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ABSTRACT

Basis risk or residual risk arising from disparity between an index's estimate of losses and actual losses is inherent in index-based insurance products. We approximate basis risk as the false negative probability (FNP) within pasture, rangeland, and forage (PRF) rainfall index insurance for the south-central coastal region of California. We estimate the FNP on average that at least one of two selected coverage intervals will fail to provide an indemnity when a loss is realized at 48%. The average FNP is reduced to only 11% when considering whether both selected intervals fail to provide an indemnity when a loss is realized.

KEYWORDS

false negative probability, index insurance, PRF insurance

INTRODUCTION

Risk-averse farmers and ranchers frequently rely on crop insurance products to mitigate financial risks. For producers looking to offset risk associated with production on pastures and rangelands, the Risk Management Agency (RMA) of the United States Department of Agriculture (USDA) offers pasture, rangeland, and forage (PRF) insurance based on a rainfall index to determine coverage. Indexes within index-based insurance products are often based on relatively easily observable and verifiable factors. This is an attractive feature of these insurance products as it has the potential to reduce moral hazard (Cheng, 2013; Elabed et al., 2013). Moral hazard refers to the idea that often those insured against risk act differently in some way than if they were not insured. It can include careless, irresponsible, or even fraudulent behaviors of the insured to increase the likelihood of a favorable outcome (indemnity payout). Using a rainfall index to characterize underlying production yields within PRF insurance prevents the need for cumbersome gathering of the individual insureds' yield data and disincentivizes the insured from succumbing to moral hazard.

As with all index-based insurance products, however, basis risk arises when the index measurements do not correlate well with actual losses. As basis risk increases for an insurance product, its effectiveness at insuring against losses decreases. Producers clearly understand this concept: The level of basis risk associated with index insurance policies has been shown to be inversely related to policy demand (Clarke, 2016; Clement et al., 2018; Elabed et al., 2013; Giné et al., 2013; Hill et al., 2013). Estimating the level of basis risk associated with any index-based insurance product, therefore, is necessary to help policy makers understand participation rates (demand) and inform producers of the risks inherent in a product. However, research addressing the level of basis risk associated with PRF insurance is limited. Among the most relevant studies are those of Maples, Brorsen, and Biermacher (2016), Yu et al. (2019), and Keeler and Saitone (2022).

Maples, Brorsen, and Biermacher (2016) evaluated the effectiveness of the rainfall index annual forage program (RIAFP) as a risk management tool for cool-season forage within the Oklahoma region. Their study focused on determining how closely yields follow the RMA rainfall index used to trigger indemnity payoffs in the RIAFP. While this is a different insurance program from PRF insurance, it relies on the same rainfall index and provides evidence of the effectiveness of the index to insure against actual losses. These authors conclude that (1) the rainfall index is well designed, correlates well with actual rainfall, and should be adequate at insuring against dry years; and (2) for their data, the rainfall index does little to provide yield risk protection (suggesting high basis risk) as the rainfall index was not correlated well with forage yield.

Yu et al. (2019), as well as Keeler and Saitone (2022), estimated the false negative probability (FNP) within PRF insurance as an approximation for basis risk associated with the product. Both of their approaches followed closely with the FNP calculation as demonstrated by Elabed et al. (2013). The FNP is defined as the probability that an indemnity would not be triggered given that based on the perceived loss an indemnity was warranted.

The objective of this study is to estimate basis risk for PRF insurance for 12 sites located within 50 miles of the coast in south-central California in San Luis Obispo County. The basis risk will be approximated by calculating the FNP both when using the index-level rainfall data as well as when using site-level rainfall data. A comparison of the FNPs can suggest whether there is potential for basis risk reduction if PRF contracts were restructured to allow use of site-level rainfall data.

Relevant Literature

Yu et al. (2019) and Keeler and Saitone (2022) both approximated PRF insurance basis risk as the FNP associated with the product. While the stated objectives of these studies were quite similar, they differed in methods as well as geographical region.

Yu et al. (2019) took a regression approach to estimate the basis risk associated with PRF insurance using forage and rainfall data from three university research stations in Kansas and Nebraska. They estimated the FNP for PRF insurance to be approximately 26% and found that using site-level precipitation data could reduce the FNP by 5%-9. These authors suggested similar studies in other regions could provide beneficial comparisons and add robustness to their findings.

Noting the Yu et al. (2019) study as the lone study investigating PRF basis risk, Keeler and Saitone (2022) estimated basis risk (FNP) for rangelands across the state of California. They, however, took a nonregression approach to basis risk estimation. They relied on the Normalized Difference Vegetative Index (NDVI) to characterize actual forage production (site-level yield) and compared this to the rainfall index to make their FNP calculations.

The NDVI is an index of a remotely sensed measure of vegetation to absorb photosynthetically active radiation. By using the NDVI within the estimation for PRF insurance basis risk, the researchers implicitly accepted that the basis risk connected with the NDVI itself when used to characterize yield would be attributed to the PRF insurance basis risk. Given the scarcity of reliable site-specific yield data, a study encompassing the geographic size of that in Keeler and Saitone's (2022) study would be an impossible task without using the NDVI to characterize forage yield. Estimating basis risk for an area that large is an important contribution of these researchers' work and adds significantly to the limited literature on PRF insurance basis risk. By calculating the FNP, using actual yield measurements rather than the NDVI as a proxy for yield, the potential basis risk of using NDVI to characterize yield can be eliminated. Of course, the yield values in our data are only estimates obtained by cutting, drying, and weighing forage samples during peak production within the forage monitoring sites. Therefore, while they are expected to be good overall estimates of forage yield, they are not expected to be completely free of variance from actual production yield.

We contribute significantly to the area of PRF insurance basis risk estimation by estimating the FNP in a similar fashion as Keeler and Saitone (2022) adapted to use actual site-level yield and rainfall data. The use of site-level data in estimating PRF basis risk for California rangelands is an important contribution of our study as it enables us to avoid implicitly adding noise to the basis risk estimates, which could be a concern when relying on the NDVI to characterize site-level yields. The resulting basis risk estimates will help producers make informed coverage selections as well as demonstrate whether PRF basis risk can be reduced through use of site-level rainfall data.

