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September 28, 2015

VIA EMAIL

Ben Nelson
Bureau of Reclamation, Bay-Delta Office
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Re: NCRA Comments on Draft Environmental Impact Statement: Coordinated Long-Term Operation of the Central Valley Project and State Water Project (Agency/Docket Numbers: RR02800000, 15XR0680A1, RX.17868946.0000000)

Mr. Nelson:

On behalf of North Coast Rivers Alliance ("NCRA") we submit the following comments on the Bureau of Reclamation's ("Reclamation's") Draft Environmental Impact Statement for the Coordinated Long-Term Operation of the Central Valley Project and State Water Project ("DEIS"), which was prepared pursuant to the National Environmental Policy Act, 42 U.S.C. §§ 4332 et seq. ("NEPA"). NCRA strongly supports the *No Action* Alternative, which fully implements the Reasonable and Prudent Alternative ("RPA") actions identified in the 2008 Fish and Wildlife Service Biological Opinion ("2008 FWS BiOp") and 2009 National Marine Fisheries Service Biological Opinion ("2009 NMFS BiOp") (collectively, "BiOps").

INTRODUCTION

The continued long-term operation of the Central Valley project ("CVP") and State Water Project ("SWP") will adversely affect numerous species reliant on the Delta. The 2008 FWS BiOp "[c]oncluded that 'the coordinated operation of the CVP and SWP, as proposed, [was] likely to jeopardize the continued existence of the Delta Smelt' and 'adversely modify Delta Smelt critical habitat.'" DEIS 1-7. Similarly, the 2009 NMFS BiOp declared that continued operation of the CVP and SWP would "[j]eopardize the continued existence of Sacramento River winter-run Chinook Salmon, Central Valley spring-run Chinook Salmon, Central Valley Steelhead, [and] Southern DPS of North American Green Sturgeon," and "[d]estroy or adversely modify critical habitat" for those species. DEIS 1-7. Federal, state, and local agencies are tasked with the duty to preserve these species and therefore any continued operation of the CVP and SWP must be accompanied by protection and conservation measures.

As the situation in the Delta becomes more dire and fish populations continue their precipitous decline, the impacts of the continued long-term operation of the CVP and SWP become more severe.[1] For example, fishing yields for Chinook salmon have seen a steep decline in recent years.[2] Indeed, the 2014 commercial catch shrunk to 151,367 Chinook from 285,592 in the previous year. *Id.* At the tail end of the 2015 commercial season, preliminary yield numbers were only 96,878 Chinook. *Id.* Recreational yields for Chinook have likewise fallen, from 112,022 Chinook in 2013 to 65,936 in 2014. *Id.* As of August 31, 2015, this year's yield so far was only 25,541 Chinook. *Id.* Protection of the Delta is paramount to the survival of these species. The RPAs identified in the BiOps help protect the Delta's many imperiled fish species *before* their populations are extirpated. The ongoing drought plaguing the state will only exacerbate these potential impacts, further highlighting the importance of implementing the No Action Alternative and subsequently *all* of the RPAs. If we fail to protect these species now, we may not have a chance in the future.

A. The Bureau Must Not Implement *Any* of the Action Alternatives Presented in the DEIS

None of the action alternatives considered in the DEIS can be approved. DEIS ES-7 to ES-14, 3-30 to 3-42. Three out of five action alternatives – Alternatives 1, 3, and 4 – fail to implement *any* of the RPAs identified in the BiOps and Alternative 2 only incorporates some of the RPAs. DEIS ES-11to ES-13, 3-31 to 3-40. Failing to fully implement the RPAs would not only risk entire populations of fish species, but it would also violate the Endangered Species Act, 16 U.S.C. §§ 1531 et seq. ("ESA"). Furthermore, the one action alternative that does implement all of the RPAs – Alternative 5 – is poisoned by the DEIS' attempt to sneak in an additional 32,000 acre-feet/year ("afy") water diversion. DEIS ES-14, 3-41 to 3-42. Since none of the action alternatives implement *all* of the RPAs while maintaining or lessening water diversions, Reclamation should approve the No Action Alternative.

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[1] Phillip Reese and Ryan Sabalow, *Feds scramble to avoid another mass salmon die-off in the Sacramento River,* SACRAMENTO BEE (Sept. 5, 2015) (detailing some of the most recent challenges facing Chinook salmon), attached as Exhibit 1and also available at: http://www.sacbee.com/news/state/california/water-and-drought/article34197762.html#storylink=cpy

[2] Pacific Fisheries Council, Status Report for the 2015 Ocean Salmon Fisheries off Washington, Oregon and California, Supplemental Informational Report 13 (Sept. 2015), attached as Exhibit 2 and also available at: http://www.pcouncil.org/wp-content/uploads/2015/09/SUP_IR13_Salmon_Catch_Update_SEPT2015BB.pdf

1. Failing to Fully Implement the RPAs Would Violate the ESA

As noted above, approval of Alternatives 1 through 4 would violate the Endangered Species Act, 16 U.S.C. §§ 1531 et seq. ("ESA"). The main goals of the ESA are "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, [and] to provide a program for the conservation of such . . . species." 16 U.S.C. § 1531(b); *See also* 50 C.F.R. § 402.01. The ESA also declares that all "Federal departments and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance" of these purposes. 16 U.S.C. § 1531(c). Thus Reclamation must "seek to conserve" the species that continue to be decimated by the major water diversions associated with the coordinated long-term operation of the CVP and SWP. *Id.*; 50 C.F.R. §§ 402.02; 402.14, 402.15.

The United States courts have ardently reaffirmed the importance of the ESA. The Supreme Court held in *Tennessee Valley Authority v. Hill*, 437 U.S. 153, 180 (1978) ("*TVA*"), that the ESA "represented the most comprehensive legislation for the preservation of endangered species ever enacted by any nation," and "that Congress intended endangered species to be afforded the highest of priorities." *Id.* at 174. Indeed, the court noted that endangered species should be given "*priority over* the 'primary missions' of federal agencies." *TVA*, 437 U.S. at 185, emphasis added. If, like here, a proposed action presents a possibility of jeopardy to an endangered or threatened species or its habitat, the agency *must* consult with FWS and NMFS to create biological opinions that include RPAs to mitigate that jeopardy. 16 U.S.C. § 1536(b)(3)(A); 50 C.F.R. § 402.14(h).

Indeed, the ESA "affirmatively command[s] all federal agencies 'to insure that actions *authorized*, *funded*, or *carried out* by them do not jeopardize the continued existence' of an endangered species or '*result* in the destruction or modification of habitat of such species . . . .'" *TVA*, 437 U.S. at 173, *quoting* 16 U.S.C. § 1536, emphasis in original. This includes the affirmative requirement to adopt RPAs where necessary. 16 U.S.C. § 1536(b)(3)(A); 50 C.F.R. § 402.14(h). Agencies cannot ignore reliable information provided by FWS and NMFS in the BiOps. "Although the agency is technically not bound by findings of the . . . biological opinion[s], courts give great deference to the expertise of the FWS [and NMFS] on these issues, and an agency that attempts to proceed with an action in the face of a critical . . . biological opinion will almost certainly be found to have acted arbitrarily and capriciously and contrary to law." *Lone Rock Timber Company v. U.S. Department of the Interior*, 842 F.Supp. 433, 440 (D.Or. 1994), *citing Sierra Club v. Marsh*, 816 F.2d 1376, 1386 (9th Cir.1987) *and TVA*, 437 U.S. 153, internal citations omitted. A decision to continue long-term operation of the CVP and SWP without implementing all of the RPAs "in the face of reliable information that [it] will adversely impact protected species" violates the ESA. *Id.*

The Ninth Circuit Court of Appeals has "recognize[d] that the preparation of an EIS will not alter Reclamation's obligations under the ESA." *San Luis & Delta-Mendota Water Authority v. Jewell*, 747 F.3d 581, 653 (2014). Here, the DEIS and both BiOps state that the continued operation of the CVP and SWP *is likely to* adversely affect protected species and their habitat, and jeopardize their continued existence. DEIS 1-7. This admission alone is more than enough to trigger these agencies' duty to insure that their actions in operating the CVP and SWP do not "jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species." 16 U.S.C. § 1536(a)(2), (b)(3)(A); 50 C.F.R. § 402.14(h). In order to insure that no such jeopardy is likely, the No Action Alternative should be approved and all of the RPAs identified in the BiOps should be implemented.

2. Alternative 5, the *Only* Action Alternative that Fully Implements the RPAs, Cannot Stand

Like the No Action Alternative, Alternative 5 would fully implement the RPAs. However, Alternative 5 also includes water contracts for the El Dorado County Water Agency ("EDCWA") and the El Dorado Irrigation District ("EID"). One of the contracts would allow EID to store up to 17,000 afy of non-CVP water in Folsom Dam; the other would provide up to 15,000 afy of CVP water to EDCWA from Folsom Dam. These contracts would result in reduced outflow from Folsom Dam rather than the greater flows needed for imperiled fish as noted above and discussed below. Neither the project's purpose and need, nor the RPAs, provide any specific justification for including these water contracts in any of the Action Alternatives. NCRA questions the decision to include these contracts in Alternative 5.

