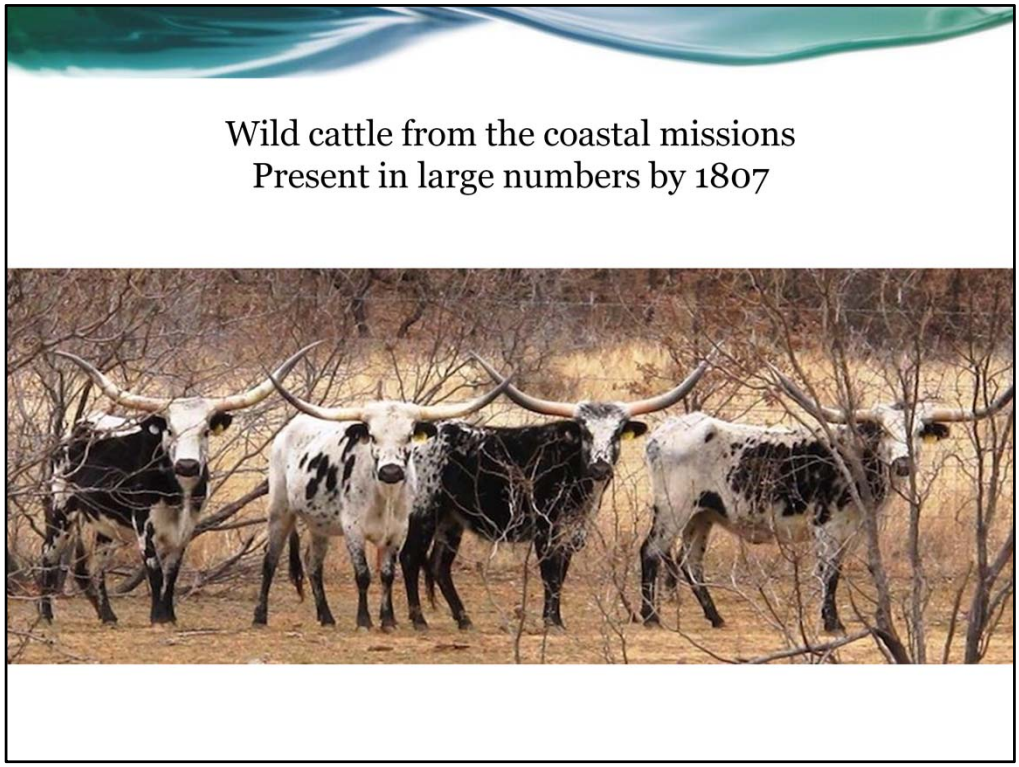


- The tule elk was the native elk in our area. It is smaller than the Roosevelt elk.
- Large numbers lived in the valley in the 1850s

- Pronghorn were abundant on the plain which lay on each side north and south of Cross Creek.
- That was just north of the present-day Visalia Airport.
- Pronghorn and elk were essentially eliminated by 1870.

Mule deer

- We had two species: mostly mule deer.
- But we apparently also had some Columbian black-tail deer; they ranged as far south as Los Angeles.
- Today you have to go to Ragged Point in the Big Sur area or Seventeen Mile Drive near Carmel to see black-tails.
- Market hunting of deer was intense in the Kaweah River drainage.
- One market hunter killed over 300 deer in the Mineral King area in the 1880s, and by 1890 deer were scarce there.
- Another hunter marketed 120 deer in 1873, all taken from a winter range along the Kaweah River.



- Wild horses and cattle were present in large numbers by 1807.
- Those feral animals were descended from stock escaped and stolen from Spanish settlements along the coast.
- Some accounts from early settlers said that they didn't bother to hunt wild game because of the abundance of wild cattle.

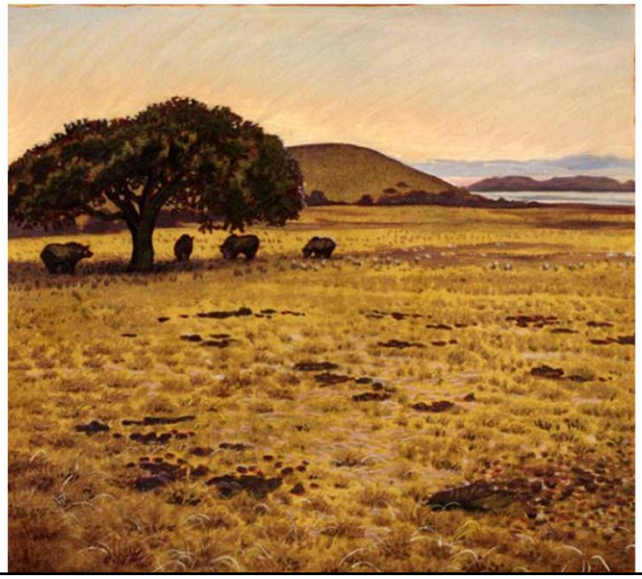
Gray Wolf

John W. Audubon recorded his wolf encounters when he came through the San Joaquin Valley in 1849

- John W. Audubon was one of John James Audubon's sons.
- He said that "their long, lonely howl at night … tell the melancholy truth all too plainly, of the long, long distance from home and friends."
- The wolves were so bold at night that Audubon had "several pieces of meat and a fine goose stolen from over (his) tent door."

- The last grizzly bear in the state was killed in 1922 at Horse Corral Meadow in what is today Giant Sequoia National Monument.

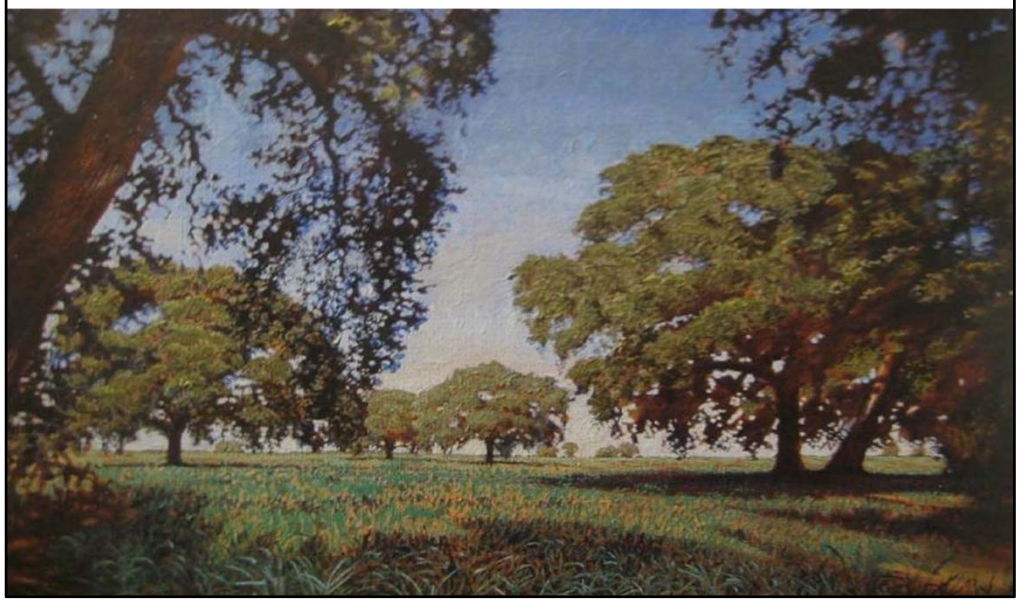
California Grizzly Bears formed herds as large as 300



- Laura Cunningham's research showed that herds of grizzly bears, some as large as 300, roamed the valleys and prairies of California.
- Prior to the coming of the soldiers, Fort Tejon was the location of a great rendezvous of grizzlies that came to feast on the acorn crop each year.