PRF insurance has been growing in popularity among producers at a very rapid rate over the last several years. For the entire United States 52,827 policies were sold covering approximately 248 million acres for 2022. This is an increase of 108% in policies and 382% in acres insured since 2016. Within California, the growth has been similar to the national average. For 2022, 1,462 policies were sold covering nearly 10.4 million acres. Within San Luis Obispo County, growth has outpaced the national average. Policies sold have increased by 290% (82 policies in 2022), and acres insured increased by 419% to 540,000 total acres in 2022 (USDA, RMA, 2022). This rapid growth of the program helps to motivate this additional research into estimating basis risk within the Mediterranean climate that predominantly characterizes the Californian rangelands. As producer demand increases for the program, it is important that they are aware of the basis risk associated with the program to adjust their expectations and aid them in making informed coverage selections to best meet their needs and individual risk management plans.

MATERIALS AND METHODS

The site-specific data, both yield and rainfall, for this study comes from 12 individual forage monitoring sites in the California south-central coast region (San Luis Obispo County) from 2001 to 2019. This forage monitoring project is referred to as the San Luis Obispo Forage Production, Ecosystem Services Project (Larsen et al., 2020). The project started in response to the United States Department of Agriculture, Farm Service Agency's (FSA) need to have data to back up drought declarations within the region. Table 1 contains the names of the 12 sites as well as the year data were first collected for each site. Additionally, each site is assigned a number (displayed in Table 1), which is placed in its approximate geographic location within Figure 1. The oldest sites were initiated in 2001. Data collection at the newest sites began as late as 2010.

Each site consists of four exclosures (see the appendix for a description). Total forage production was measured each spring by clipping three

Table 1. Site Descriptions for the Forage Monitoring Sites in San Luis Obispo Forage Production, Ecosystem Services Project

Site #	Site Name	Year Started	Soil Name	Elevation (ft.)	Distance from Coast (mi)
1	Adelaida	2001	Dibble	1060	19.0
2	Camatta	2001	Balcom-Nacimiento	1665	35.0
3	Cambria	2001	Tierra	440	2.5
4	Carrizo	2001	Belly Spring Panoza	2600	50.0
5	Huasna	2001	Los Osos–Diablo Complex	520	9.5
6	Morro Bay S	2001	Cropley Clay	90	2.5
7	Shandon	2003	Nacimiento–Los Osos	1920	38.0
8	Bitterwater	2004	Choice Silty Clay	2060	44.0
9	Soda Lake	2004	Panoza-Beam	2650	48.0
10	Creston	2010	Arbuckle-Positas	1190	22.0
11	Pozo	2010	Xerofluvents- Xerorthents	1580	23.0
12	Morro Bay N	2010	Cropley Clay	90	2.5

Note: The site numbers correspond to Figure 1, which shows the general locations of the sites on a regional map.

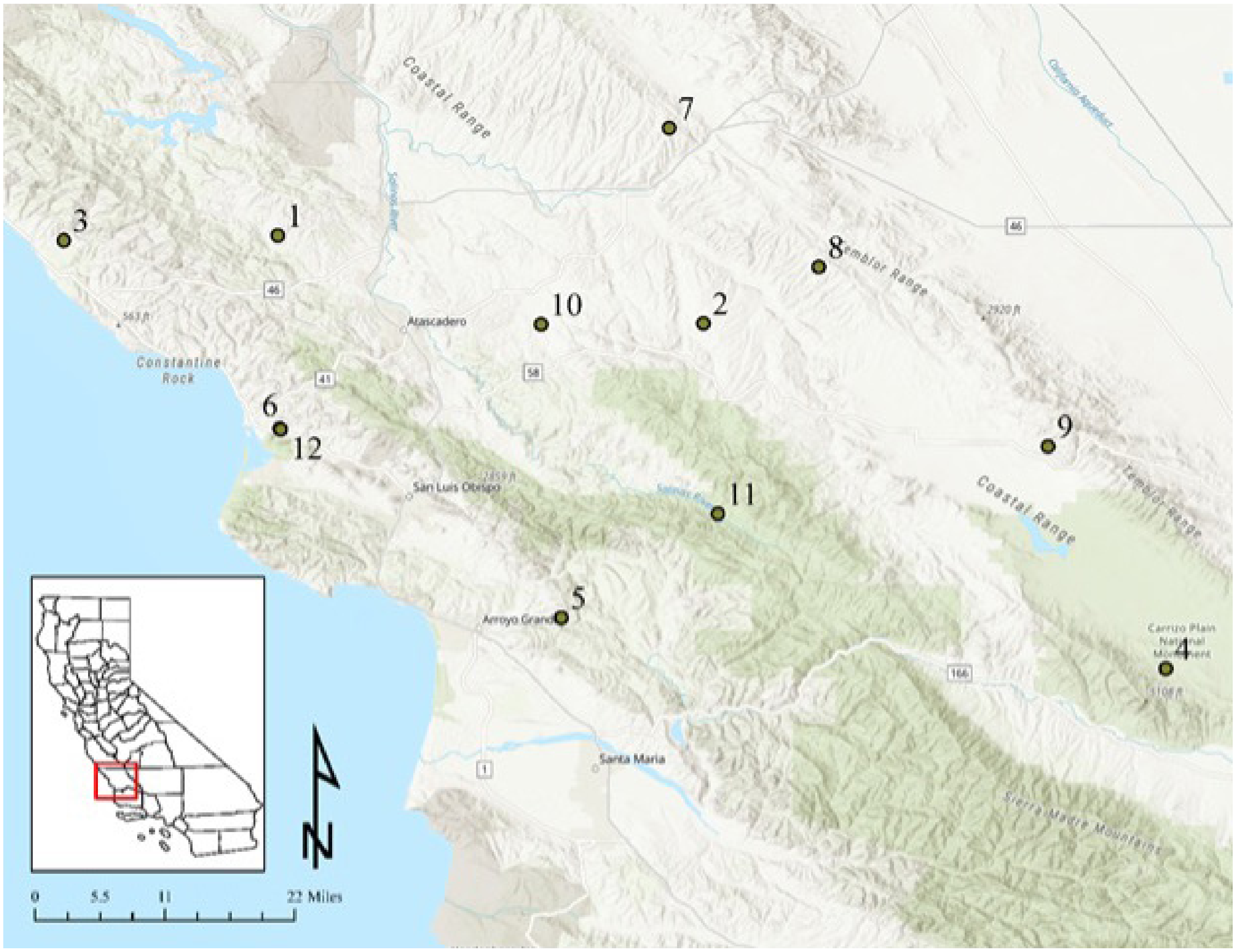

Figure 1. Approximate locations of the 12 forage monitoring sites (reference Table 1 for site numbers' corresponding name).