When compared with the No-Action Alternative, Alternative 5 would increase egg mortality for fall-run Chinook Salmon within the Sacramento and Feather River Systems during critically dry and below normal years, respectively. DEIS 9-347. The DEIS acknowledges that these effects would be more adverse than the No-Action Alternative. Therefore the No-Action Alternative must be selected.

There is an additional reason why Alternative 5 must be rejected. Its impacts are worse than those revealed in the DEIS. The DEIS should be revised to fully account for the likely increase in below normal rainfall years due to climate change. Although the DEIS does assume that climate change will increase short-duration, high-rainfall events that reduce snow-pack, and increase water temperature, it does not mention intensified drought conditions. Yet emerging research confirms that impacts associated with drought conditions – such as an increase in below

normal rainfall years – are likely to increase with California's average temperature.[3] An increase in so-called below normal and critically dry years will amplify Alternative 5's detrimental effects on fall-run Chinook Salmon. For this additional reason, Alternative 5 must not be approved.

CONCLUSION

For the reasons stated above, NCRA strongly urges adoption of the No-Action Alternative as the best hope to prevent extirpation of California's native fish.

Respectfully submitted,

Stephan C. Volker
Attorney for North Coast Rivers Alliance

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[3] *See* Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, and E. R. Cook, (2015), Contribution of anthropogenic warming to California drought during 2012–2014, Geophys. Res. Lett., 42, 6819–6828, doi:10.1002/2015GL064924, attached as Exhibit 3(finding that human caused warming intensified drought impacts). While Appendix 5A states that CalSim II modeling examined climate change effects, the DEIS does not state that CalSim II modeling included any consideration of rising temperature's impact on drought intensity. Instead, CalSim II applies historic trends forward.

Exhibit List

1. Phillip Reese and Ryan Sabalow, *Feds scramble to avoid another mass salmon die-off in the Sacramento River,* SACRAMENTO BEE (Sept. 5, 2015)

2. Pacific Fisheries Council, Status Report for the 2015 Ocean Salmon Fisheries off Washington, Oregon and California, Supplemental Informational Report 13 (Sept. 2015)

3. Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, and E. R. Cook, (2015), Contribution of anthropogenic warming to California drought during 2012–2014, Geophys. Res. Lett., 42, 6819–6828, doi:10.1002/2015GL064924,

EXHIBIT
1

Feds scramble to avoid another mass salmon die-off in the Sacramento River

By Phillip Reese and Ryan Sabalow preese@sacbee.com

A year ago, California lost nearly an entire generation of endangered salmon because the water releases from Shasta Dam flowed out warmer than federal models had predicted. Thousands of salmon eggs and newly hatched fry baked to death in a narrow stretch of the Sacramento River near Redding that for decades has served as the primary spawning ground for winter-run Chinook salmon.

Earlier this year, federal scientists believed they had modeled a new strategy to avoid a similar die-off, only to realize their temperature monitoring equipment had failed and Shasta's waters once again were warming faster than anticipated.

In the months since, in what is essentially an emergency workaround, they've revised course, sharply curtailing flows out of Shasta. The hope is that they reserve enough of the reservoir's deep, cold water pool to sustain this year's juvenile winter-run Chinook. But it's meant sacrificing water deliveries to hundreds of Central Valley farmers who planted crops in expectation of bigger releases; and draining Folsom reservoir – the source of drinking water for much of suburban Sacramento – to near-historic lows to keep salt water from intruding on the Delta downstream.

In spite of all this, another generation of wild winter-run Chinook salmon could very well die.

For all the focus on fallowed farm fields and withered lawns in California's protracted drought, native fish have suffered the most dire consequences. The lack of snowmelt, warmer temperatures and persistent demand for limited freshwater supplies have left many of the state's reservoirs – and, by extension, its streams and rivers – hotter than normal. The changing river conditions have threatened the existence of 18 native species of fish, the winter-run Chinook among them.

Chinook are called king salmon by anglers for a reason. They can grow to more than 3 feet in length, and the biggest can top more than 50 pounds. Decades ago, before dams were built blocking their traditional spawning habitat, vast schools of these silver-sided fish with blue-green backs migrated from the ocean to spawn and die in the tributaries that feed the Sacramento River in runs timed with the seasons.

The largest run that remains in the Sacramento River system is the fall run, which survives almost entirely due to hatchery breeding programs below the Shasta, Oroville and Folsom dams. The winter run, in contrast, is still largely reared in the wild, laying its eggs in the gravel beds below Shasta's concrete walls. Their numbers have dwindled in the face of predators and deteriorating river conditions. The federal government declared the run endangered in 1994, and it has flirted with extinction ever since.

Following last year's failed federal efforts, only about 5 percent of the winter-run Chinook survived long enough to begin to migrate out to sea. The species has a three-year spawning cycle, meaning that three consecutive fish kills could lead to the end of the winter run as a wild species. One hatchery below Lake Shasta breeds winter-run Chinook in captivity.

Officials with the U.S. Bureau of Reclamation, which operates both Shasta and Folsom dams, say they believe their emergency efforts at Shasta are working and they anticipate "some" winter-run Chinook will survive this year.

"We believe that we are on track," said bureau spokesman Shane Hunt. "We are sitting in a much better place today than we were a year ago today."

Several biologists interviewed remain dubious. They note that preserving more cold water in Shasta has meant many stretches of the Sacramento River are warmer than they were last year. They worry that salmon eggs and fry will still die – only gradually instead of suddenly.

“We stand a pretty good chance of losing the wild cohort again this year, like we did last year,” said Peter Moyle, a UC Davis researcher and one of the nation’s leading fisheries biologists. “If we get lucky some of those fish will survive. We’re definitely pushing the population to its limits.”

Agricultural leaders, meanwhile, say there’s good reason to suspect the government models will again prove flawed and the fish will die despite the sacrifices farmers have made.

Rep. Jim Costa, a Democrat and third-generation farmer who represents a wide swath of the San Joaquin Valley, is among those who think there’s a good chance farmers have been punished for no benefit to the fish.

“That begs the question: What are we accomplishing?” Costa said. “We are in extreme drought conditions. ... The water districts that I represent in the San Joaquin Valley have had a zero – zero – water allocation. ... Over half a million acres have been fallowed ... It just seems to defy common sense and logic.”

Some members of California’s fisheries industry also have lost confidence in the bureau, arguing the government has badly mismanaged its rivers. Beyond the very existence of a wild population of fish, they say, the government is risking millions of dollars for California’s economy and hundreds of fishing jobs – and a key source of locally caught seafood for markets and restaurants.

Two consecutive fish kills involving an endangered species could lead to more stringent regulation of commercial and recreational fishing. It’s a real possibility, state and federal fisheries regulators said, that salmon fishing could be severely restricted along much of California’s central coast and in the Sacramento River system next year.

Larry Collins, a commercial fisherman operating out of Pier 45 in San Francisco, said that in the fight over water, the fishing industry – and wild fish – lack the political clout compared with municipal and agricultural interests.

“I’ve been around a long time, and I’ve fought the battle for a long time, and I’ve watched the water stolen from the fish,” he said. “The fish are in tough shape because their water is growing almonds down in the valley. To me, it’s just outright theft of the people’s resource for the self-aggrandizement of a few, you know?”

“You got money you can buy anything,” he added. “You can buy extinction.”

Federal models prove faulty

On paper, the requirements for salvaging the winter-run Chinook seem fairly basic. The winter-run Chinook spawn from April to August. Juvenile fish swim downriver from July to March. If the water in the Sacramento River is too hot as the fry emerge from their eggs, they die. Warm water also makes it more difficult for the juveniles to survive their swim downstream to the ocean.

But in practice, there are broad variables to keeping the river cool, involving snowmelt, heat waves, water depths and the temperatures of the tributaries entering the reservoir, as well as conditions in the river downstream.

A year ago, federal and state officials had a plan to keep temperatures in key portions of the Sacramento River below 56 degrees; temperatures above 56 can trigger a die-off. The models built by the Bureau of Reclamation indicated operators could release large amounts of water from Lake Shasta while still maintaining a cool temperature, easing the pressure on farms and cities. According to their calculations, the water would be cold enough at key points in the Sacramento River to ensure survival of 30 percent of the salmon run.

But the models were wrong. The Bureau of Reclamation essentially ran out of cold water reserves in Lake Shasta,

limiting its ability to control temperatures in the Sacramento River. Average daily river temperatures rose well above levels needed by salmon to survive. The 5 percent that did transition from eggs to fry were left to navigate to the ocean in tough conditions.

“That 5 percent – I guarantee you they didn’t make it down through the Delta,” said Bill Jennings, executive director of the California Sportfishing Protection Alliance.

Fast forward to this year, and another plan gone awry.

During the spring, government officials again said they would keep winter-run Chinook alive by maintaining water temperatures below 56 degrees. The State Water Resources Control Board signed off on their plan in mid-May.

Only weeks later, Bureau of Reclamation officials told the state that their temperature monitoring equipment wasn’t working. In fact, they said, temperatures in Shasta were warmer than anticipated – and dramatic intervention would be needed to keep winter-run Chinook alive. They asked the board to consider a new plan and immediately restricted flows from Shasta.