- Today, jaguars are present in Mexico and occasionally venture into the timbered mountains of southern Arizona and New Mexico.
- But jaguars inhabited a much larger area of the U.S. during the early settlement days of California.
- The were found in the Colorado Desert (think Palm Springs area), on islands in the delta of the Colorado River, and in the Cuyamaca Mountains of San Diego County.
- They were reported from the South Coast Ranges as far north as Monterey and San Francisco up to at least 1826.
- James Capen (Grizzly) Adams recorded vivid accounts of his encounters with jaguars on the south side of Tejon Pass in the Tehachapis in the summer of 1855.
- The last known jaguar in California was killed in Palm Springs in 1860.

The Kaweah Delta was Filled with Oaks



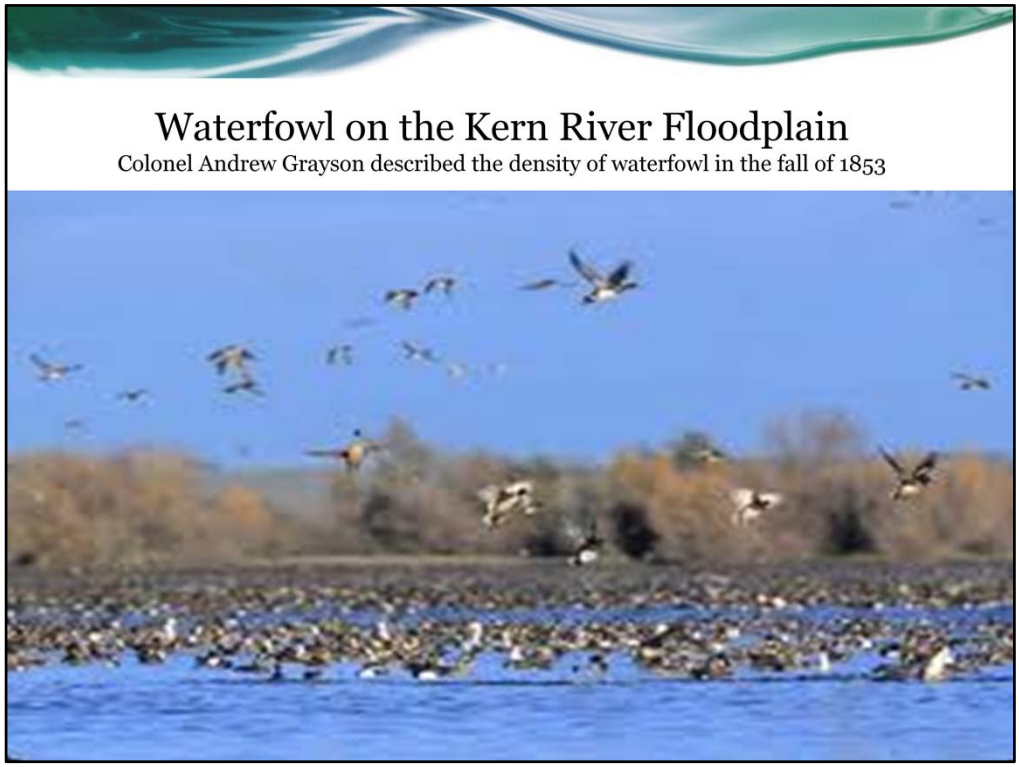
Our New Settlement Needed Fuel

Today the great oak forests are gone from around Visalia.
The only surviving remnants are at Mooney Grove and Kaweah Oaks Preserve.
Now you have to drive up into the foothills to find band-tail pigeons.

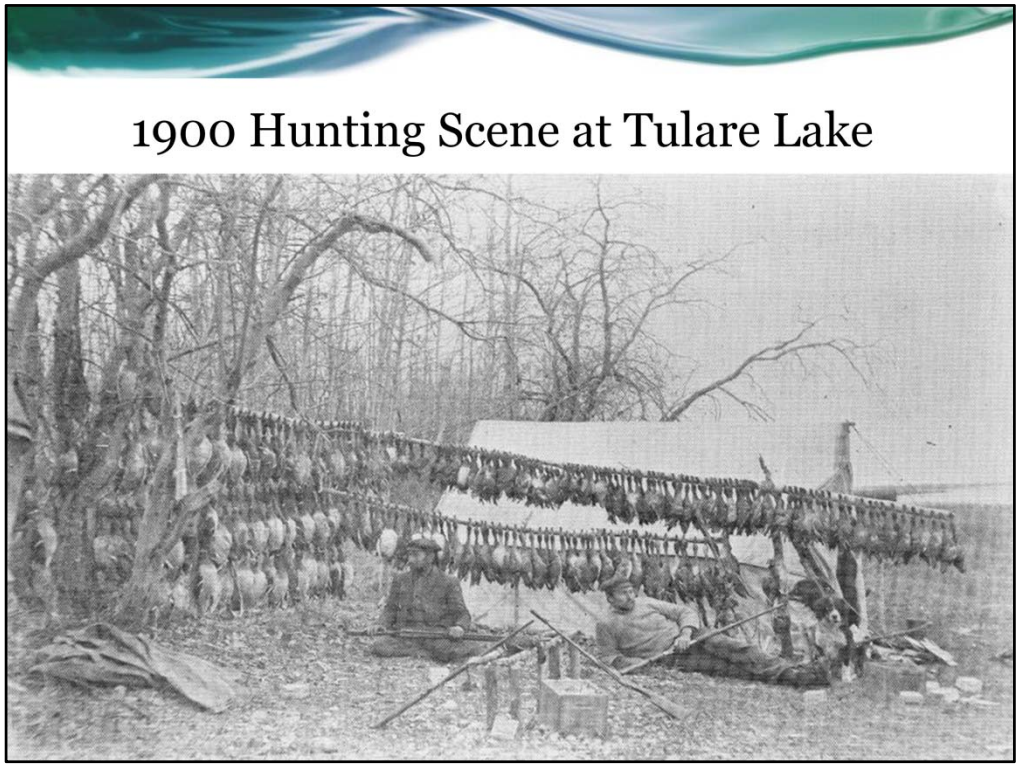
Western Pond Turtles

Large numbers lived around the lake in the 1850s

- The turtles were once so abundant that a roar was created when sunning turtles were disturbed and took flight into the water.
- The turtles were caught in seines and shipped live in sacks to San Francisco.
- There they were relished in terrapin soup and other delicacies.
- The boats landed on the north shore at Lemoore. The railhead was at Hanford.
- The Water Witch harvested 300 dozen in one season

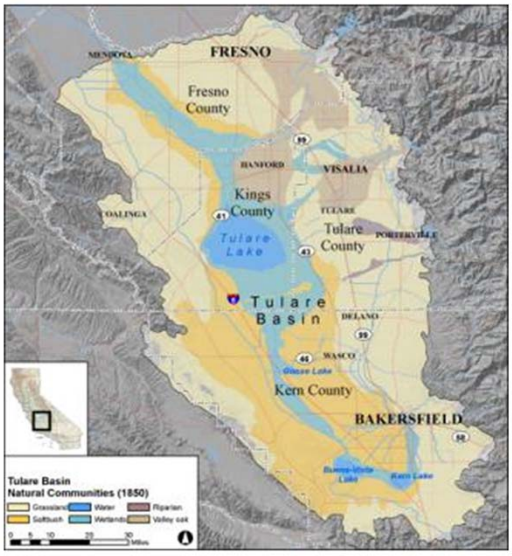


- At this time, the Kern River channel still ran by the Beale Library and along old Hwy 99 on the way to Kern Lake.