1 ft^2 quadrants within each of the four exclosures at every site at the time of peak growth stage. Samples were oven dried at 65 degrees Celsius for a minimum of 24 hours and then weighed. Rainfall was measured at each site using rain gauges starting in 2013. Prior to that, rainfall data was obtained from the nearest weather station operated by the County of San Luis Obispo, Bureau of Land Management's Remote Automated Weather Stations (RAWS), or from the nearest ranch headquarters. All rainfall collection sites were within 6 miles of the forage monitoring site, with the majority substantially closer than 6 miles. Summary statistics (mean and standard deviation) for the site-level rainfall data for each monitoring site are included in Table A1 in the appendix. The 12 sites in the study were carefully selected to provide variability of forage production and represent a variety of precipitation zones, soil types, slopes and aspects, and varying temperature regimes.

PRF Rainfall Index Insurance

The rainfall index used for coverage purposes in PRF insurance uses National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA, CPC) data. This data uses a grid system to determine precipitation amounts within an area. Each grid is 0.25 degree in latitude by 0.25 degree in longitude, or approximately 17 by 17 miles at the equator. Producers' insured acreage is assigned to one or more grids based on the location.

Coverage for PRF insurance is based on producer selections of coverage level, index intervals, productivity factor, and number of acres. Coverage levels range from 70% to 90%. Index intervals represent two-month periods for which the producer must select at least two[1] of these intervals to ensure the rainfall index does not fall below the selected coverage level. Producers cannot select two overlapping intervals (example: Jan–Feb and Feb–Mar) and cannot insure more than 60% of their total forage in any one interval.

There has been some research into the risk implications of various interval selection strategies (Cho & Brorsen, 2021; Westerhold et al., 2018). Westerhold et al. (2018) found that by selecting intervals within the growing season with high expected precipitation, producers could reduce net income risk. For this reason, producers are encouraged to select the intervals they feel represent the ones when precipitation is most important to their production. Within the region of the forage monitoring sites of this study, the forage growth year generally begins in October and continues through April into early May. During the months of June–September, the region receives little to no precipitation on average, but occasional rainfall in some years adds greater variability to the average rainfall during these months. For this reason, the RMA restricts the intervals from which producers may select coverage in this region by not allowing for selections of May–June, June–July, July–August, and August–September.

For indemnity purposes, the RMA assigns a base value to the crop in a grid based on intended use, forage or grazing. Producers are made aware of the value and are instructed to choose a productivity factor ranging from 60% to 150% for their insured crop based on their perceived value of their individual crop. Higher productivity factors and coverage levels result in higher insurance premiums (USDA, RMA, 2017). If the rainfall index in a selected index interval falls below the producer-selected coverage level, then an indemnity payout is triggered. Rainfall index data for the grids corresponding to the 12 forage monitoring sites was gathered from the RMA PRF insurance support tool website (USDA, RMA, 2020). The RMA does not publish information pertaining to which weather stations make up the index calculations within specific grids. However, analysis of NOAA CPC weather station maps indicates that there are abundant weather stations in the area of the forage monitoring sites (Feuz, 2021). Summary statistics (mean and standard deviation) for the rainfall index-level data for each monitoring site are included in Table A2 in the appendix.

Methods

The objective of this paper is to estimate the expected basis risk of PRF insurance in the south-central coast region of California. Following Yu et al. (2019) and Keeler and Saitone (2022), we approximate basis risk as the FNP. We adapt the methods of Keeler and Saitone (2022) to allow for calculation of the FNP using site-level yield data rather than the NDVI as a proxy for yield. Producers are required to select at least two intervals to insure. Thus, as noted by Keeler and Saitone (2022), there are three relevant FNPs that must be considered. The first is the probability that the rainfall in the first interval insured was below the coverage level yet the rainfall in the second interval was above the coverage level given that an actual loss was incurred (forage production below selected coverage level). This would result in an indemnity but would still be a false negative in one of the intervals insured, and thus the indemnity amount may not provide adequate compensation for losses. The second relevant FNP is the same as the first, but an indemnity is triggered in the first interval rather than the second. The third relevant FNP is the probability that the rainfall in both insured intervals was above the coverage level, resulting in no indemnity payment given that an actual loss was incurred. These three relevant FNPs are calculated as

$$(1)\quad FNP^{1}_{s,i,t} = Prob(RI_{s,k,t} \geq C, RI_{s,l,t} < C \mid YI_{s,t} < C,)$$

$$(2)\quad FNP^{2}_{s,i,t} = Prob(RI_{s,k,t} < C, RI_{s,l,t} \geq C \mid YI_{s,t} < C,)$$

$$(3)\quad FNP^{3}_{s,i,t} = Prob(RI_{s,k,t} \geq C, RI_{s,l,t} \geq C \mid YI_{s,t} < C,)$$

where C is the coverage rate selected by the insured and $RI_{s,i,t}$ and $YI_{s,t}$ are the rainfall index and yield index, respectively, for site , index interval combination i (k, l), and year t.

The yield index, $YI_{s,t}$, can be constructed as in

$$YI_{s,t} = {}^{y_{s,t}}/_{\bar{y}_s} \cdot 100 \qquad (2)$$

where $y_{s,t}$ is the peak forage yield of site s in year t, and $\bar{y}_s$ is the average peak yield of site i.

RESULTS AND DISCUSSION

After calculation of the FNPs as in equations (1–3), we add $FNP^1_{s,i,t} + FNP^2_{s,i,t}$ to represent the combined probability of failing to receive an indemnity in one of the interval combinations when a loss was incurred. We then present and discuss the results of both the combined $FNP^1_{s,i,t} + FNP^2_{s,i,t}$ as well as the $FNP^3_{s,i,t}$ (probability of failing to be indemnified in either two-month interval when a loss was incurred). All results are presented in the format X% [Y%] where the combined $FNP^1_{s,i,t} + FNP^2_{s,i,t}$ is listed first with the $FNP^3_{s,i,t}$ displayed directly following, enclosed in brackets. The FNP calculations for index-level rainfall data and site-level rainfall data are displayed in Tables 2 and 3 respectively.

From Tables 2 and 3, the average FNP of not receiving an indemnity in one [both] of the two selected intervals across all intervals and coverage rates using index-level data is calculated at 47.8% [11.4%] and 42.3% [8.1%] using site-level data. In comparison, Keeler and Saitone (2022) estimated the average range of the FNP for the 85% coverage level over a nearly 40-year period for 63 million acres of rangelands in California at 31–46% [14%–25%]. Overall, our estimates are similar but with greater variability and range.