The state water board took up the issue at a meeting on June 16. Members of the board bemoaned their lack of good choices and later adopted a plan that left no one happy. Water releases would be curtailed out of Lake Shasta. Folsom Lake would be drawn to historic lows. Deliveries to farmers would be reduced.

And, despite those measures, the average daily temperature in the Sacramento River would rise to 57 degrees on most days and 58 degrees on some days, according to the government models. That’s too high a temperature for all winter-run Chinook to survive, but the Bureau of Reclamation, in documents supporting the change, said its modeling predicted roughly 20 percent of the fish would survive to early adulthood. That would be lower than a typical year – but not a disaster.

But are this year’s models more accurate? Already this summer, average daily temperatures at a key point in the Sacramento River have risen above 58 degrees on seven separate occasions, including several times in late August, state data show.

Federal officials said their models anticipated some temperature spikes, and noted that on each occasion so far, they were able to release cold water into the river and bring temperatures back down.

“It can have an effect” on fish, said Hunt, the bureau spokesman, of river temperatures above 58 degrees. But, he added, “That temperature is not a lethal temperature immediately.”

Jon Rosenfield, a biologist with the Bay Institute, disagreed, saying that many winter-run salmon likely were doomed by the temperature spikes. He offered the analogy of a chicken egg: “If you take an egg and dip it in boiling water, you are jeopardizing its ability to develop into a chick,” he said. “The longer you do that and the hotter the temperatures, the less likely it is to develop.”

Another concern is whether there is still enough cold water in Shasta to keep river temperatures low into the fall. Hunt says yes – that the government projects that Shasta will contain 350,000 acre-feet of cold water, below 56 degrees, at month’s end, far more than in 2014.

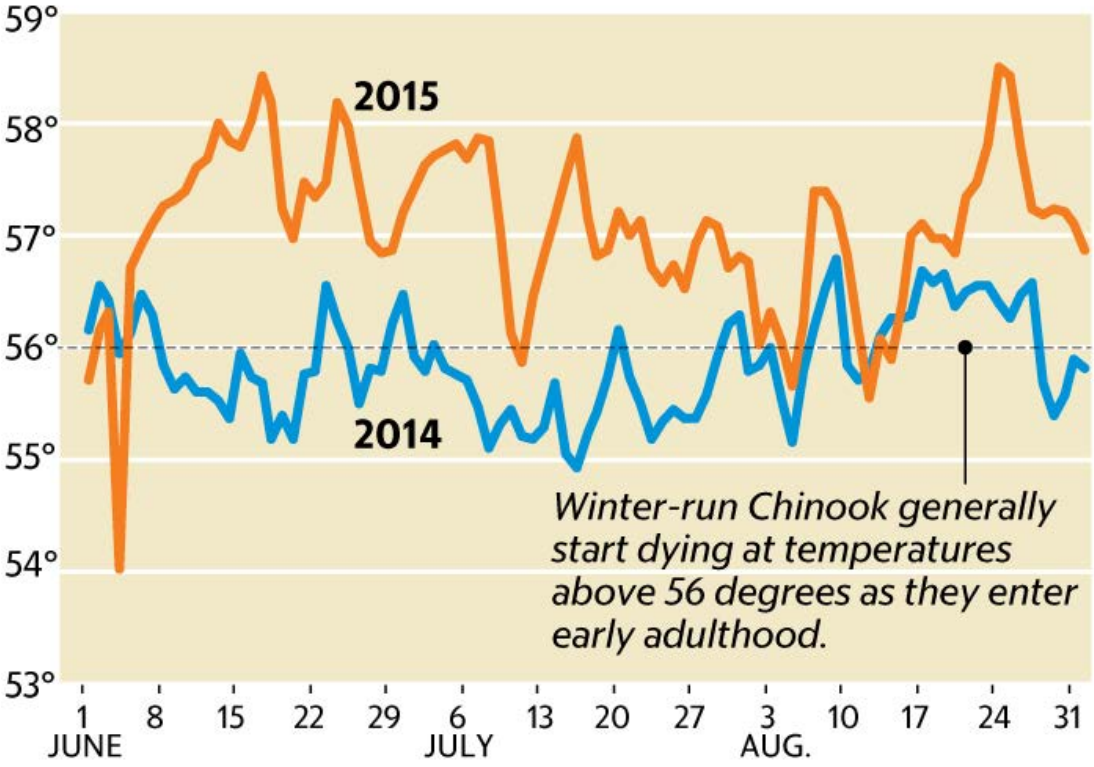
Rosenfield expressed doubts that the bureau is in position to do detailed calculations on its cold water supply. “They are way behind in anything using modern technology in measuring how much cold water they have,” Rosenfield said.

Scientists won’t know whether this year’s plan worked until fish surveys are completed in the winter. In a worst-case scenario, the government could rely even more heavily on its hatchery to sustain winter-run Chinook. Rosenfield called that option a “Band-Aid,” noting it would not preclude the loss of the fish as a wild species. Hatchery fish, he said, tend to come from a limited gene pool and may also have difficulty surviving in warm water.

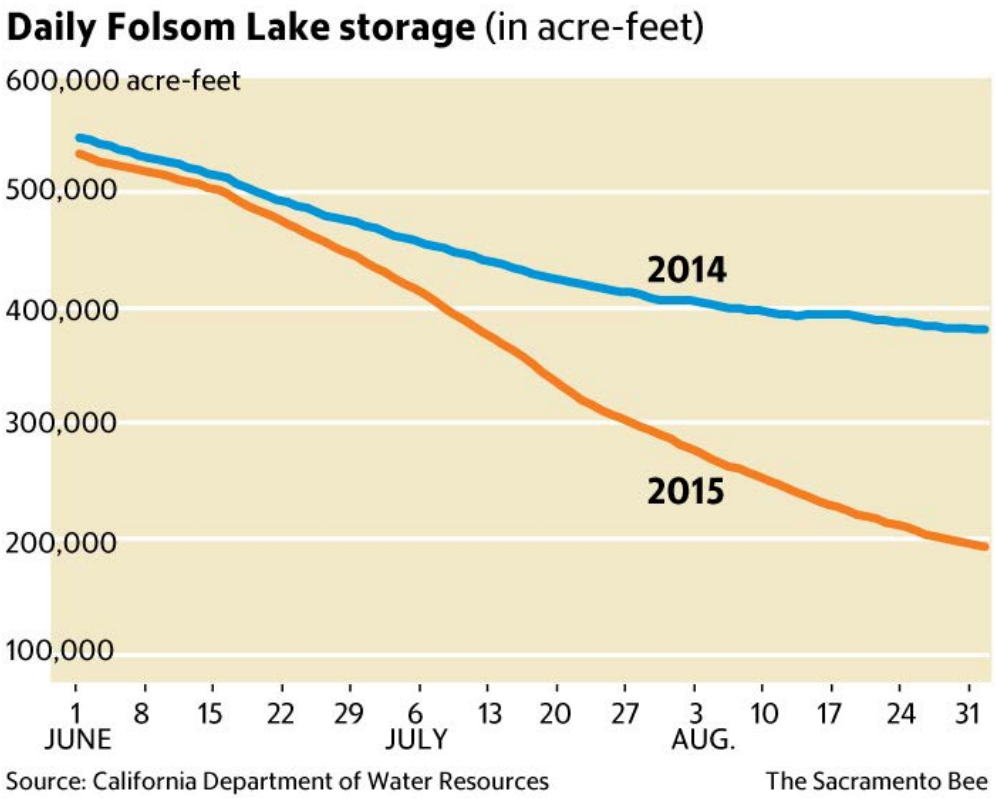
Higher river temperatures; low lake levels

Under a new plan, federal officials have allowed temperatures in the Sacramento River in Shasta County to rise above 56 degrees consistently throughout the summer. They predict the warmer temperatures will not cause a mass salmon die-off; some biologists are dubious.

Average daily water temperatures in the Sacramento River above Clear Creek



One consequence of the temperature plan to keep winter-run Chinook alive has been increased flows out of Folsom Lake.



Looking to the future

Jeff Gonzales worries about the ripple effects of another bad salmon season. Gonzales, a retired fire captain from Durham who guides clients on river-fishing trips, remembers when fisheries managers shut down the season for the fall-run Chinook in 2008 and 2009.

In those years, officials closed the fall-run fishing season in response to an unprecedented decline in the numbers of Chinook that had returned to the Sacramento, American and Feather rivers to spawn. The run plummeted amid poor ocean conditions and environmental problems in the Sacramento-San Joaquin Delta.

Gonzales thinks a similar scenario could be well underway, and that this year's fall run is also in danger. He's troubled by photos his fellow guides have sent him of fully-grown fall-run salmon floating dead in southern stretches of the Sacramento River. He attributes the deaths to warm water.

On Thursday morning, he was guiding clients on the river near Los Molinos, between Chico and Red Bluff, in search of fall-run salmon. The river is so warm, he said, that it's been tough to find fish in his normal spots. The fish, he said, have either raced upstream seeking colder water, or are holding off the entrance to the Delta in the Pacific, waiting for a cold water flow.

That means slow-going for him and other guides.