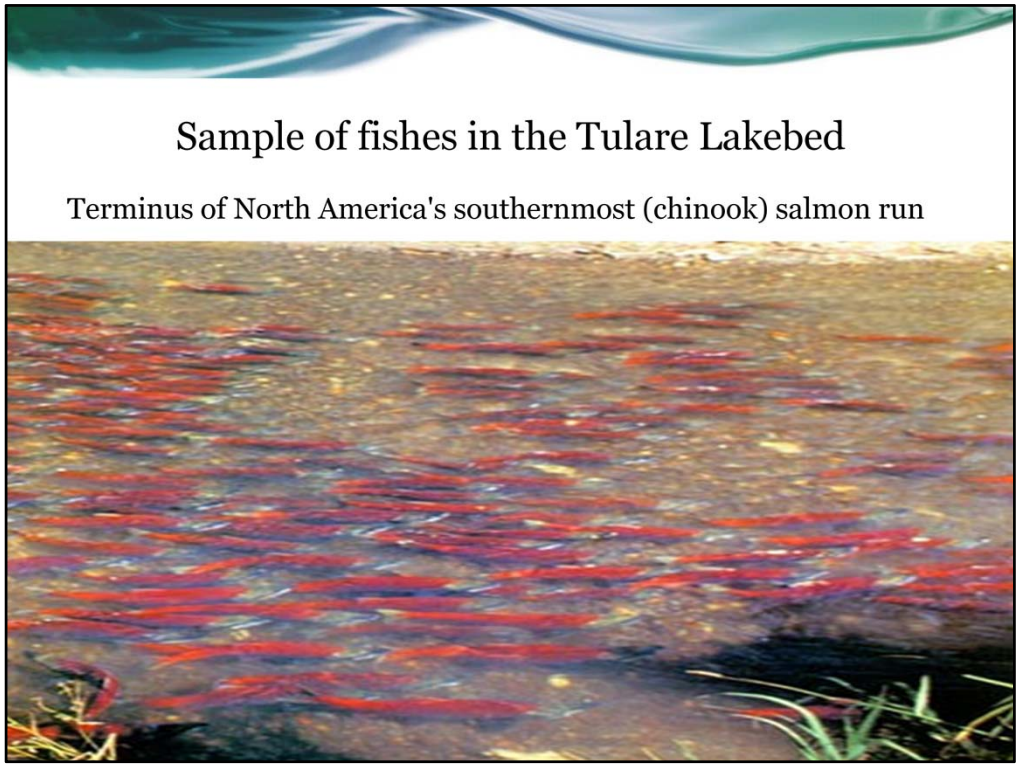


Market hunting of birds was common.
Most of the birds were bought by the Chinese meat markets and restaurants in San Francisco.

Tulare Lake Basin natural communities
Kings River connections



- The wetlands radiated out from Tulare Lake like the spokes of a wheel.
- At the time of settlement, the Kings River flowed into Tulare Lake.
- Until 1878, when Tulare Lake filled up, it would flow back through Summit Lake into the Fresno Slough and on to the San Joaquin River and San Francisco Bay.
- Anything could swim over the delta sill in a wet year.

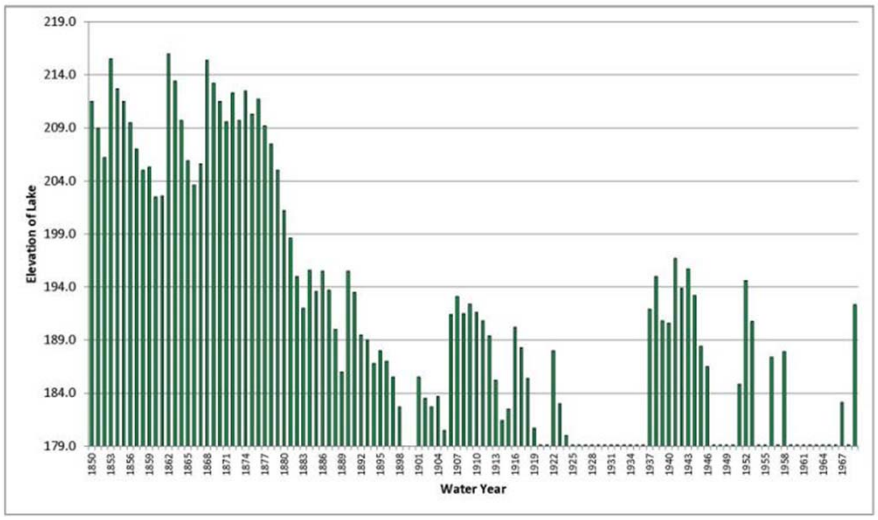


- Tulare Lake was the terminus of North America's southernmost (chinook) salmon run.
- In a wet spring, the salmon could come over the sill into Tulare Lake.
- Just like the sailors did in 1853.

On November 2, 1819, Spanish Lieutenant José María Estudillo observed Tachi tribesmen catching salmon and other fish in the Kings River by means of hand nets.

This they did before my very eyes, with great agility, diving quickly and staying under the water so long that I prayed.

Elevation of water in the Tulare Lakebed for 120 years: 1850–1969



- Point out the huge floods of 1853, 1862, and 1868.
- The floods held the lake over through massive droughts.
- The 1878 flood filled Tulare Lake to elevation 207.5 feet, causing it to spill over the delta sill and into Fresno Slough and the San Joaquin River for the last time.
- That was the last natural overflow of the lake.
- Beginning in about 1855, canals started tapping the rivers to irrigate fields and orchards.
- They reduced the inflow of floodwaters to the lake.
- As the lake shrank, the alkalinity rose. The ecosystem started to go into a tailspin.
- 1888 seems to have been the pivotal year. The fishing (or seining) was terrific that year as the ecosystem crashed.
- Over 133,600 pounds of fish from Tulare Lake were shipped to San Francisco in one ten-week period in the fall of 1888.
- By the end of that year, the catfish, lake trout, pond turtles, mussels, and clams had reportedly died out of all three lakes (Tulare, Kern, and Buena Vista) due to the increasing alkalinity.
- The lake went from full-pool in 1878 to bone-dry in 1898 in just 20 years.

Sample of fish eaters in the Tulare Lakebed

Marine mammals: sea otters, harbor seals, and sea lions

If fish could come over the sill during high water, then so could marine mammals. And they did.
Sea otters, harbor seals, and sea lions were all present in Tulare Lake.

Sea Lions Still Venture Up the San Joaquin River

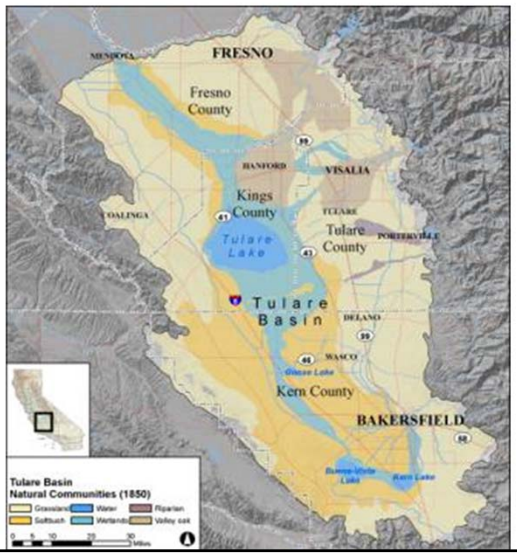
February 2004, north of Los Banos

- In February 2004, a 315-pound male California sea lion came up the river and canals as far as Henry Miller Road north of Los Banos.
- He just kept going upstream until he ran out of water.
- At that point, he was about 65 miles from San Francisco Bay and only 100 miles from Tulare Lake.
- When a California Highway Patrol car arrived, the animal lumbered over, jumped up on the trunk, and lay down.