Table 2. Average False Negative Probability by Interval and Coverage Rate Using Pasture, Rangeland, and Forage Insurance Index-Level Rainfall Data

	Coverage Rate					
Intervals	70	75	80	85	90	
	Results displayed as: $FNP^1_{s,i,t} + FNP^2_{s,i,t}[FNP^3_{s,i,t}]$ (%)					Average
Oct–Nov (t-1)†; Jan–Feb (t)	42 [13]	39 [13]	42 [9]	43 [8]	36 [8]	40 [10]
Oct–Nov (t-1)†; Feb–Mar (t)	65 [13]	64 [13]	61 [9]	61 [9]	53 [9]	61 [11]
Oct–Nov (t-1)†; Mar–Apr (t)	60 [12]	59 [13]	52 [13]	47 [14]	40 [15]	52 [13]
Oct–Nov (t-1)†; Apr–May (t)	45 [17]	41 [16]	35 [13]	26 [14]	17 [15]	33 [15]
Oct–Nov (t-1)†; May–Jun (t)	45 [12]	41 [14]	42 [12]	39 [10]	40 [8]	41 [11]
Nov–Dec (t-1)†; Jan–Feb (t)	42 [20]	37 [16]	40 [16]	43 [13]	37 [12]	40 [15]
Nov–Dec (t-1)†; Feb–Mar (t)	65 [20]	62 [16]	60 [17]	59 [15]	57 [12]	61 [16]
Nov–Dec (t-1)†; Mar–Apr (t)	77 [10]	75 [7]	74 [8]	72 [6]	70 [5]	74 [7]
Nov–Dec (t-1)†; Apr–May (t)	62 [15]	57 [10]	57 [8]	47 [8]	47 [5]	54 [9]
Nov–Dec (t-1)†; May–Jun (t)	38 [22]	36 [19]	40 [18]	37 [16]	35 [15]	37 [18]
Jan–Feb (t); Mar–Apr (t)	55 [8]	52 [9]	49 [8]	51 [8]	43 [9]	50 [8]
Jan–Feb (t); Apr–May (t)	53 [7]	51 [3]	43 [3]	39 [3]	29 [4]	43 [4]
Jan–Feb (t); May–Jun (t)	37 [10]	36 [9]	36 [8]	36 [8]	35 [5]	36 [8]
Feb–Mar (t); Apr–May (t)	43 [23]	52 [14]	44 [13]	53 [7]	47 [5]	48 [12]
Feb–Mar (t); May–Jun (t)	53 [13]	46 [16]	40 [17]	40 [16]	37 [14]	43 [15]
Mar–Apr (t); May–Jun (t)	58 [7]	59 [7]	52 [9]	49 [9]	48 [9]	53 [8]
Average	53 [14]	50 [12]	48 [11]	46 [10]	42 [9]	

Note: Average FNP risk across all intervals and coverage rates = **47.3% [11.4%]**
Full sample (N = 190) was used in these calculations, which is equal to the summation of the number of years available from each of the 12 forage monitoring sites. All results are percentages and equal to the probability that no indemnity is triggered when a loss has been incurred.

Table 3. Average False Negative Probability by Interval and Coverage Rate Using Site-Level Rainfall Data

Interval	Coverage Rate					
	70	75	80	85	90	
	Results displayed as: $FNP^1_{s,i,t} + FNP^2_{s,i,t}[FNP^3_{s,i,t}]$ (%)					Average
Oct–Nov (t-1)[†]; Jan–Feb (t)	38 [18]	36 [16]	35 [13]	34 [10]	35 [8]	36 [13]
Oct–Nov (t-1)[†]; Feb–Mar (t)	63 [13]	62 [12]	55 [12]	53 [10]	54 [7]	57 [11]
Oct–Nov (t-1)[†]; Mar–Apr (t)	55 [10]	48 [14]	42 [14]	40 [14]	40 [13]	45 [13]
Oct–Nov (t-1)[†]; Apr–May (t)	42 [10]	35 [14]	29 [14]	28 [13]	25 [13]	32 [13]
Oct–Nov (t-1)[†]; May–Jun (t)	45 [3]	43 [3]	36 [4]	32 [5]	34 [2]	38 [3]
Nov–Dec (t-1)[†]; Jan–Feb (t)	43 [18]	43 [14]	40 [13]	36 [11]	39 [8]	40 [13]
Nov–Dec (t-1)[†]; Feb–Mar (t)	68 [13]	64 [13]	57 [13]	56 [10]	59 [7]	61 [11]
Nov–Dec (t-1)[†]; Mar–Apr (t)	60 [10]	61 [10]	62 [6]	64 [3]	66 [2]	63 [6]
Nov–Dec (t-1)[†]; Apr–May (t)	50 [8]	51 [9]	52 [5]	52 [2]	51 [2]	51 [5]
Nov–Dec (t-1)[†]; May–Jun (t)	50 [3]	51 [1]	44 [3]	38 [3]	36 [3]	44 [3]
Jan–Feb (t); Mar–Apr (t)	50 [7]	46 [7]	45 [6]	45 [6]	42 [7]	46 [7]
Jan–Feb (t); Apr–May (t)	40 [5]	36 [6]	35 [5]	34 [3]	32 [4]	35 [5]
Jan–Feb (t); May–Jun (t)	30 [5]	25 [4]	25 [4]	21 [5]	18 [4]	24 [4]
Feb–Mar (t); Apr–May (t)	32 [17]	39 [13]	39 [12]	44 [8]	42 [8]	39 [12]
Feb–Mar (t); May–Jun (t)	38 [8]	39 [6]	36 [6]	37 [6]	36 [4]	37 [6]
Mar–Apr (t); May–Jun (t)	27 [7]	30 [6]	29 [6]	29 [7]	33 [5]	30 [6]
Average	46 [10]	44 [9]	41 [9]	40 [7]	40 [6]	

Note: Average FNP risk across all intervals and coverage rates = **42.3%** [**8.1%**]
Full sample (N = 190) was used in these calculations, which is equal to the summation of the number of years available from each of the 12 forage monitoring sites. All results are percentages and equal to the probability that no indemnity was triggered when a loss was incurred.
[†] (t-1) indicates that the data from those intervals were taken from the previous calendar year to provide a complete water year of data.

This is most likely the result of our comparatively smaller dataset (greater influence of outliers) from the 12 forage monitoring sites ranging from 10 to 19 years in length.