On Thursday, his four clients, all firefighters enjoying an off-day, spent a four-hour stretch watching ospreys, wood ducks and herons glide by as their lures wriggled in the swift current. Every so often, a Chinook would breach the water and slap the surface with its tail, almost tauntingly. That morning, just one client saw his rod bend under the weight of a lunging 15-pound, silver-sided king.

Some clients have canceled trips because of the paltry catches, Gonzales said, and business will only get worse if the salmon seasons get shut down due to yet another winter-run die-off.

Maneuvering through the currents, the river rippling out before him, he lamented not just the loss of the fish but of a cultural heritage.

“You’ve gotta think about our future here, you know?” Gonzales said. “Our children and our grandchildren may not be able to see what we’re seeing here.”

Phillip Reese: 916-321-1137, @PhillipHReese.

EXHIBIT
2

STATUS REPORT OF THE 2015 OCEAN SALMON FISHERIES OFF WASHINGTON. OREGON. and CALIFORNIA.

Preliminary Data Through August 31, 2015.[a/]

Fishery and Area	Season Dates	Effort Days Fished	CHINOOK Catch	CHINOOK Quota	CHINOOK Percent	COHO[b/] Catch	COHO[b/] Quota	COHO[b/] Percent
COMMERCIAL								
Treaty Indian[c/]	*5/1-6/30*	683	30,916	30,000	103%		Non-Retention	
	7/1-9/15	364	26,944	29,084	93%	2,961	42,500	7%
Non-Indian North of Cape Falcon[d/]	*5/1-6/30*	2,118	38,930	40,200	97%		Non-Retention	
	7/1-9/1 [e/]	1,090	25,248	26,800	94%	2,924	19,200	15%
	9/4-9/22"	NA	NA			NA	NA	NA
Cape Falcon - Humbug Mt.	*4/1-8/27*	6,645	82,752	None	NA		Non-Retention	
	9/3-9/30	NA	NA	None	NA		Non-Retention	
Humbug Mt. - OR/CA Border[g/]	*4/1-5/31*	161	1,177	NA	NA		Non-Retention	
	6/1-6/26	100	1,528	1,800	85%		Non-Retention	
	7/1-7/31	88	769	1,184	65%		Non-Retention	
	8/6-8/27	23	50	772	6%		Non-Retention	
OR/CA Border - Humboldt S. Jetty	*9/11-9/30*	NA	NA	3,000			Non-Retention	
Humboldt S. Jetty - Horse Mt.				Closed				
Horse Mt. - Pt. Arena	*5/1-5/31, 6/15-6/30, 7/12-8/26*	3,577	59,515	None	NA		Non-Retention	
	9/1-30	NA	NA	None	NA		Non-Retention	
Pt. Arena - Pigeon Pt.	*5/1-31,6/7-30, 7/8-8/29*	2,281	20,775	None	NA		Non-Retention	
	9/1-30	NA	NA	None	NA		Non-Retention	
Pt. Reyes-Pt. San Pedro	*10/1-2, 5-9 &12-15*	NA	NA	None	NA		Non-Retention	
Pigeon Pt. - Pt. Sur	*5/1-31,6/7-30, 7/8-8/15*	2,289	12,176	None	NA		Non-Retention	
Pt. Sur - U.S./Mexico Border	*5/1-31,6/7-30, 7/8-31*	866	4,412	None	NA		Non-Retention	
RECREATIONAL								
U.S./Canada Border - Queets River[h/]	*5/15-16, 22-23, 5/30-6/12*	751	215	10,000	12%		Non-Retention	
Queets River - Leadbetter Poin[h/]	*5/30-6/12*	2,080	745				Non-Retention	
Leadbetter Point - Cape Falcon[h/]	*5/30-6/12*	499	242				Non-Retention	
U.S./Canada Border - Cape Alava	*6/13-9/3*	13,255	8,199	8,400	98%	3,665	14,850	25%
	9/4-9/30						4,100	0%
Cape Alava-Queets River	*6/13-9/3*	2,685	2,113	2,600	81%	388	3,610	11%
	9/4-9/30						625	0%
	10/1-10/12			100	0%		100	0%
Queets River - Leadbetter Pt.	*6/13-9/3*	36,583	15,946	27,900	57%	22,793	52,840	43%
	9/4-9/30						13,000	0%
Leadbetter Pt.-Cape Falcon	*6/14-9/3*	32,970	8,881	15,000	59%	38,300	79,400	48%
	9/4-9/30						15,300	0%
Cape Falcon - Humbug Mt.	*3/15-10/31*	29,466	1,227	None	NA	Non-Retention except for periods listed		
Cape Falcon to OR/CA Border	*6/27-8/9*	Included Above or Below		NA	NA	14,925	55,000	27%
Cape Falcon to Humbug Mt.	*9/4-9/30"*	Included Above		NA	NA	NA	20,700	NA
Humbug Mt. - OR/CA Border (OR-KMZ)	*5/1-9/7*	2,795	321	None	NA	Included Above		
OR/CA Border - Horse Mt. (CA-KMZ)	*5/1-9/7*	8,711	3,640	None	NA		Non-Retention	
Horse Mt. - Pt. Arena (Ft. Bragg)	*4/4-11/8*	11,181	5,023	None	NA		Non-Retention	
Pt. Arena - Pigeon Pt. (San Francisco)	*4/4-10/31*	28,061	12,972	None	NA		Non-Retention	
Pigeon Pt. - P. Sur (Monterey N.)	*4/4-9/7*	12,648	2,547	None	NA		Non-Retention	
Pt. Sur - U.S./Mexico Border (Monterey S.)	*4/4-7/19*	1,996	359	None	NA		Non-Retention	

TOTALS TO DATE (through Aug. 31)	Effort 2015	Effort 2014	Effort 2013	Chinook Catch 2015	Chinook Catch 2014	Chinook Catch 2013	Coho Catch 2015	Coho Catch 2014	Coho Catch 2013
TROLL									
Treaty Indian	**1,047**	1,342	1,232	**57,860**	62,217	49,518	**2,961**	49,625	43,553
Washington Non-Indian	**2,468**	1,887	2,218	**53,564**	37,993	39,361	**1,874**	10,313	5,764
Oregon	**7,757**	9,491	6,473	**96,890**	195,852	74,407	**1,050**	3,997	309
California	**9,013**	11,807	15,401	**96,878**	151,367	285,592	**0**	0	0
Total Troll	**20,285**	24,527	25,324	**305,192**	447,429	448,878	**5,885**	63,935	49,626
RECREATIONAL									
Washington	**82,288**	101,428	70,938	**34,597**	38,290	26,810	**57,820**	96,034	39,387
Oregon	**38,796**	89,147	65,431	**3,292**	15,194	26,865	**22,251**	70,189	11,680
California	**62,597**	103,319	138,490	**24,541**	64,936	112,022	**38**	476	361
Total Recreational	**183,681**	293,894	274,859	**62,430**	118,420	165,697	**80,109**	166,699	51,428
PFMC Total	**203,966**	318,421	300,183	**367,622**	565,849	614,575	**85,994**	230,634	101,054

a/ Inseason estimates are preliminary.

b/ Non-Indian coho fisheries prior to Sept. are mark-selective and non-mark-selective recreational fisheries occur in Sept., (except SOF rec.) see the regulations for details.

c/ Effort is reported as landings. Chinook summer quota of 30,000 decreased by subtracting spring quota overage on an impact neutral basis by 916 fish.

d/ Numbers shown as Chinook quotas for non-Indian troll and rec. fisheries North of Falcon are guidelines not quotas; only the total Chinook allowable catch is a quota.

e/ September quotas to be adjusted due to iimpact neutral trades and rollovers.

f/ Remaining mark-selective coho quota to be converted to non-mark-selective quota on an impact neutral basis.

g/ July and August quotas adjusted from preseason due to impact neutral rollover of

h/ Mark-selective fishery for Chinook

i/ 12,500 preseason quota plus an impact equivalent roll-over from the Cape Falcon to OR/CA border mark-selective recreational coho fishery.

EXHIBIT
3

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2015GL064924

Key Points:
- Warming since 1901 caused a significant trend toward drought in California
- Recent drought was naturally driven and modestly intensified by warming
- Warming has rapidly amplified the probability of severe drought

Supporting Information:
- Text S1, Table S1, and Figures S1–S7

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Contribution of anthropogenic warming to California drought during 2012–2014

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Abstract A suite of climate data sets and multiple representations of atmospheric moisture demand are used to calculate many estimates of the self-calibrated Palmer Drought Severity Index, a proxy for near-surface soil moisture, across California from 1901 to 2014 at high spatial resolution. Based on the ensemble of calculations, California drought conditions were record breaking in 2014, but probably not record breaking in 2012–2014, contrary to prior findings. Regionally, the 2012–2014 drought was record breaking in the agriculturally important southern Central Valley and highly populated coastal areas. Contributions of individual climate variables to recent drought are also examined, including the temperature component associated with anthropogenic warming. Precipitation is the primary driver of drought variability but anthropogenic warming is estimated to have accounted for 8–27% of the observed drought anomaly in 2012–2014 and 5–18% in 2014. Although natural variability dominates, anthropogenic warming has substantially increased the overall likelihood of extreme California droughts.