Tule Balsa (rafts)
Reminiscent of the reed boats on Lake Titicaca in Bolivia

- 19,000 Yokuts lived in the Tulare Lake Basin
- Yokuts tribesmen built tule balsa (rafts) and fished in the lake.
- Tule balsa (rafts) could hold up to a dozen people.
- They could stay out on the lake for days.
- They had openings for spearing fish.
- The Yokuts preferred chinook and steelhead over other species of fish.
- Some of the rafts had fireplaces for cooking.

Connection of national park to Tulare Lake Basin wetlands



- Sequoia National Park is the second national park; established in 1890.
- The national park was on the edge of the Tulare Lake ecosystem.
- The park had forgotten that we were connected to that ecosystem.
- We were connected by the 4 river corridors and because the birds could fly back and forth.

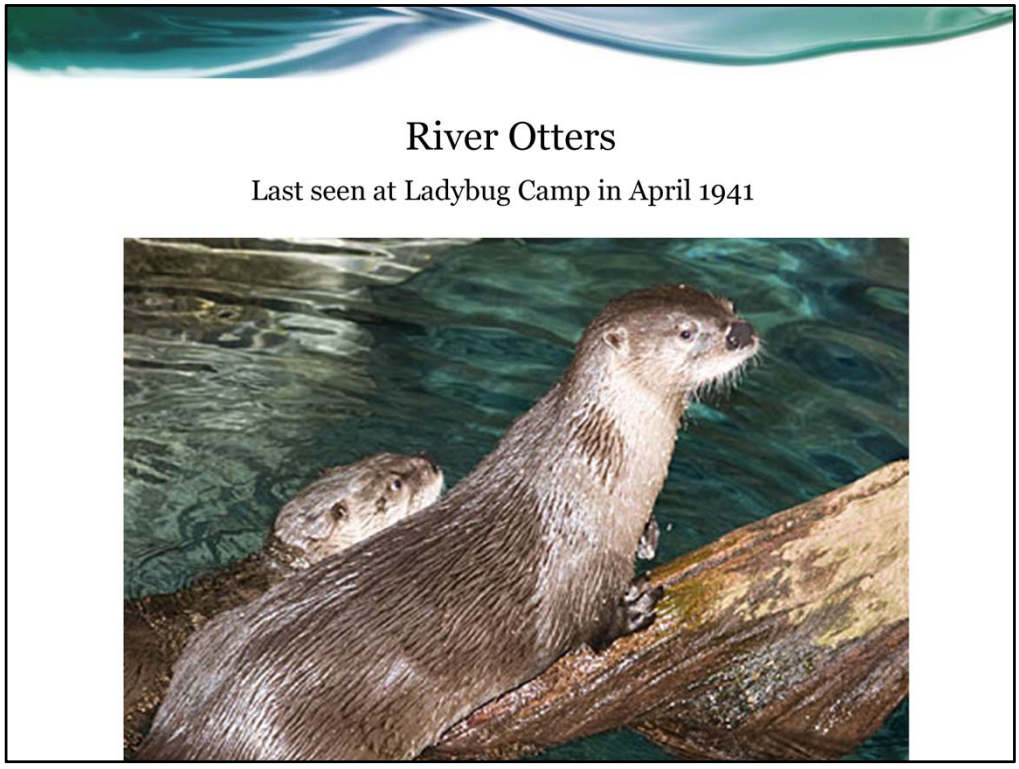
Prior to about 1906 , it was a common sight in the park to see many ducks, geese, swans, and other such fowl during the autumn, winter, and spring.

Wetland connections and National Park Birds

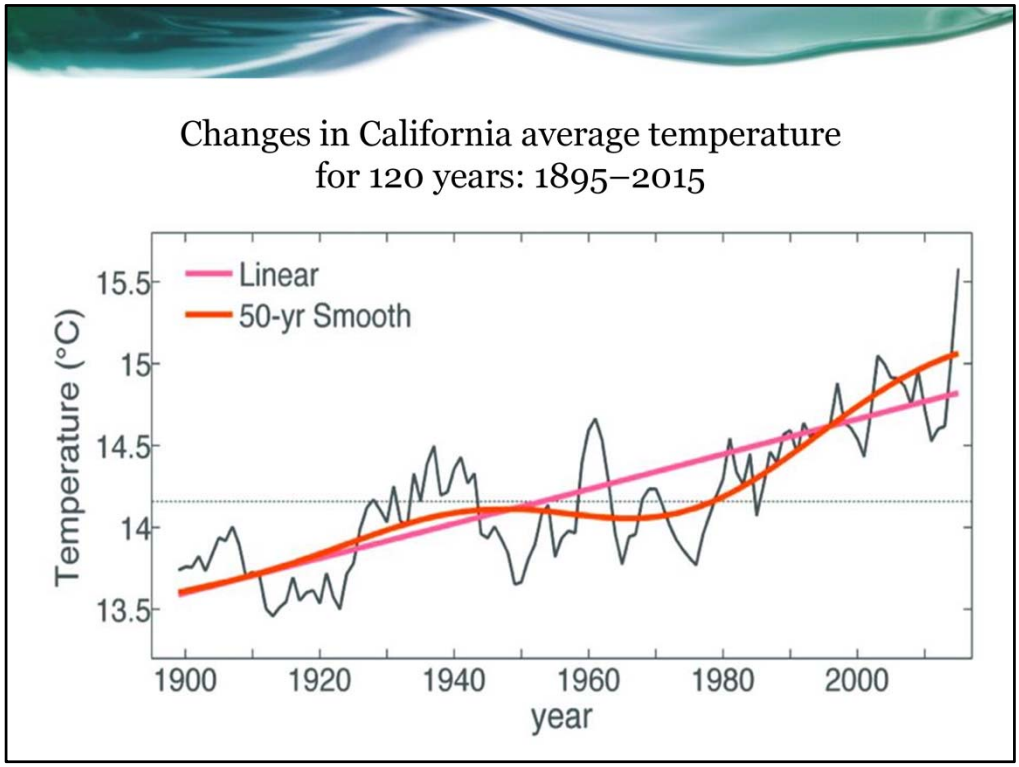
- 21 tundra swans roosted near Potwisha in the winter of 1907.

- Who has been to Potwisha?
- It is 3 miles inside the park entrance.
- This large flock of tundra swans used to fly by park headquarters each evening and morning as they went between their feeding grounds in the valley dryland wheat fields and their roost near Potwisha.
- This was in the day before pumps became available for groundwater irrigation.
- This is a reminder that national parks are not islands.