The difference of average FNP_index-level (Table 2) less average FNP_site-level (Table 3) is 5.5% [3.3%]. This difference is our estimation of index related risk, or the amount of risk that could be reduced using site-level rainfall data. This relatively small difference suggests that basis risk may be reduced only modestly when using site-level rainfall data as compared to index-level rainfall data. Our estimate of index related risk is similar to the level estimated by Yu et al. (2019) for Kansas and Nebraska rangelands at 5–9%. This suggest that the level of index related risk is similar between the Mediterranean grasslands of the Californian coast and those of Nebraska and Kansas and adds robustness to the previous findings of Yu et al. (2019). Our low levels of estimated index related risk suggest (similar to Yu et al., 2019) that the primary source of basis risk with PRF insurances comes from nonprecipitation factors such as soil conditions, temperature, wind speed, nutrient availability, and so forth.

It is important, however, to recognize that average index related risk may not be consistent across coverage rates and interval combinations. Looking at the results in Tables 2 and 3, the average FNP can be compared by interval combinations and coverage rates to provide evidence of consistency for the overall average difference of 5.5%

Table 4. Average FNP Difference (PRF Index-Level FNP – Site-Level Rainfall FNP) by Interval and Coverage Rate Using PRF Index Data

	Coverage Rate					
Interval	70	75	80	85	90	
	Results displayed as: $FNP^{1}_{s,i,t} + FNP^{2}_{s,i,t}[FNP^{3}_{s,i,t}]$ (%)					Average
Oct–Nov (t-1)†; Jan–Feb (t)	4 [–5]	3 [–3]	7 [–4]	9 [–2]	1 [0]	5 [–3]
Oct–Nov (t-1)†; Feb–Mar (t)	2 [0]	2 [1]	6 [–3]	8 [–1]	–1 [2]	3 [0]
Oct–Nov (t-1)†; Mar–Apr (t)	5 [2]	11 [–1]	10 [–1]	7 [0]	0 [2]	7 [0]
Oct–Nov (t-1)†; Apr–May (t)	3 [7]	6 [2]	6 [–1]	–2 [1]	–8 [2]	1 [2]
Oct–Nov (t-1)†; May–Jun (t)	0 [9]	–2 [11]	6 [8]	7 [5]	6 [6]	3 [8]
Nov–Dec (t-1)†; Jan–Feb (t)	–1 [2]	–6 [2]	0 [3]	7 [2]	–2 [4]	0 [3]
Nov–Dec (t-1)†; Feb–Mar (t)	–3 [7]	–2 [3]	3 [4]	3 [5]	–2 [5]	0 [5]
Nov–Dec (t-1)†; Mar–Apr (t)	17 [0]	14 [–3]	12 [2]	8 [3]	4 [3]	11 [1]
Nov–Dec (t-1)†; Apr–May (t)	12 [7]	6 [1]	5 [3]	–5 [6]	–4 [3]	3 [4]
Nov–Dec (t-1)†; May–Jun (t)	–12 [19]	–15 [18]	–4 [15]	–1 [13]	–1 [12]	–7 [15]
Jan–Feb (t); Mar–Apr (t)	5 [1]	6 [2]	4 [2]	6 [2]	1 [2]	4 [2]
Jan–Feb (t); Apr–May (t)	13 [2]	15 [–3]	8 [–2]	5 [0]	–3 [0]	8 [–1]
Jan–Feb (t); May–Jun (t)	7 [5]	11 [5]	11 [4]	15 [3]	17 [1]	12 [4]
Feb–Mar (t); Apr–May (t)	11 [6]	13 [1]	5 [1]	9 [–1]	5 [–3]	9 [1]
Feb–Mar (t); May–Jun (t)	15 [5]	7 [10]	4 [11]	3 [10]	1 [10]	6 [9]
Mar–Apr (t); May–Jun (t)	31 [0]	29 [1]	23 [3]	20 [2]	15 [4]	24 [2]
Average	7 [4]	6 [3]	7 [3]	6 [3]	2 [3]	

Note: Average difference (index level - site level) in FNP across all intervals and coverage rates = **5.5% [3.3%]**
Full sample (N = 190) was used in these calculations, which is equal to the summation of the number of years available from each of the 12 forage monitoring sites. All results are percentages and equal to the difference in FNP when calculated using index-level rainfall data versus when calculated using site-level rainfall data.
† (t-1) indicates that the data from those intervals were taken from the previous calendar year to provide a complete water year of data.

[3.3%]. Table 4 displays results for index related risk calculations (index-level FNP – site-level FNP) for each coverage level and interval combination. From Table 4, we gather that much of the variance in index related risk can be attributed to the May–June interval, as combinations containing this interval have higher average index related FNPs. For interval combinations containing the May–June interval, index related risk is 7.8% [7.9%]. The other intervals depict index related risk of a lower magnitude 5.8% [1.1%]. This suggests that for a producer in this Mediterranean climate trying to mitigate basis risk for PRF insurance the May–June interval would not be well suited for producer selection of PRF coverage. This is not surprising considering that the RMA does not allow coverage in this interval or the other summer month intervals for this area of the country (June–July, July–August, and August–September) as these intervals receive relatively little average rainfall with increased variability (reference Tables A1 and A2 in the appendix). This low average rainfall with high variability partly explains the relatively higher expected index related risk associated with this interval.

Correlation of Rainfall Index and Site-Level Rainfall

Index related risk at the magnitude of 5.5% [3.3%] on average across all intervals and coverage levels represents only a modest reduction to basis risk if

PRF contracts were allowed to rely on site-level rainfall data rather than the rainfall index. We also found that when excluding intervals combinations including the May–June interval, index related risk decreases to near 1% (FNP^3). This suggests that, on average, we would expect the rainfall index to perform nearly equally well as the site-level rainfall within PRF insurance. This would point toward the rainfall index and site-level rainfall being highly correlated and deserves some attention to better understand and validate the FNP results.

As noted by Maples, Brorsen, and Biermacher (2016), the correlation between the rainfall index and site-level rainfall data are of particular interest. A key finding of their research was that the rainfall index was highly positively correlated to local (south-central Oklahoma) rainfall data and statistically significant. The Pearson product-moment correlation between the rainfall index and site-level rainfall data from our study are calculated for each interval and displayed in Table 5. Similar to the study of Maples, Brorsen, and Biermacher (2016), the correlations for each interval are highly positive and statistically significant (alpha = 0.01) with the exception of the August–September interval. For that interval, the rainfall index is only moderately positively correlated with the site-level rainfall data. The weak correlation for this interval is not a surprising result as rainfall in this interval is minimal and varies greatly. Consequently, PRF coverage in California is not allowed for this interval. This high level of correlation between the rainfall index and site-level rainfall would suggest that, on average, we should expect index related risk to be minimal for this region as indicated by our results.