1. Introduction

During 2012–2014, drought in California (CA) caused water use restrictions, rapid drawdown of groundwater reserves [*Famiglietti*, 2014; *Harter and Dahlke*, 2014], fallowed agricultural fields [*Howitt et al.*, 2014], and ecological disturbances such as large wildfires and tree mortality [e.g., *Moore and Heath*, 2015; *Worland*, 2015]. The ultimate cause of the recent drought was a persistent ridge of high atmospheric pressure over the Northeast Pacific that blocked cold-season storms from reaching CA and stifled precipitation totals [e.g., *Seager et al.*, 2015]. Tree ring reconstructions from CA indicate that the resultant 3 year precipitation shortfall of 2012–2014 has been matched less than once per century over the past several hundred years [*Griffin and Anchukaitis*, 2014; *Diaz and Wahl*, 2015]. Dynamical studies agree that the Northeast Pacific ridge that caused the precipitation shortfall was part of an atmospheric wave train originating from the western tropical Pacific due to warm sea surface temperatures (SSTs) in that region [*Funk et al.*, 2014; *Seager et al.*, 2014a, 2015; *Wang and Schubert*, 2014; *Wang et al.*, 2014; *Hartmann*, 2015]. The observed ridging anomaly was stronger than the modeled response to tropical SST forcing [e.g., *Wang and Schubert*, 2014; *Seager et al.*, 2015], however, and leaves room for contributions from internal atmospheric variability or anthropogenic climate change. Although it has been suggested that anthropogenic emissions enhance the probability of *extreme* Northeast Pacific ridging events without necessarily affecting the long-term mean state [*Swain et al.*, 2014; *Wang et al.*, 2014, 2015], model projections of increased extremes in cold-season precipitation totals do not emerge as relevant until the second half of this century [*Berg and Hall*, 2015]. Furthermore, observed CA precipitation totals indicate no long-term trend despite cooccurring increases in western tropical Pacific SSTs [*Seager et al.*, 2015], climate models do not produce negative CA precipitation trends when forced by observed SST trends [*Funk et al.*, 2014], and future anthropogenic climate change is projected to result in slight *positive* trends in CA precipitation totals [*Neelin et al.*, 2013; *Seager et al.*, 2014b, 2015; *Simpson et al.*, 2015], all arguing against the likelihood of an anthropogenic role in the recent CA precipitation shortfall.

Importantly, there is widespread consensus that warmth has intensified the effects of the recent precipitation shortfall by enhancing potential evapotranspiration (PET) [*AghaKouchak et al.*, 2014; *Griffin and Anchukaitis*, 2014; *Diffenbaugh et al.*, 2015; *Mann and Gleick*, 2015; *Shukla et al.*, 2015]. Because warming is a well-understood and robustly modeled response to anthropogenic emissions of greenhouse gases, it is expected that warming-induced drying will continue for centuries to come [e.g., *Cook et al.*, 2015; *Diffenbaugh et al.*, 2015]. However, the degree to which anthropogenic warming and resultant increases in PET were responsible for the recent drought severity in CA is unknown.

Griffin and Anchukaitis [2014] used the Palmer Drought Severity Index (PDSI), a proxy for near-surface soil moisture [*Palmer*, 1965], to investigate the role of temperature in the recent drought, but they did not separate the influence of anthropogenic warming from natural temperature variability and their employed version of PDSI (from the National Oceanic and Atmospheric Administration (NOAA)) uses a simplified formulation of PET. *Mao et al*. [2015] attempted to isolate the anthropogenic component of warming using a more physically based PET calculation but focused only on the Sierra Nevada Mountain region and spring snowpack, and simply characterized anthropogenic warming as the observed linear trend in daily minimum temperatures. Other studies investigate the effect of warming on the likelihood of severe drought events in CA [e.g., *AghaKouchak et al*., 2014; *Diffenbaugh et al*., 2015; *Shukla et al*., 2015] but do not directly address the anthropogenic contribution to recent drought severity. Each study noted above considers only a single climate data product without addressing the structural uncertainty across different data products.

Here we quantify the severity of recent CA drought using an ensemble of data products and multiple PDSI formulations, determine the relative roles of individual components of the water balance, and determine the proportion of recent drought severity that can be attributed to increases in PET due to anthropogenic warming.

2. Methods

2.1. Palmer Drought Severity Index

We calculate monthly PDSI to characterize temporal and spatial variations in CA drought from 1901 to 2014: most humidity, wind speed, and insolation data sets do not extend prior to 1901. The PDSI is based on a simple two-layer soil moisture model and is locally normalized to reflect moisture anomalies relative to long-term mean conditions. PDSI is a primary tool used for drought monitoring in the United States [*Heim*, 2002; *Svoboda et al*., 2002] and generally agrees well with modeled and observed soil moisture anomalies [*Dai et al*., 2004; *Cook et al*., 2015; *Smerdon et al*., 2015; *Zhao and Dai*, 2015] and tree ring records [*Cook et al*., 2007]. While some recent studies have taken more complex modeling approaches to investigate the recent CA drought [*Mao et al*., 2015; *Shukla et al*., 2015], we use the PDSI because it allows efficient calculations of centennial-length records at high spatial resolution, which can be computed many hundreds of times with different climate variables, input data sets, and methodological schemes. The PDSI only reflects drought variability from a climatological perspective. Our results therefore do not explicitly reflect human water demand, stream flow and reservoir storage, or accessibility of groundwater. The PDSI also considers all precipitation to occur as rain, neglecting snow storage and subsequently delayed inputs to soil moisture and runoff. To assess implications of this latter simplification, PDSI is compared to modeled soil moisture by *Mao et al*. [2015] for the snow-dominated Sierra Nevada mountains.

Other studies also have used the PDSI to examine recent CA drought [*Griffin and Anchukaitis*, 2014; *Diffenbaugh et al*., 2015; *Robeson*, 2015]. A key difference between these studies, which use data developed by NOAA, and our study is the formulation of PET. The NOAA calculations involve the simplified Thornthwaite formula [*Thornthwaite*, 1948] that considers monthly mean temperature to be the only climatological driver of PET variability. This approach can overemphasize the influence of warmth when temperatures are high, and further inaccuracies are introduced by ignoring the nontemperature components of PET [e.g., *Hobbins et al*., 2008; *Hoerling et al*., 2012; *Sheffield et al*., 2012]. The more physically based Penman-Monteith (PM) formula [*Penman*, 1948; *Monteith*, 1965] considers the suite of variables affecting PET: mean daily maximum temperature (T_{max}), mean daily minimum temperature (T_{min}), humidity, wind speed, and net radiation. We use the PM formula and repeat calculations using Thornthwaite in some cases for comparison. Additionally, we use the newer self-calibrated PDSI ($PDSI_{sc}$), developed to make drought severity comparable among locations [*Wells et al*., 2004].

Consistent with several prior studies [e.g., *Cook et al*., 2004, 2007, 2010; *Griffin and Anchukaitis*, 2014], we focus on June–August (JJA). $PDSI_{sc}$ is an integration of hydroclimate over multiple months to several years [*Guttman*, 1998] and summer is the ideal season for characterizing drought intensity in CA for two reasons: (1) it is when drought effects tend to be most critical; and (2) it is when $PDSI_{sc}$ is most accurate in mountain regions because snowpack has melted or is at a minimum [e.g., *Dai et al*., 2004]. To facilitate interpretation, each grid cell's annual record of JJA $PDSI_{sc}$ is normalized so that two $PDSI_{sc}$ units equal a 1 standard deviation departure from the 1931–1990 mean, retaining a similar variance in the records of JJA $PDSI_{sc}$ as is in the

monthly records. Again for interpretability, we renormalize statewide mean JJA $PDSI_{sc}$ records. We use a 1931–1990 calibration interval in all $PDSI_{sc}$ calculations to be consistent with NOAA methodology.

2.2. Climate Data

We calculate $PDSI_{sc}$ records for all 432 combinations of four precipitation, four temperature, three vapor pressure, three wind speed, and three insolation data sets. Data sets are listed with references in Table S1 in the supporting information and described in Text S1. We bilinearly interpolate each monthly climate field for each data set to the spatial resolution of the PRISM data set (0.04167°) [*Daly et al*., 2004]. For each climate variable, data sets were calibrated so that climatological means and variances match during 1961–2010 (see Text S1). Uncertainties are high for humidity, wind speed, and insolation because they are largely based on models or observations of other variables [e.g., *Dai*, 2011]. Although consideration of multiple data products helps to characterize some of this uncertainty, data products are not all produced independently. Errors therefore may be recurrent in multiple data products (see Text S1).

2.3. Decomposition of PET and $PDSI_{sc}$

We calculate the influence of a given variable, or subset of variables, on PET as the PET anomaly calculated while holding all other variables at their mean annual cycles [e.g., *Cook et al*., 2014; *Scheff and Frierson*, 2014; *Zhao and Dai*, 2015]. Mean annual cycles were always defined over 1961–2010. For $PDSI_{sc}$, the contribution of precipitation was defined as $PDSI_{sc_P}$, calculated by holding PET at its mean annual cycle and only allowing precipitation to vary. The contribution of PET was calculated as the difference between $PDSI_{sc_P}$ and a recalculation of $PDSI_{sc}$ in which both precipitation and PET vary. We isolated the influences of the temperature and nontemperature components of PET by applying versions of PET in which only the component of interest varies. Contributions of subcomponents of PET and $PDSI_{sc}$ anomalies were nearly perfectly additive, but all relative anomalies were rescaled to sum to exactly 100% of the total anomaly.