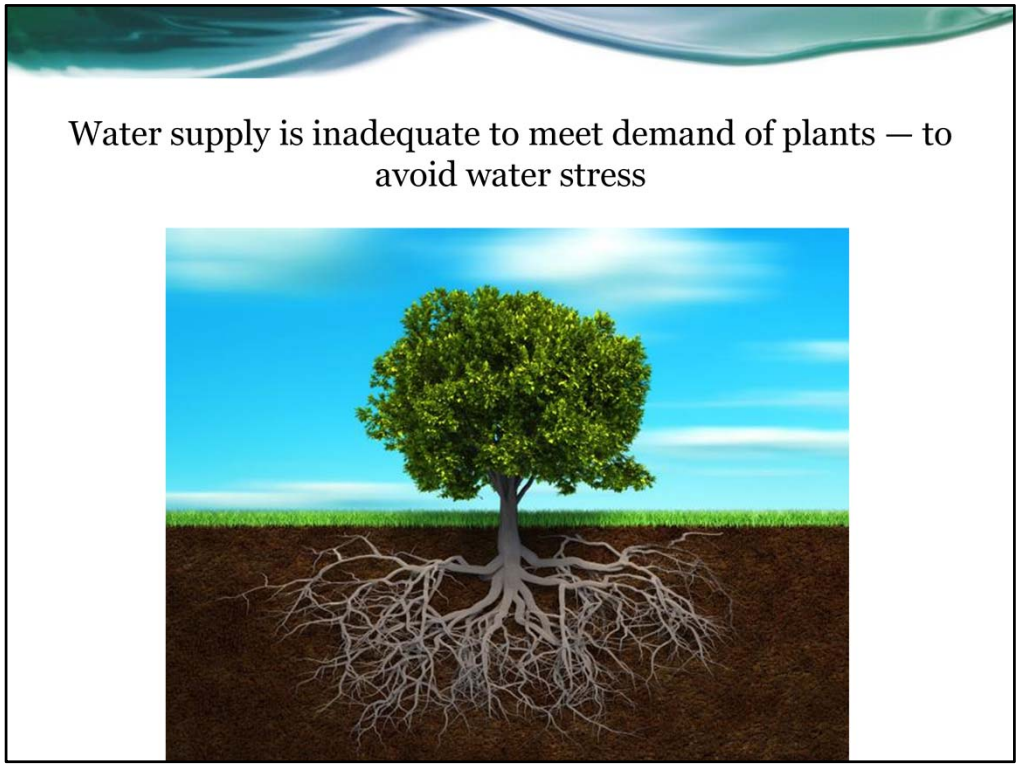
In the 25-year period from 1906–31, the park lost 30 species in 16 families.



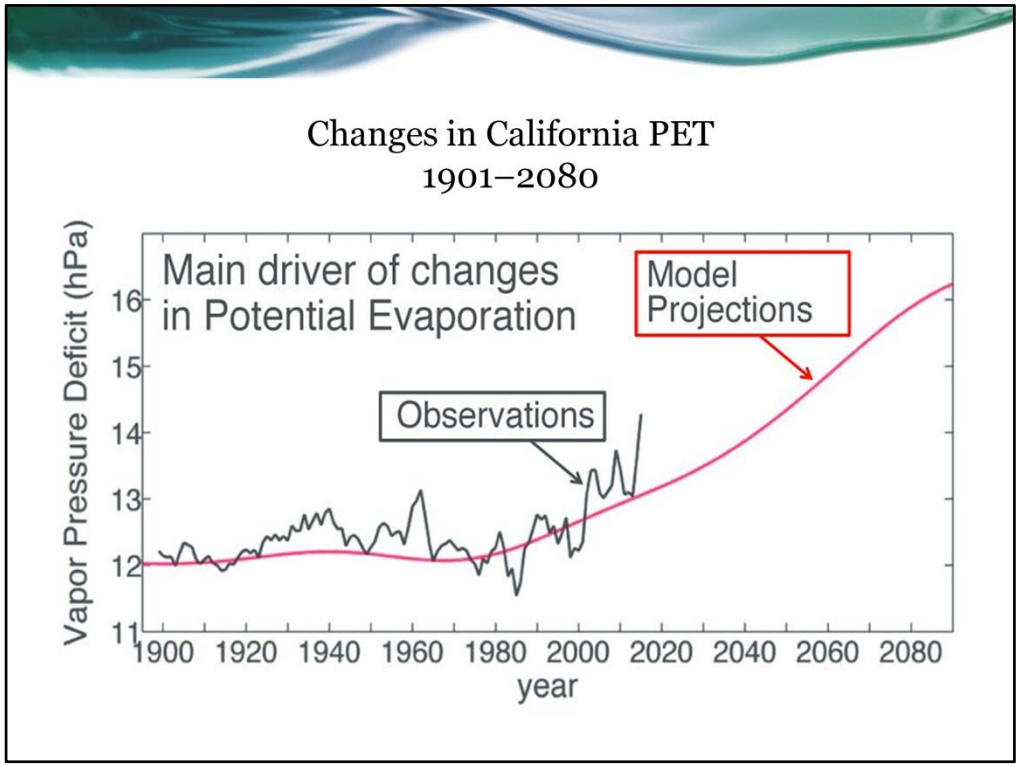
Who has been to the Ladybug Trail up the South Fork of the Kaweah?



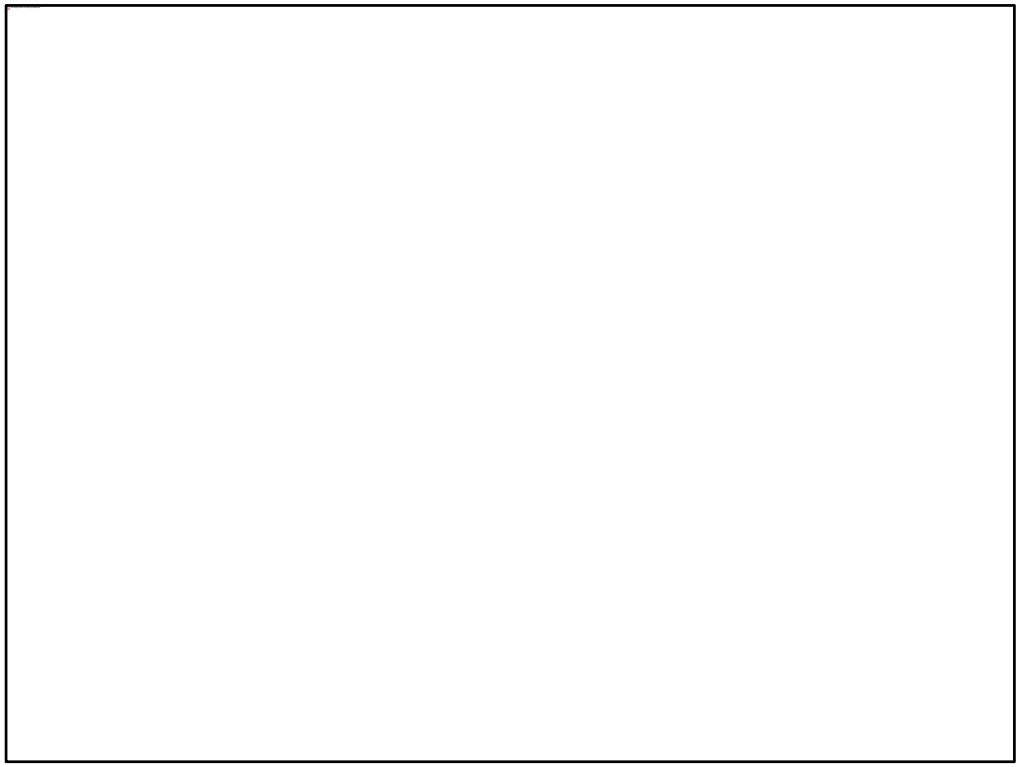
- This graph is from a 2015 study led by Park Williams of Columbia University.
- It shows the statewide changes in precipitation for 120 years.
- Temperature has been climbing since the end of the Little Ice Age in 1850.
- It has not been climbing at a steady rate.
- The average temperatures started climbing at an increased rate around 1970.
- This is driven primarily by a rise in nighttime temperatures.
- Many people have observed the decrease in valley fog, apparently due to warmer nighttime temperatures.
- 2016 was the 20th year in a row with U.S. temperatures above the 20th-century average.
- Each of the last 3 decades has been much warmer than the decade before.
- Temperatures along the West Coast have warmed much more than those in adjacent regions.
- Rising temperatures have also increased potential evapotranspiration and decreased PDSI.