Table 5. Pearson Correlation of Index-Level Rainfall and Site-Level Rainfall Data

Interval	Correlation (*r*)	P-value
January–February	0.913	0.000
February–March	0.885	0.000
March–April	0.857	0.000
April–May	0.800	0.000
May–June	0.802	0.000
June–July	0.829	0.000
July–August	0.814	0.000
August–September	0.195	0.007
September–October	0.832	0.000
October–November	0.796	0.000
November–December	0.883	0.000

Note: Full sample (N = 190) was used in these calculations, which is equal to the summation of the number of years available from each of the 12 forage monitoring sites.

Comparison of Expected Net Returns

The FNP estimates provide a good approximation of the basis risk associated with PRF contracts using site-level vs. index-level rainfall data. However, the FNP estimates do not provide any measure of expected difference in net returns if contracts relied on site-level rainfall data as compared to index-level data. Thus, estimating the expected net returns for each site with various coverage levels for both site-level and index level PRF contracts provides a useful comparison. Of course, in calculating the expected net returns we must make several assumptions as to the PRF contract details, which make the results less generalizable yet still provide a means of comparison that demonstrate the magnitudes of expected differences in net return between PRF contracts relying on site-level and index-level rainfall data. For the estimation of expected net returns we assume a forage value of $100/ton; 50/50% divisional split of coverage between the April–May and November–December intervals; 2022 county base value of $22.30/acre; premium subsidies of 59%, 55%, and 51% for coverage levels of 70%, 80%, and 90% respectively; and 2022 grid-specific premium rates for the intervals April–May and November–December. The net returns are calculated as total revenue (forage revenue and possible PRF indemnification) less PRF subsidized premium. Thus, the net returns estimated do not include any additional costs and are only net of PRF premium. We also estimate the net returns for each site expected when no PRF coverage is purchased.

The expected net returns with their standard deviations (in parentheses) are displayed in Tables 6 and 7 for site-level and index-level rainfall respectively. In comparing the results of Tables 6 and 7, we can identify that on average across all sites and coverage levels expected net returns would increase when using PRF insurance as compared to no PRF

Table 6. **Average Expected Net Returns per Acre and Standard Deviation by Coverage Level for PRF Contracts Using Site-Level Rainfall Compared to No PRF Coverage**

Site	Avr. Yield	70% Coverage		80% Coverage		90% Coverage		No PRF coverage	
Adelaida	4178	$208.79	($101.19)	$210.20	($100.81)	$211.81	($100.37)	$208.88	($102.86)
Camatta	1505	$75.40	($44.94)	$76.68	($44.54)	$78.11	($44.18)	$75.24	($47.75)
Cambria	7199	$371.44	($116.59)	$373.95	($116.59)	$376.45	($116.59)	$359.95	($116.59)
Carrizo	3453	$184.05	($113.52)	$186.56	($113.52)	$189.08	($113.52)	$172.63	($113.52)
Huasna	4587	$240.66	($125.83)	$243.18	($125.83)	$245.70	($125.83)	$229.34	($125.83)
Morro Bay S	3538	$188.70	($82.68)	$191.19	($82.68)	$193.68	($82.68)	$176.88	($82.68)
Shandon	2971	$159.84	($98.42)	$162.36	($98.42)	$164.88	($98.42)	$148.53	($98.42)
Bitterwater	2054	$113.95	($77.72)	$116.48	($77.72)	$119.00	($77.72)	$102.71	($77.72)
Soda Lake	1547	$88.54	($75.36)	$91.07	($75.36)	$93.60	($75.36)	$77.37	($75.36)
Creston	1065	$64.74	($27.87)	$67.25	($27.87)	$69.76	($27.87)	$53.24	($27.87)
Pozo	3011	$161.87	($57.58)	$164.39	($57.58)	$166.91	($57.58)	$150.56	($57.58)
Morro Bay N	3331	$178.41	($91.40)	$180.90	($91.40)	$183.38	($91.40)	$166.59	($91.40)

Note: The estimated net returns are expected gross returns (forage revenue and possible PRF indemnification) less PRF subsidized premium and were calculated based on $100/ton forage. PRF contract assumptions included 50/50% division split of coverage between the April–May and November–December intervals; 2022 county base value of $22.30/acre; premium subsidy of 59%, 55%, and 51% for coverage levels of 70%, 80%, and 90% respectively; 2022 grid specific premium rates for the intervals April–May and November–December.

Table 7. **Average Expected Net Returns per Acre and Standard Deviation by Coverage Level for PRF Contracts Using Index-Level Rainfall Compared to No PRF Coverage**

Site	Avr. Yield	70% Coverage		80% Coverage		90% Coverage		No PRF coverage	
Adelaida	4178	$207.84	($101.55)	$209.19	($101.22)	$210.65	($100.82)	$208.88	($102.86)
Camatta	1505	$74.25	($46.69)	$75.55	($46.38)	$77.00	($45.99)	$75.24	($47.75)
Cambria	7199	$358.76	($115.90)	$359.99	($115.58)	$361.38	($115.34)	$359.95	($116.59)
Carrizo	3453	$171.86	($111.69)	$173.10	($111.33)	$174.44	($110.88)	$172.63	($113.52)
Huasna	4587	$228.90	($124.23)	$230.34	($123.78)	$231.86	($123.36)	$229.34	($125.83)
Morro Bay S	3538	$175.35	($81.51)	$176.54	($81.21)	$177.92	($80.86)	$176.88	($82.68)
Shandon	2971	$147.75	($97.15)	$149.16	($96.85)	$150.70	($96.49)	$148.53	($98.42)
Bitterwater	2054	$101.33	($76.69)	$102.60	($76.31)	$104.07	($75.86)	$102.71	($77.72)
Soda Lake	1547	$75.89	($73.80)	$77.03	($73.47)	$78.32	($73.07)	$77.37	($75.36)
Creston	1065	$52.65	($25.39)	$54.05	($25.09)	$55.55	($24.78)	$53.24	($27.87)
Pozo	3011	$149.46	($55.30)	$150.65	($54.97)	$152.03	($54.52)	$150.56	($57.58)
Morro Bay N	3331	$164.89	($89.40)	$165.96	($89.24)	$167.24	($88.99)	$166.59	($91.40)

Note: The estimated net returns are expected gross returns (forage revenue and possible PRF indemnification) less PRF subsidized premium and were calculated based on $100/ton forage. PRF contract assumptions included 50/50% division split of coverage between the April–May and November–December intervals; 2022 county base value of $22.30/acre; premium subsidy of 59%, 55%, and 51% for coverage levels of 70%, 80%, and 90% respectively; 2022 grid specific premium rates for the intervals April–May and November–December.

coverage when using site-level rainfall data. An increase is also seen to a lesser extent when index-level data is used; however, this increase is only consistent when coverage is purchased at the 90% level. Additionally, we can calculate that across all sites and coverage levels expected net returns increase on average by $11.60 per acre when relying on site-level rainfall data as compared to index-level data. This marginal increase in expected net return per acre is expected as the basis risk would be marginally reduced as suggested by the estimations of FNPs.