2.4. Effect of Anthropogenic Warming

Anthropogenic warming was isolated from that of natural temperature variability by considering four warming scenarios that are described in detail in the next two paragraphs. For each scenario, natural temperature variability is calculated as the observed temperature minus the anthropogenic trend. All records of anthropogenic warming and natural variability were calculated independently for T_{max} and T_{min}, each grid cell, and each month. For each warming scenario, we recalculated PET twice: once considering only the anthropogenic warming record and once considering the residual record of natural temperature variability. Methods were repeated from above to assess $PDSI_{sc}$ anomalies caused by anthropogenic warming and natural temperature variability.

The four anthropogenic warming scenarios are defined as follows: (1) linear trend, (2) 50 year low-pass filter (using a 10-point butterworth filter), (3) unadjusted mean trend from an ensemble of climate models, and (4) an adjusted version of #3. The first two warming scenarios represent empirical fits to the observed temperature records during 1895–2014. Although a linear trend is commonly used to represent the anthropogenic effect, a linear fit to a centennial temperature record may underestimate the human effect on temperature in recent decades because radiative forcing during this period has increased relatively rapidly [e.g., *Myhre et al*., 2013]. The 50 year low-pass filter partially addresses this issue, but multidecadal natural temperature variability inhibits complete isolation of the anthropogenic effect with either the linear trend or the 50 year filter. Additionally, trends toward the end of the 50 year filter record are affected by boundary constraint assumptions. Although continued warming is likely, we pad the end of the temperature record with a repetition of the last 25 years in reverse order, likely leading to an underestimation of anthropogenic warming in the most recent years.

In the third and fourth warming scenarios, we use modeled records of T_{min} and T_{max} produced for the Coupled Model Intercomparison Project Phase 5 (CMIP5) [*Taylor et al*., 2012] to represent anthropogenic warming trends for each month. Thirty-six models in the CMIP5 archive are used, based on the availability of T_{max} and T_{min} data for the historical (1850–2005) and future (2006–2099, RCP 8.5 [*van Vuuren et al*., 2011]) simulations. For each model, T_{min} and T_{max} are each averaged across all available runs for the historical and future periods, bilinearly interpolated to the geographic resolution of PRISM, and bias corrected for each grid cell so that monthly means during 1961–2010 matched observational means. We calculate 50 year low-pass filtered time series for each month during 1850–2099 and average across the 36 models. The resultant ensemble mean records for 1895–2014 represent the CMIP5 records of anthropogenic warming used in the

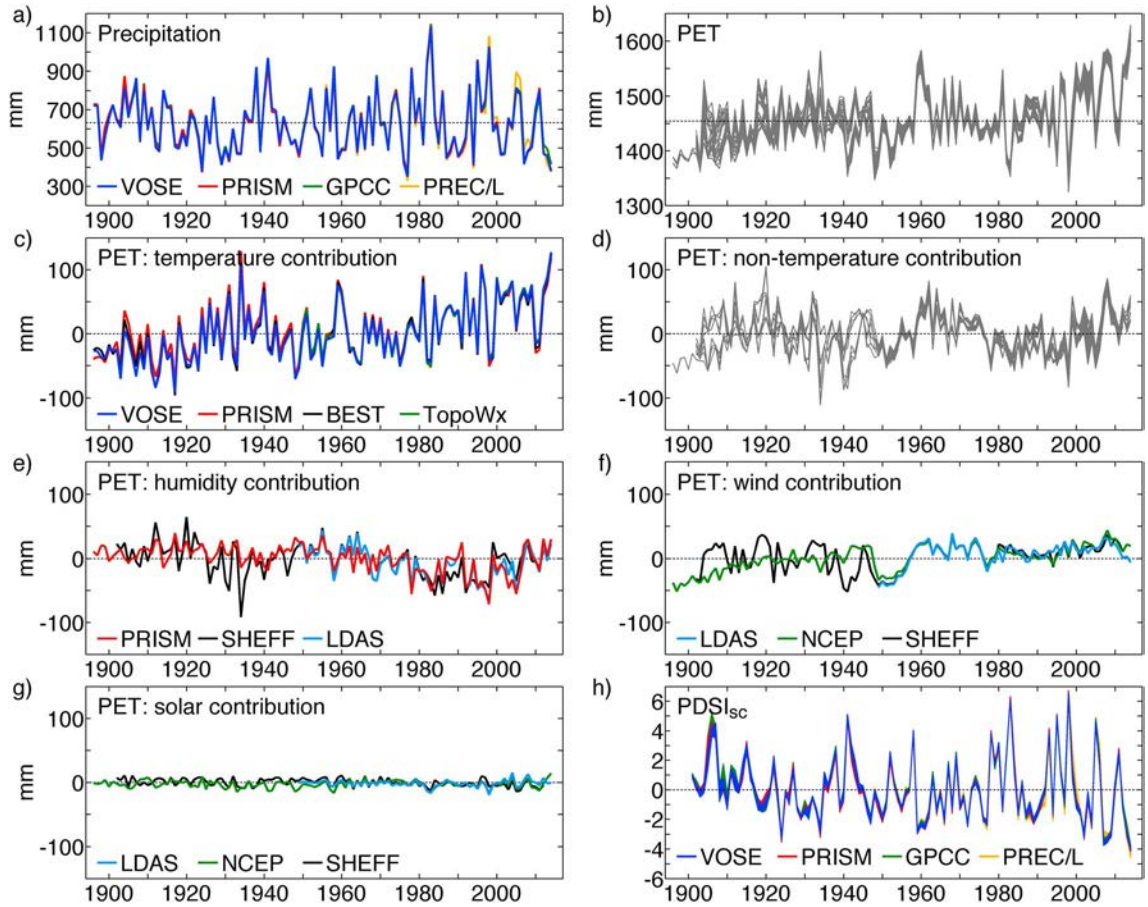

Figure 1. Contributors to interannual (water year) drought variability in CA, calculated from multiple data sets. (a) Precipitation. (b) PET totals, calculated using the PM equation for all combinations of four temperature, three humidity, three wind velocity, and three insolation data sets. (c) Temperature contribution to PET anomalies. Contributions of (d) all nontemperature variables, (e) humidity, (f) wind velocity, and (g) insolation to PET anomalies. (h) JJA $PDSI_{sc}$ calculated with all 432 combinations of the climate-variable data sets. Horizontal black lines: 1931–1990 means. Colors distinguish data products.

third warming scenario. For the fourth scenario, we linearly adjust these records to best fit the observations from 1895 to 2014. This approach reduces biases in the modeled trends but carries the implicit assumption that observed temperature trends are entirely anthropogenic in origin, which is a questionable assumption. For example, *Johnstone and Mantua* [2014a] indicate that some of the observed warming trend may be due to warming in the Northeast Pacific that is not linked to anthropogenic climate change, but also see *Abatzoglou et al*. [2014] and *Johnstone and Mantua* [2014b].

3. Results and Discussion

3.1. Recent Drought Conditions

Figure 1a shows annual water year (WY: October–September) CA precipitation totals for 1896–2014 and demonstrates general agreement among the four gridded data sets. The WY 2014 precipitation total was the third lowest (fourth lowest for Global Precipitation Climatology Centre (GPCC) [*Schneider et al*., 2014]) on record (behind WYs 1977 and 1924) and WY 2012–2014 precipitation was the lowest (third lowest for GPCC) 3 year running average on record (Figure S1a). The effects of the recent precipitation deficit have been amplified by positive PET anomalies. Figure 1b shows the 108 records of WY PET, calculated from all combinations of temperature, humidity, wind, and insolation data sets. Among the PET records, 32 include data for 2014. WY 2014 PET was 9–12% above average and the highest on record in every case. PET for WY 2012–2014 was 7–9% above average and either the highest or second highest (behind WY 2007–2009) on record (Figure S1b).

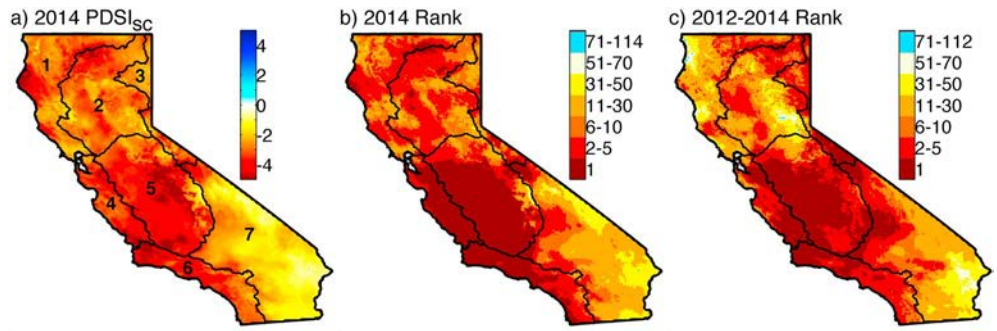

Figure 2. Maps of (a) JJA PDSI$_{sc}$ and ranking for (b) 2014 and (c) 2012–2014. Rankings are based on all years between 1901 and 2014, and a ranking of 1 indicates record-breaking drought. PDSI$_{sc}$ in this figure is based on VOSE precipitation and temperature, PRISM humidity, and LDAS [*Mitchell et al.*, 2004; *Rodell et al.*, 2004] wind speed and insolation. Polygons bound the seven NOAA climate divisions (division numbers shown in Figure 2a).