- A third way of looking at drought is a period of time when our water supplies are inadequate to meet the water demand of plants.
- Water demand, from a plant's point of view, is the supply it needs to avoid stress.
- Plants lose water vapor through their leaves and needles; they are natural vaporizers.
- The term for this is transpiration or, more generally, evapotranspiration (ET).
- Water vapor is invisible, but it constitutes an enormous amount of water.
- The Tulare Lake Basin loses 23 million acre-feet of water through evapotranspiration in an average year.
- All the water we use each year is converted to ET and sent over the Sierra; that's why we are not immersed under a giant lake.
- Think of evapotranspiration like a straw that runs from the canopy to the roots.
- The suction in that straw is called potential evapotranspiration (PET).
- Potential in this sense is how much water would be sucked back up that straw to the canopy if supply were readily available down in the root zone.
- The hotter the temperature, the greater the suction in that straw.
- On a hot day, PET is like a giant sucking sound.
- The higher the temperature, the more water plants need to avoid water stress. Just like humans.
- The water supply that comes up that straw in response to PET, gets vaporized through the leaves and needles.
- If plenty of water comes up that straw, the plant is happy.
- PET is the amount of water plants need to avoid stress.
- But in drought conditions, plants may not be able to get all the water that they need.
- If there isn't enough water supply available in the root zone to meet demand (PET), the plant is under water stress.
- The difference between demand (PET), and supply (actual ET), is how much water stress the plant is under.
- That is how much additional water supply would be needed to make up for the water deficiency.
- That difference between PET and actual ET is the size of the drought from the viewpoint of plants.
- Initial studies suggest that the conifer biomass in the upper watersheds would have had to be reduced by at least 50% to provide enough water during the recent drought for the remaining trees and make them resilient and able to resist bark beetles.



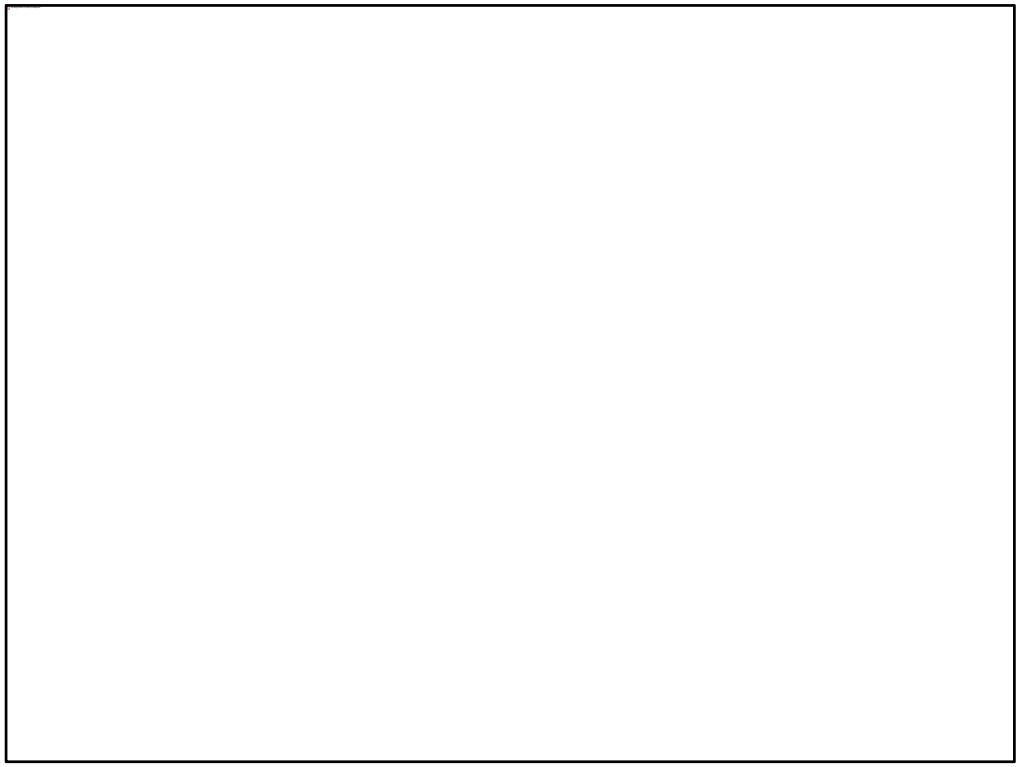
- This graph is from a 2015 study led by Park Williams of Columbia University.
- It shows the statewide changes in potential evapotranspiration since 1901.
- PET is the amount of water plants need to avoid stress.
- PET started climbing at an increased rate in the mid-1980s.
- The 2015 Williams study essentially replicated the 2015 Stanford study.
- They found that precipitation is the primary driver of droughts in California, but temperature has become a large and growing component.
- The 2012–2014 drought would have been a fairly bad drought no matter what. But it was made worse by the increase in temperature and potential evapotranspiration. They calculated that about 15% to 20% of the 2012–2014 drought was due to the effects of increased temperature and potential evapotranspiration.
- The odds of California suffering droughts at the far end of the scale, like the 2012–2014 drought, have roughly doubled over the past century.
- Temperatures in California are forecast to continue increasing over at least the next few decades. Potential evapotranspiration is also forecast to continue increasing.
- Our climate is changing, but it is still highly variable.
- A 2016 study led by Daniel Swain at Stanford showed that we still periodically get short periods of intense rainfall; the frequency of those really wet periods has not been decreasing in recent decades.
- Currently, these are periods when short bursts of intense rainfall overpower the effects of potential evaporation.
- The 16-year drought that we are in has been interrupted by 2 of these bursts so far.
- Several studies have shown that these periods have been getting shorter as temperature and potential evapotranspiration increase.
- The Williams study found that by the 2060s, 50 years from now, more or less permanent drought conditions will set in. By then, potential evaporation will overpower virtually all the short bursts of intense rainfall.
- Supply (precipitation) will no longer be able to compensate for the increased demand (PET). PDSI will always be negative.