CONCLUSION

We approximate basis risk as the FNP on average across all interval combinations and coverage levels at 47.8% [11.4%] for our 12 sites within San Luis Obispo County, California. These results are specific to this region of California characterized by Mediterranean-type annual grasslands. This potentially limits the results from having broad policy implications. However, in general this study demonstrates that PRF insurance contains substantial basis risk. Similar to research for other geographic locations (Maples, Brorsen, and Biermacher, 2016), our results also tend to highlight that the rainfall index is a good proxy for site-level rainfall. This suggests that index related risk for PRF insurance should be expected to be small. Our estimated index related risk is only 5.5% [3.3%].

PRF-rainfall index insurance was designed to help producers protect their operation from risks of forage loss due to the lack of precipitation. This research indicates that the PRF insurance program has a significant amount of basis risk within the south-central coast region of California and does not do an adequate job of ensuring that producers experiencing a loss will receive an indemnity. Though the FNP for the region in this study is estimated to be approximately 47.3% [11.4%], this does not necessarily suggest that PRF insurance is not a worthwhile investment for producers. Producers should expect that while there is a risk of false negative indemnification, there is also a nearly equal probability of false positive indemnification that would help to negate the risk of FNP. There is also the probability of true positives and true negatives, which is essentially the probability that the program works as intended, providing an indemnity in times of loss and no indemnity when no loss is incurred. For this reason, producers should continue to evaluate this product with their crop insurance agents and consider its use within their risk management programs.

The insurance premiums for PRF insurance are heavily subsidized with the average subsidy equal to approximately 55% of the premium amount from 2007 to 2019. During that same time, the indemnity payout to subsidy-adjusted premium ratio was approximately 1.9, suggesting that for every dollar invested into PRF insurance premiums a producer could expect to have $1.90 returned in the form of an indemnity (Coble et al., 2020). Thus, despite the inevitable accompanying basis risk and inadequate protection against loss in dry years, this product has still proven to be beneficial for many producers financially over the long run. Policy makers must continue to evaluate potential methods to improve PRF insurance contracts through consideration of suggestions noted in recent literature: lower the range of the productivity factor, reduce coverage level choice sets to possibly increase participation rates, reduce interval selection choice sets (Cho & Brorsen, 2021), make updates to county base values, consider restoration of PRF insurance that relies on a vegetation index rather than rainfall in some areas, and consider factoring in livestock numbers to PRF contracts (Willis, 2020). Consideration and implementation of such changes may be necessary to better serve producers and more adequately insure against losses resulting from particularly dry years.

NOTE

1. In some areas of the country producers are not allowed to insure more than 40% of their total forage in any one interval, requiring producers to select at least three intervals to insure.

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Appendix

The design of each site included four exclosures. The exclosures were made from 16′ welded wire cattle panels. Three of the exclosures were put together using two 16′ panels and 4 t-posts to form a 10′ diameter exclosure (see Figure A1). The fourth exclosure was put together using 3¼ cattle panels to form a 16′ diameter circle (Figure A1), which also housed the weather station (see Figure A2).

Since the amount of residual dry matter (RDM) influences forage growth, the exclosures were moved each fall just prior to the rainy season. They were moved in a random direction and distance between 20 and 60 feet. They were kept on the same soil type, aspect, and slope. Exclosures 1–3 were moved each fall. Exclosure 4 was not moved, since the fourth one had the weather station. That exclosure was weed-whacked to reduce the RDM and to match the surrounding plot condition that existed at the time of movement in the fall (see Figure A3). For peak production, three 1 ft^2 quadrats are clipped for production (composite samples) for a total of 12 quadrates for each plot. Composite samples included all forage, grasses and forbs, within the 1 ft^2 quadrats. The dry-weight-rank method was used to determine species composition for each quadrat.

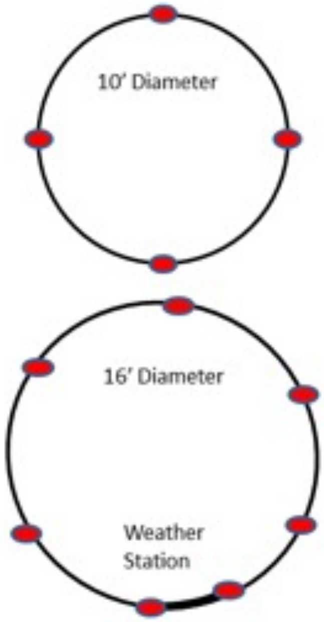

Figure A1. Exclosure design showing how the four exclosures are designed on each plot. They are made by using welded wire cattle panels and t-posts. Three exclosures were 10 feet in diameter, while one exclosure was over 16 feet in diameter.