All PET data sets indicate positive and significant trends during WY 1949–2014, ranging from 8.2 to 13.7 mm/decade when considering linear trends. These trends are almost entirely due to warming. Since WY 1949, warming positively forced PET by 10–12 mm/decade (65–82 mm total), equivalent to 10–13% of the mean WY precipitation (Figure 1c). The VOSE [*Vose et al.*, 2014], BEST [*Rohde et al.*, 2013], and TopoWx (which only goes back to 1948 [*Oyler et al.*, 2015]) data sets indicate that the temperature contribution to PET was highest on record in 2014 while PRISM indicates that the temperature contribution was higher in 1934. All four data sets agree that the temperature contribution to PET during WY 2012–2014 was substantially higher than that of any other 3 year period on record (Figure S1c).

Nontemperature variables account for approximately one third of WY PET variability (Figure 1d), although much uncertainty exists among the nontemperature data sets. Nearly all interannual variability and inter–data set spread in nontemperature PET (Figure 1d) are due to contributions from vapor pressure and wind speed (Figures 1e–1g). According to the data sets considered, positive wind speed trends contributed positively to PET (4.5 to 4.8 mm/dec), positive humidity trends contributed negatively (−3.5 to −4.0 mm/dec), and insolation had a minimal influence due to very low interannual variability in warm-season insolation relative to the mean. Prior to 1948, trends in the nontemperature components of PET are much less certain due to a nearly complete lack of pre-1948 observational data [e.g., *Dai*, 2011].

Within CA, PET trends were spatially heterogeneous, with much of the Central Valley experiencing reduced PET during the second half of the twentieth century due to suppressed daytime warming and increased humidity, consistent with the effects of increased irrigation [*Lobell and Bonfils*, 2008]. These results are broadly consistent with observed decreases in warm-season pan evaporation at sites in the Central Valley during 1951–2002 [*Hobbins et al.*, 2004]. These agricultural trends appear distinct from the well-known global declines in pan evaporation that appear to have been caused by pollution-induced solar dimming during the 1950s–1980s and reductions in wind speed [*Roderick et al.*, 2009]. While long-term records of insolation and wind speed are sparse in CA, those that exist indicate insignificant wind trends of inconsistent sign [*Pryor et al.*, 2009; *Pryor and Ledolter*, 2010] and twentieth century insolation decreases that were too small to substantially affect statewide mean PET, similar to prior findings in Australia [*Roderick et al.*, 2007].

Figure 1h shows all 432 records of JJA PDSI$_{sc}$ for 1901–2014 (128 records extend through 2014). Colors in Figure 1h indicate the precipitation product; spread among colors reflects disagreement among precipitation products and spread within colors reflects disagreement among PET products. All records indicate that 2014 JJA PDSI$_{sc}$ was the lowest on record (−4.64 to −3.67), with 25–37% of CA experiencing record-breaking drought locally. The year 2014 had the highest proportion of record-breaking drought area on record for all data sets, with the most severe anomalies centered in the southern Central Valley and the central and southern CA coasts (Figures 2a and 2b).

Considering 3 year running average PDSI$_{sc}$, 2012–2014 JJA drought intensity was found to be similar to, but generally not as severe as, that of 2007–2009 when averaged across CA, regardless of data sets used (Figure S1h). The similarity of mean PDSI$_{sc}$ during these two periods is interesting given that WY 2012–2014 had the lowest precipitation total on record and PET levels were comparable during each period. The difference

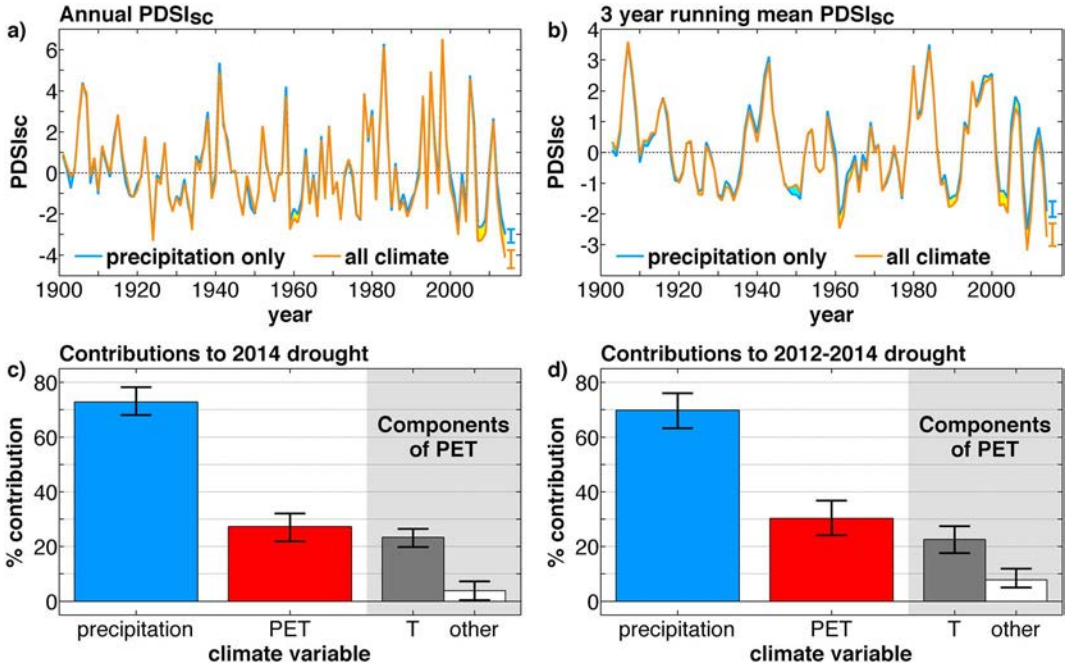

Figure 3. Contributions of precipitation and PET to drought variability. (a) Annual and (b) 3 year running mean JJA $PDSI_{sc}$ records calculated when (blue) only precipitation is allowed to vary from the climatological mean and (orange) when both precipitation and PET vary. Thus, departures of the blue line from zero are due to precipitation variability and departures of the orange line from the blue line are due to PET variability. Shading between lines in Figures 3a and 3b indicate periods when (cyan) low PET reduces drought and (yellow) high PET intensifies drought. Percent contributions of precipitation and PET to the (c) 2014 and (d) 2012–2014 $PDSI_{sc}$ anomalies. The bars in the shaded area of Figures 3c and 3d break the contribution of PET into contributions from temperature (*T*) and nontemperature (other: humidity, wind, and solar). Time series and bars represent mean conditions across all combinations of climate data products and whiskers bound all values from all combinations of data products.

was in the timing of precipitation. Unlike the 2012–2014 drought, which intensified over time, the 2007–2009 drought was most intense at the onset and the moisture deficit established in 2007 partially propagated into 2008 and 2009. Additionally, spring months for WY 2012-2014 were generally wetter than WY 2007–2009, contributing to soil moisture at a critical time immediately prior to summer (Figure S2).

The finding that the 2012–2014 $PDSI_{sc}$ was not as severe as that of 2007–2009 conflicts with prior findings based on NOAA PDSI (which is based on VOSE precipitation and temperature) that 2012–2014 was the most severe 3 year drought on record in CA [*Griffin and Anchukaitis*, 2014; *Robeson*, 2015]. This is attributable to the NOAA calculation of PDSI, which amplifies the effect of extreme heat anomalies in 2014 via the Thornthwaite PET equation (Figures S3 and S4). Importantly, while our calculations indicate that 2012–2014 was probably not a record-breaking drought event when averaged across CA, 2012–2014 drought severity *was* record breaking in much of the agriculturally important Central Valley (Figure 2c). In contrast, drought in 2007–2009 was most severe in the sparsely populated and already dry desert region of southeastern CA.

$PDSI_{sc}$ does not account for snowpack effects, which are important for human water supply, and our calculations of statewide $PDSI_{sc}$ may therefore not always accurately reflect drought from the perspective of human water supply, which is disproportionately linked to the Sierra Nevada Mountains. For that region, *Mao et al.* [2015] used the Variable Infiltration Capacity (VIC) hydrologic model [*Liang et al.*, 1994] to simulate hydrological dynamics during 1920–2014. Using the *Mao et al.* [2015] meteorological forcing to calculate $PDSI_{sc}$ for the Sierra Nevada Mountains, we find strong agreement ($r = 0.93$) with VIC JJA soil moisture (Figure S5). VIC soil moisture nevertheless indicates slightly more severe drought than $PDSI_{sc}$ during the most extreme drought years, likely due to early disappearance of snowpack [e.g., *Mote*, 2006; *Mankin and Diffenbaugh*, 2015] and subsequently reduced spring and summer melt-driven soil moisture inputs (Figure S6). Given that the calculation of $PDSI_{sc}$ neglects snowpack and therefore cannot capture the effect of early snowmelt on summer soil moisture, the warming effect on summer $PDSI_{sc}$ presented in the next section is likely conservative for snow-dominated areas.