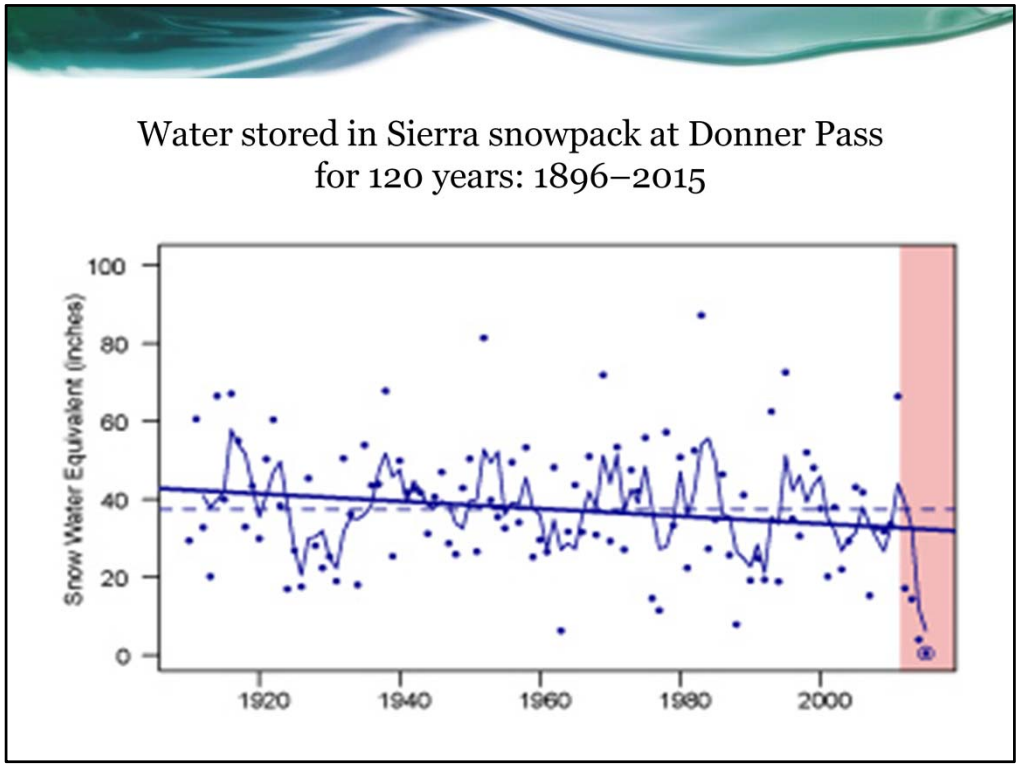
- This picture of pine mortality due to western pine beetle attack was taken in the Sierra National Forest.
- Sustained high PDSI levels during the 2007–09 and 2012–15+ droughts severely stressed conifers throughout the Southern Sierra.
- Drought-related moisture stress predisposes white firs and pines to successful attack by bark beetles.
- Conifer mortality was particularly apparent in the lower montane zone (3000–6000 foot elevation), involving virtually all conifer species except giant sequoia.

- The US Forest Service estimated that over 100 million trees died in California between 2010-2016.
- 62 million of those died in 2016 despite average rain the previous winter.
- Among other things, this has raised fuel loads and the risk of large wildfires.
- The current episode of beetle-caused mortality is much higher than what occurred in the 1918-34 and 1976–77 droughts.

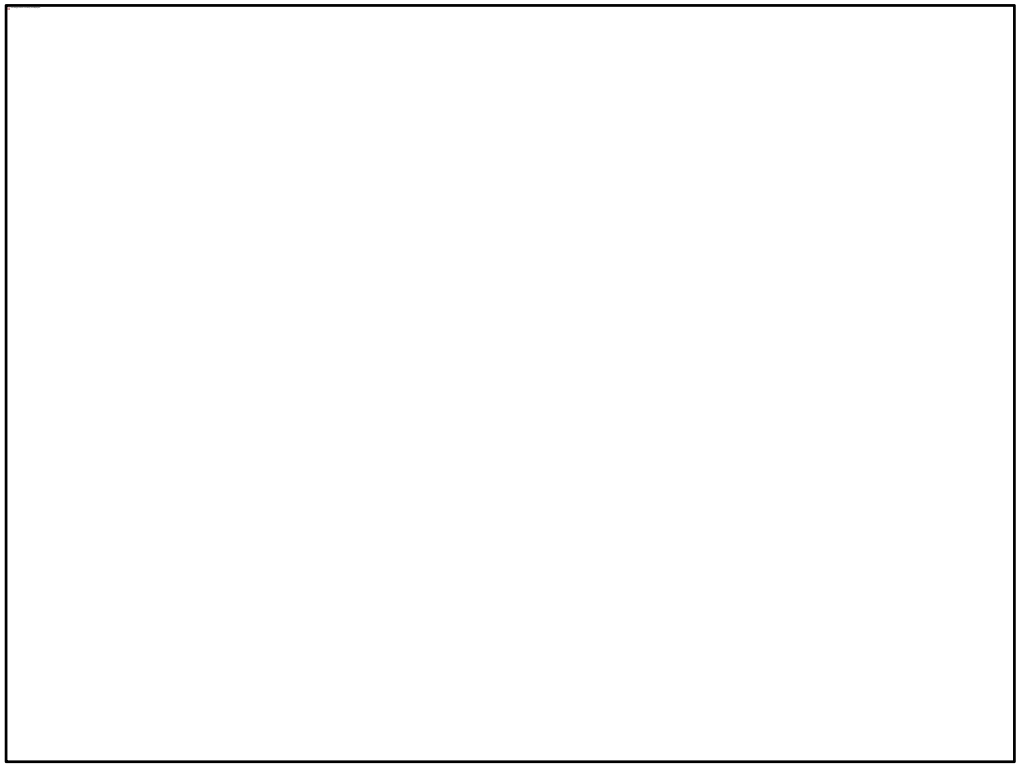
- From an ecological perspective, this mortality event is roughly equivalent to a hot, patchy fire.
- Bark beetles, under epidemic population levels, are not very selective thinning agents.
- They are a crude tool, but the result is more or less what land managers want to accomplish, especially in the face of global climate change.
- The mortality significantly reduces stand density in a mosaic patchwork.



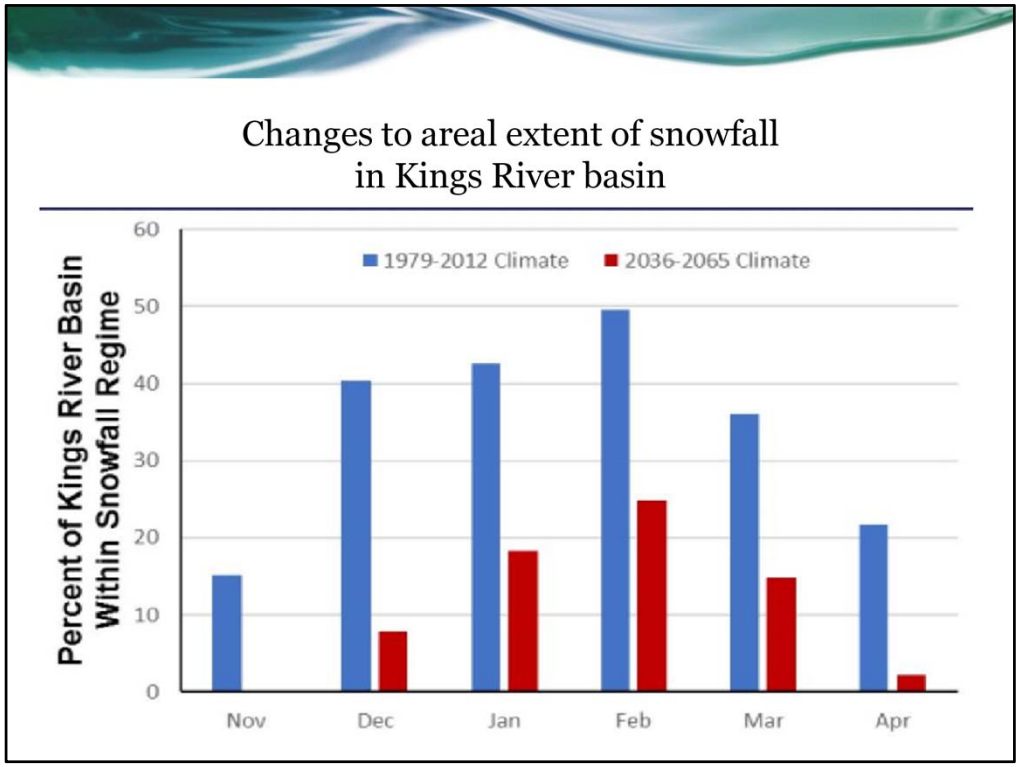
- This is a picture on Tejon Ranch by Daniel Griffin.
- It appears that blue oaks will be significantly impacted by the effects of global climate change.
- Tejon Ranch protects 14,000 acres of blue oak woodlands.
- Only Fort Hunter Liggett and Wind Wolves Preserve contain larger tracts of blue oaks.
- A vulnerability analysis was conducted in 2011 for blue oaks on Tejon Ranch under possible future climate scenarios.
- It predicted a general decline in climatic suitability for oaks on Tejon Ranch by mid-century, and further reductions by the end of the century.
- The overall trend was movement upslope and toward north-facing aspects.
- Blue oaks are predicted to lose between 70-80% of their range on the ranch by mid-century.
- The percentage of stable range for blue oaks is predicted to be between 10-16% by mid-century and less than 2% by the end of the century.
- This change in suitable range for blue oaks occurs under warmer-wetter and warmer-drier climate scenarios.
- It is driven largely by the increase in PET, a function of rising temperatures.