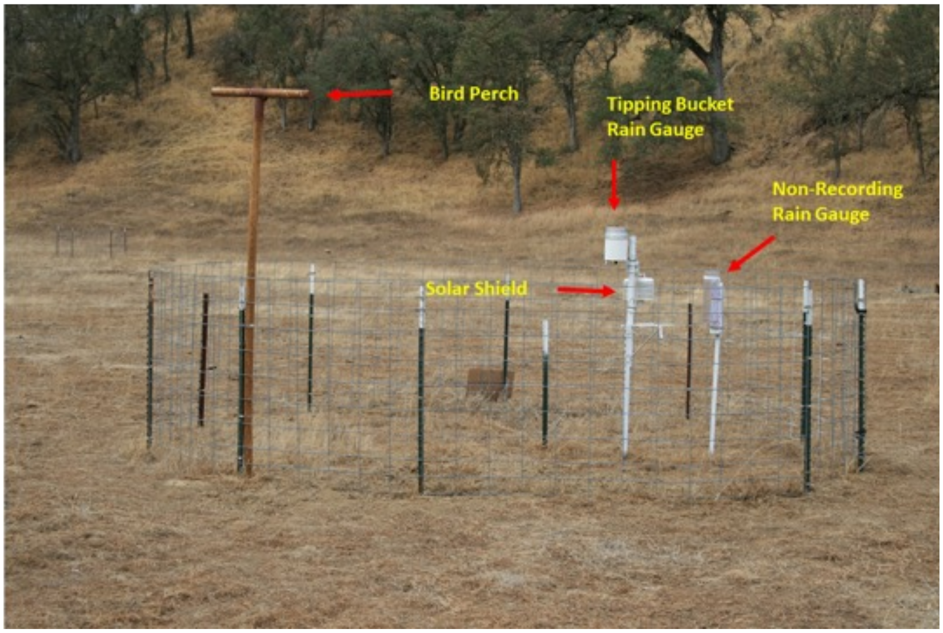

Figure A2. Tipping bucket rain gauge. Pictorial showing the tipping bucket rain gauge, a nonrecording rain gauge, and a solar shield for the temperature sensor inside exclosure #4. The bird perch helps reduce birds perching on the rain gauge

Figure A3. Exclosure example. Pictorial demonstration showing how the exclosures were set up on each site. Exclosures 1–3 were moved each fall, while exclosure 4 was not moved due to the weather station setup. Exclosure 4 was weed-whacked to reduce residual dry matter to match the surrounding area.

Table A1. Summary Statistics: Site-Level Precipitation (inches)

	Adelaida		Camatta		Cambria		Carrizo	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
January	4.15	3.70	1.74	1.78	4.62	3.82	1.56	1.45
February	3.94	2.81	1.69	1.23	4.09	2.84	1.37	1.21
March	2.74	2.37	1.25	1.15	3.23	2.72	1.18	1.03
April	1.16	1.34	0.52	0.61	1.27	1.23	0.58	0.79
May	0.42	0.67	0.16	0.25	0.60	0.83	0.16	0.25
October	1.24	1.80	0.60	0.64	1.32	1.62	0.48	0.68
November	1.58	1.49	0.66	0.61	1.61	1.50	0.71	0.77
December	3.60	3.12	1.86	1.72	4.30	3.23	1.53	1.65
	Huasna		Morro Bay S		Morro Bay N		Shandon	
January	4.60	4.20	3.39	2.89	3.67	2.71	2.64	2.15
February	3.87	2.84	2.85	2.11	1.84	2.24	1.91	1.39
March	3.22	2.61	2.56	2.08	2.74	1.96	1.57	1.42
April	1.51	2.06	1.06	1.20	0.72	0.78	0.83	0.97
May	0.39	0.71	0.51	0.63	0.36	0.57	0.29	0.42
October	1.45	1.72	0.85	1.13	0.56	0.53	0.71	0.92
November	1.87	1.67	1.32	0.93	1.25	0.96	0.88	0.77
December	3.99	3.30	2.92	2.51	2.17	1.69	2.19	1.79
	Bitterwater		Soda Lake		Creston		Pozo	
January	1.83	1.49	1.64	1.38	2.55	2.23	4.34	4.49
February	1.55	1.14	1.41	1.24	2.12	1.77	3.86	4.21
March	1.28	1.10	1.45	1.30	1.85	1.58	4.09	3.12
April	0.47	0.75	0.37	0.56	0.64	0.82	1.24	1.20
May	0.19	0.31	0.27	0.45	0.12	0.22	0.32	0.65
October	0.58	0.65	0.61	0.81	0.83	0.54	1.34	1.65
November	0.90	1.27	0.49	0.56	0.86	0.93	1.40	1.19
December	1.52	1.56	1.68	1.82	1.98	2.13	3.55	3.61

Note: Morro Bay S and Morro Bay N are within 300 feet of each other with the primary difference in the two sites being that one is a south aspect and the other a north aspect.

Table A2. Summary Statistics: Pasture, Rangeland, and Forage Insurance Rainfall Index Values

	Adelaida		Camatta		Cambria		Carrizo	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Jan–Feb	104.72	77.93	101.13	73.99	101.96	70.09	107.32	79.63
Feb–Mar	101.38	57.78	99.22	56.48	102.86	52.83	96.75	59.76
Mar–Apr	93.39	63.59	98.67	72.71	99.32	66.75	94.00	60.39
Apr–May	94.86	77.08	100.26	96.04	106.11	88.44	96.42	69.91
May–Jun	137.25	206.26	105.04	132.38	146.04	205.93	88.93	87.81
Sep–Oct	106.29	165.64	102.06	145.58	106.57	128.88	81.17	92.58
Oct–Nov	100.73	67.93	105.78	69.67	103.44	63.87	95.35	54.36
Nov–Dec	102.91	60.40	108.09	68.37	111.87	65.56	111.07	91.23
	Huasna		Morro Bay S		Morro Bay N		Shandon	
Jan–Feb	95.76	69.57	96.53	70.35	105.47	95.56	97.46	66.01
Feb–Mar	92.93	51.49	89.62	44.51	101.09	54.40	92.19	47.26
Mar–Apr	91.33	69.91	85.01	51.09	87.24	47.94	86.82	63.45
Apr–May	94.11	97.51	107.08	60.54	86.86	21.18	87.92	78.96
May–Jun	121.97	150.86	206.24	151.46	194.69	84.82	103.12	126.04
Sep–Oct	97.02	122.26	121.93	120.67	83.06	64.09	104.08	149.50
Oct–Nov	96.96	63.88	97.46	60.68	85.92	63.70	94.62	71.02
Nov–Dec	101.68	70.76	97.86	60.48	77.68	51.09	94.24	61.82
	Bitterwater		Soda Lake		Creston		Pozo	
Jan–Feb	116.38	76.11	121.09	82.03	94.57	84.47	99.60	87.64
Feb–Mar	103.85	52.50	108.58	58.27	98.77	55.16	105.86	62.61
Mar–Apr	98.56	74.21	109.51	89.59	96.29	49.25	105.24	52.84
Apr–May	97.81	98.01	112.48	120.86	77.31	48.76	86.42	57.99
May–Jun	91.44	107.43	97.75	113.22	116.41	144.57	99.94	143.12
Sep–Oct	128.14	160.79	122.33	148.18	71.06	70.99	75.92	76.74
Oct–Nov	113.13	78.28	110.03	74.83	91.39	56.43	99.06	54.73
Nov–Dec	116.57	84.79	122.59	97.88	96.23	69.53	105.79	79.77

Note: Morro Bay S and Morro Bay N are within 300 feet of each other with the primary difference in the two sites being that one is a south aspect and the other a north aspect.