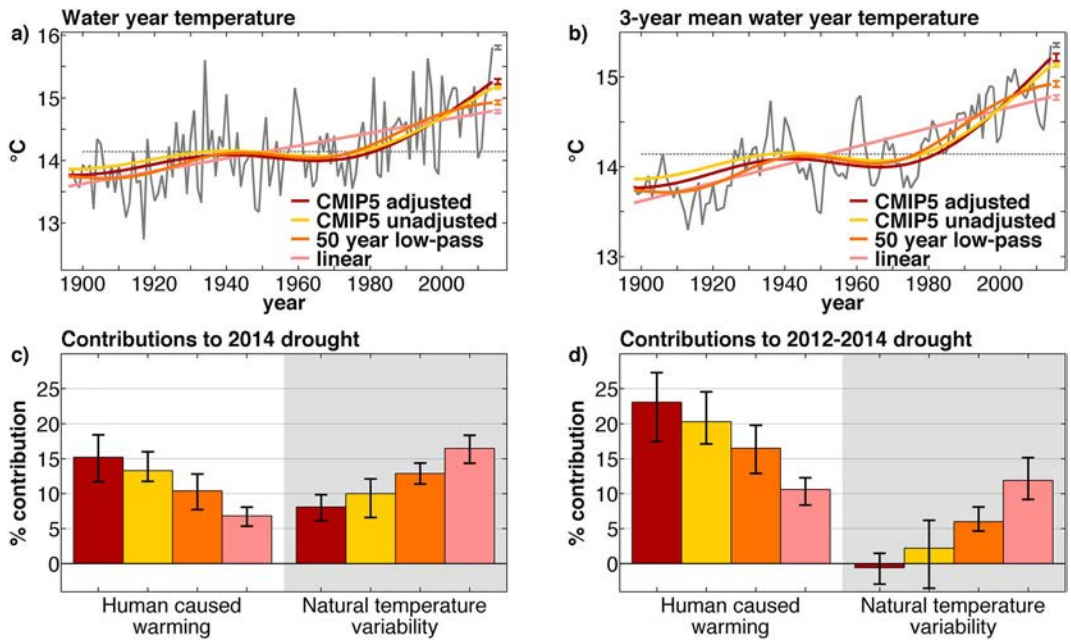

Figure 4. Contributions of anthropogenic warming and natural temperature variability to recent temperature and drought. (a) Annual and (b) 3 year running water year temperature records with four alternate scenarios of anthropogenic warming. Contributions of anthropogenic warming versus natural temperature variability to (c) 2014 and (d) 2012–2014 JJA $PDSI_{sc}$ anomalies, where bar colors correspond to the colors of the four anthropogenic warming trends in Figures 4a and 4b. For each of the anthropogenic warming scenarios, natural temperature variability is calculated as the observed temperature minus the warming trend. All time series and bars represent mean conditions across all combinations of climate products. Whiskers bound all values for all combinations of data products.

3.2. Effect of Warming on Recent Drought

Figures 3a and 3b compare $PDSI_{sc}$ (orange) to an alternate calculation in which only precipitation varies and PET is held at its mean annual cycle (blue). While there is no long-term trend in precipitation-driven $PDSI_{sc}$ since 1948 or 1901, trends in actual $PDSI_{sc}$ are significant and negative ($p < 0.05$ according to Spearman's Rho and Kendall's Tau) due to increasing PET. During 2014 and 2012–2014, PET anomalies accounted for 22–32% and 24–37% of the JJA $PDSI_{sc}$ anomalies, respectively (Figures 3c and 3d). Recalculating $PDSI_{sc}$ considering the temperature and nontemperature components of PET separately, we find that the intensifying effect of high PET on recent drought was nearly entirely caused by warmth (Figures 3c and 3d). High temperatures accounted for 20–26% and 18–27% of the JJA $PDSI_{sc}$ anomalies in 2014 and 2012–2014, respectively (Figures 3c and 3d).

The contribution of temperature is further separated into contributions from natural temperature variability and anthropogenic warming in Figure 4. Figures 4a and 4b show the WY temperature record and the four anthropogenic warming scenarios, which indicate an anthropogenic warming contribution in WY 2014 of 0.61–1.27°C relative to the 1931–1990 mean. The empirically derived trends suggest a weaker anthropogenic warming contribution in recent years than the CMIP5 trends because (1) the linear trend does not account for the nonlinear increase in anthropogenic forcing and (2) the 50 year low-pass filter trend indicates slowed warming in the past two decades that is partly due to our conservative smoothing approach and partly due to decadal climate variability. The CMIP5 trends represent the nonlinear increase in radiative forcing without being affected by decadal climate variability or smoothing artifacts. The similarity between the adjusted and unadjusted CMIP5 warming trends suggest that the CMIP5 provides a reasonable representation of the anthropogenic warming influence in CA despite having stronger warming trends than the conservatively designed empirical trends.

Breaking the temperature contributions to $PDSI_{sc}$ into anthropogenic and natural components, the four anthropogenic warming trends account for 5–18% of the JJA $PDSI_{sc}$ anomaly in 2014 and 8–27% of the anomaly in 2012–2014 (Figures 4c and 4d). Despite differences in these relative contributions of warming

to drought during 2014 versus 2012–2014, the *absolute* contributions of anthropogenic warming to drought during these two periods were virtually identical. The absolute anthropogenic contribution does not change much interannually but instead acts as a gradually moving drought baseline upon which the effects of natural climate variability are superimposed (Figure S7a).

As of 2014, the anthropogenic warming forcing accounted for approximately −0.3 to −0.7 standardized $PDSI_{sc}$ units, depending on the anthropogenic warming scenario and combination of climate data sets considered (Figure S7a). To illustrate how this trend in background drought conditions affected the probability of severe drought as of 2014, we compare the probability distribution of 1901–2014 $PDSI_{sc}$ values calculated in the absence of anthropogenic warming to the same distributions shifted negative by 0.46, the 2014 $PDSI_{sc}$ forcing by the 50 year low-pass filter warming trend (Figure S7b, based on VOSE temperature and precipitation data). Comparing the two distributions, we find that severe summer droughts with $PDSI_{sc} \leq -3$ were approximately twice as likely under 2014 anthropogenic warming levels (Figure S7c). Although uncertainty in probabilities of extreme events is large when based on observed records [e.g., *Swain et al*., 2014], and the anthropogenic trend may not result in a perfectly uniform shift in the $PDSI_{sc}$ distribution, this analysis illustrates the general fact that the anthropogenic drying trend, while still small relative to the range of natural climate variability, has caused previously improbable drought extremes to become substantially more likely, consistent with the conclusions of other recent studies [e.g., *AghaKouchak et al*., 2014; *Cook et al*., 2015; *Diffenbaugh et al*., 2015; *Shukla et al*., 2015; *Williams et al*., 2013, 2014, 2015].

Regarding anthropogenic contributions, there are some important caveats. First, anthropogenic climate change has potentially affected more than just temperature in CA [e.g., *Swain et al*., 2014; *Wang et al*., 2014, 2015]. Lack of long-term observational data on wind speed and humidity in CA, and uncertainties in existing data, make it difficult to quantify anthropogenic influences on these variables. For CA precipitation, current models project a weak overall increase [*Neelin et al*., 2013; *Seager et al*., 2014b, 2015; *Simpson et al*., 2015], but no such precipitation trend has emerged. Hence, we only characterize anthropogenic effects on temperature in this study. Second, observed warming trends are affected by processes not related to greenhouse gas emissions such as land use (e.g., agriculture, urbanization) and natural low-frequency climate variability. While climate models provide a definition of anthropogenic warming that should be unbiased by observations, the accuracy of this approach, as in other attribution studies [e.g., *Bindoff et al*., 2013], is confined by the accuracy of climate models. Finally, our analyses do not account for snowpack, making our results a likely underestimation of the contribution of heat anomalies to recent drought in snow-dominated mountain areas and should be interpreted conservatively regarding the effects of warming on water resources for systems strongly affected by the timing of seasonal runoff from mountains.

4. Conclusions

Anthropogenic warming has intensified the recent drought as part of a chronic drying trend that is becoming increasingly detectable and is projected to continue growing throughout the rest of this century [e.g., *Cook et al*., 2015]. As anthropogenic warming continues, natural climate variability will become increasingly unable to compensate for the drying effect of warming. Instead, the soil moisture conditions associated with the current drought will become increasingly common. Impacts of drought on society may be increasingly intensified due to declining availability of groundwater reserves [e.g., *Famiglietti*, 2014]. The Central Valley may be particularly vulnerable to warming-driven drought if reductions in water supply cause reductions in irrigation, as irrigation has slowed warming in this region [*Lobell and Bonfils*, 2008]. The dramatic effects of the current drought in CA, combined with the knowledge that the background warming-driven drought trend will continue to intensify amidst a high degree of natural climate variability, highlight the critical need for a long-term outlook on drought resilience, even if wet conditions soon end the current drought in CA.

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