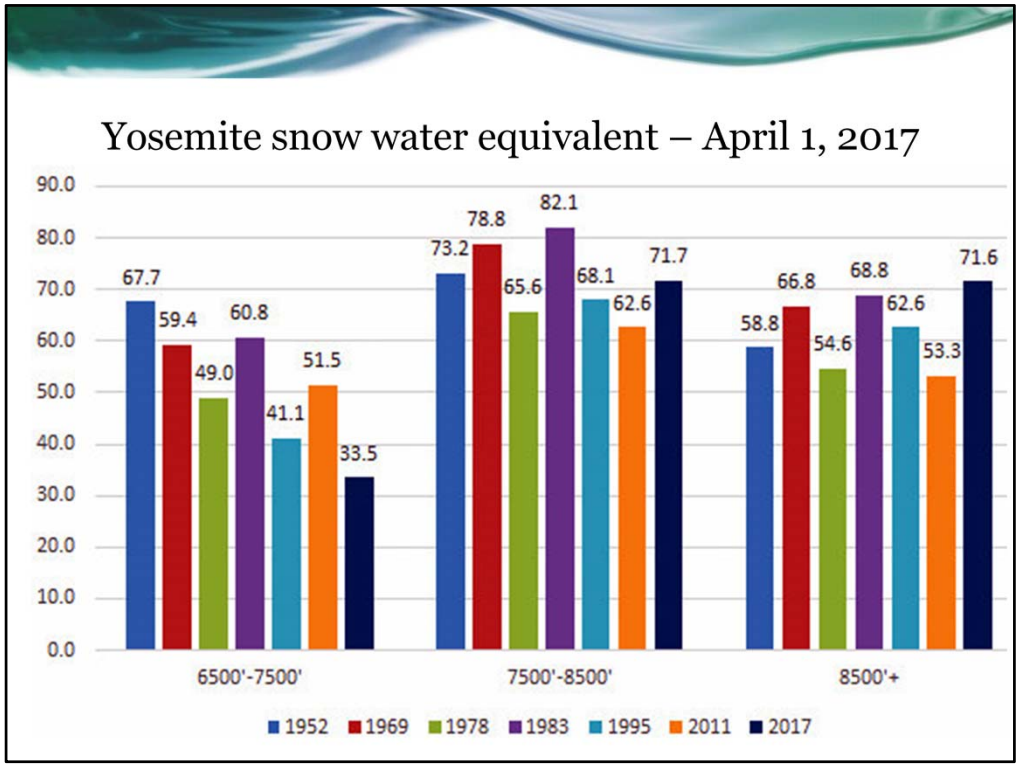
- One other result of rising temperature is its effect on the Sierra snowpack.
- This graph is from a 2016 Stanford study led by Daniel Swain.
- It shows Snow Water Equivalent as of April 1.
- The red shaded regions depict the 2013-2015 drought
- We rely on that snowpack for 30% of our water.
- There was more than 37 million acre-feet of snow in the entire Sierra at the end of March in 2011.
- There was only about one million acre-feet at the end of March in 2015.
- The amount of water stored in the Sierra Nevada snowpack reached its lowest level in over 500 years in 2015.
- Partly this was due to record warm temperatures in the winter on 2014–15.
- The vast majority of California's precipitation falls as rain and snow in the winter months.
- The rain fills the reservoirs, while the snow accumulates in the mountains, effectively acting as another reservoir.
- The snowpack gradually releases the water during the spring and summer.
- Precipitation in the Sierra isn't like in the Rockies.
- In the Sierra, it tends to be right on the borderline between rain and snow.
- It only takes a slight warming to turn the precipitation to rain.
- For every five degrees of warming, the freezing point of a storm, or the altitude of the "snow level" will rise by a thousand feet, driving the snowpack higher into the mountains.
- If rain falls on top of snow, it diminishes the snowpack further by melting it and triggering earlier runoff.
- Overall the freezing level in the Sierra has been going up, especially in the spring.
- The coldest winter temperatures in the Sierra in the winter of 2014–15 were above freezing on average. That was the first time this had occurred since recordkeeping began.
- What this warming trend means is that:
    - There will be more winter runoff because storms will have higher freezing points
    - more water is lost through sublimation (direct evaporation without melting)
    - melting is starting to occur earlier at higher altitudes
    - runoff is starting earlier; this will be an increasing trend
- California's snowpack has shrunk by 10% on average since World War II.
- Historically (1915-2003), 2/3 of the state's snowfall equivalent has been at mid-elevations, below 8200 feet.
- Based on the current temperature trend, snowfall equivalent (SFE) is projected to decline 50% statewide by the end of the 21st century.



- Atmospheric rivers are the source of nearly half of California's precipitation, and they cause the large majority of our major serious floods.
- This was a typical pineapple express type of atmospheric river.
- Pineapple Expresses are a subset of atmospheric rivers, distinguished primarily by the source of the water vapor and the strength of the southwesterly trending vapor-transport atmospheric river extending toward the West Coast.
- About 30% of atmospheric rivers fall into the Pineapple Express category.
- There is now quite a bit of evidence that future droughts here will be warmer and more intense, yet will be interrupted by increasingly powerful atmospheric river storms.
- The number of atmospheric rivers is projected to increase faster than their average intensity.
- Some research suggests that atmospheric rivers could become up to twice as common as they are now in parts of California by the end of the century, though this is still a matter of scientific debate.



- This slide and modeling work was done by Mohammad Safeeq at UC-Merced.
- This chart reflects snowfall in the Kings River basin above Pine Flat.
- The bars show the *average* areal extent of snowfall for the particular month being illustrated.
- We got a lot of tropical moisture during the winter of 2016-17; that always drives the snowline higher.
- Precipitation and snowpack were both well above average in California during the winter of 2016-17.
- However, Sierra snow water equivalent lagged overall precipitation.
- For example, in early March Northern Sierra snow water equivalent was 145% of average (vs 202% of average) for overall precipitation.
- This effect has been particularly pronounced at middle-elevation regions where wintertime temperatures are more “marginal” for frozen precipitation than at colder, higher elevations.
- While this winter has certainly been colder than recent (record warm) ones, conditions have still been near to above average across most of the state.
- More importantly, conditions have been considerably warmer than during most of California’s historically wet winters.



- This graph shows the results of the April 1, 2017 snow survey for Yosemite in the Central Sierra.
- It groups snow survey courses into low, medium, and high elevation bands.
- It compares the winter of 2017 with other recent big snow years.
- At high elevations like Hockett Meadows and Farewell Gap, 2017 was slightly bigger than 1969 and 1983.
- At mid-elevations, 2017 was somewhat smaller than 1969 and 1983.
- At lower elevations like Giant Forest or the Mineral King valley, 2017 was much smaller than previous big snow years.
- This trend at the mid- and lower elevations also happened in the 1995 big snow year.
- Historically (1915-2003), 2/3 of the state's snowfall equivalent has been at mid-elevations, below 8200 feet.