Pacific Drought Knowledge Exchange

Climate Change, Climate Variability, & Drought Portfolio

Lanai, Hawaii

EAST-WEST CENTER

2023-06-01

Pacific Drought Knowledge Exchange

Climate change, climate variability, and drought (CCVD) will exert a growing impact on Hawaii's ecosystems, agriculture and communities in the future. While resource managers are tasked with preparing for this with the best available information, it is hard to know what data, research and recommendations are available. The Pacific Drought Knowledge Exchange (PDKE) program focuses on facilitating knowledge exchange between the research community and resource managers and stakeholders, thereby expanding the utility of climate and drought-related scientific products.

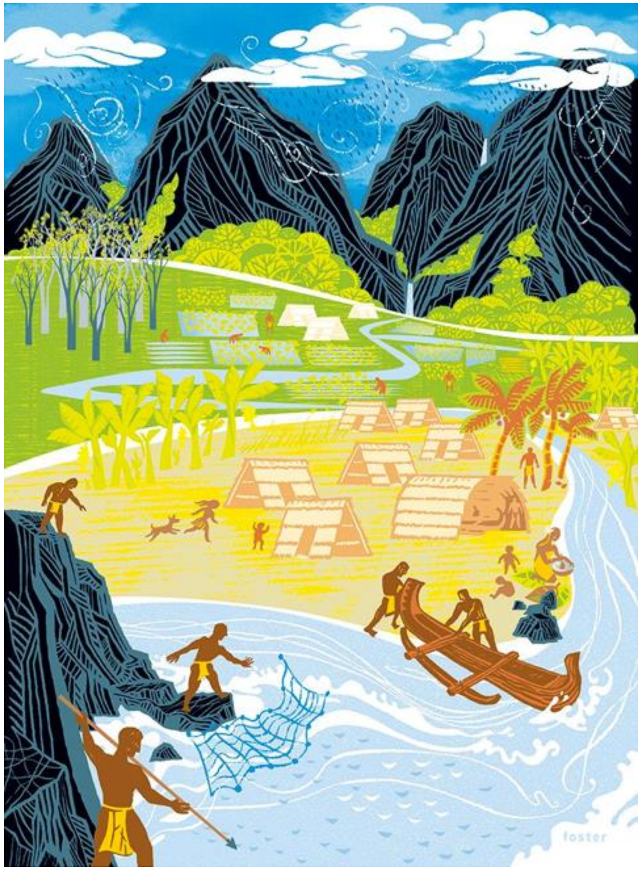
This CCVD portfolio is a comprehensive synthesis of climate and drought information developed specifically for Lanai. It is designed to provide relevant climate and drought information needed to inform land management and guide future research and extension. While we try to include a wide range of useful site-specific data products, we also recognize that every site is unique and PDKE is happy to collaborate on producing additional drought products beyond the CCVD portfolio to meet stakeholder needs.

The PDKE program was piloted in November of 2019 with funding from the Pacific Islands Climate Adaptation Science Center (PICASC). Subsequent PDKE activities and updates to the CCVD portfolio have been funded by PICASC, the East-West Center, and the National Integrated Drought Information System (NIDIS).

Part 1: Describing the Area

In describing any area of management in Hawaii, it is important to present both traditional and contemporary knowledge. Traditional Hawaiian landscape divisions are well-documented and were established largely following geological features and the natural flow of resources throughout the landscape.

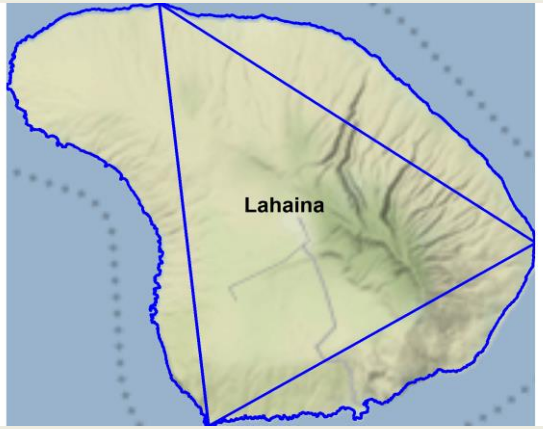
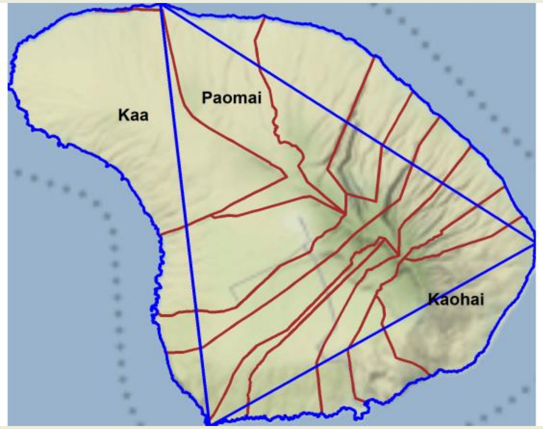
This portfolio provides a brief description of Lanai in context of traditional Hawaiian landscapes, as well as contemporary knowledge on elevation and current landcover.



Credit: Matt Foster

Hawaiian Land Divisions

There are three types of traditional Hawaiian landscape divisions available as GIS layers and presented here for Lanai. The land divisions are shown in red and Lanai is shown in blue.

Mokupuni	Moku	Ahupuaa
		
Mokupuni is the largest land division and refers to entire islands. Lanai is in the mokupuni of Lanai.	Within mokupuni are smaller divisions called moku. Lanai is in the moku of Lahaina.	Within each moku are several ahupuaa which commonly extend from uplands to the sea. Lanai is situated within 13 ahupuaa - primarily Kaa; Kaohai; and Paomai.

Elevation

Lanai is located on the Island of Lanai and covers a vertical elevation range of 3382 ft. In Hawaii, climate gradients can change significantly over short distances due to changes in elevation, topography, and orientation to the prevailing winds.

Elevation Lanai

Minimum = 0 ft
Mean = 1037 ft
Maximum = 3382 ft

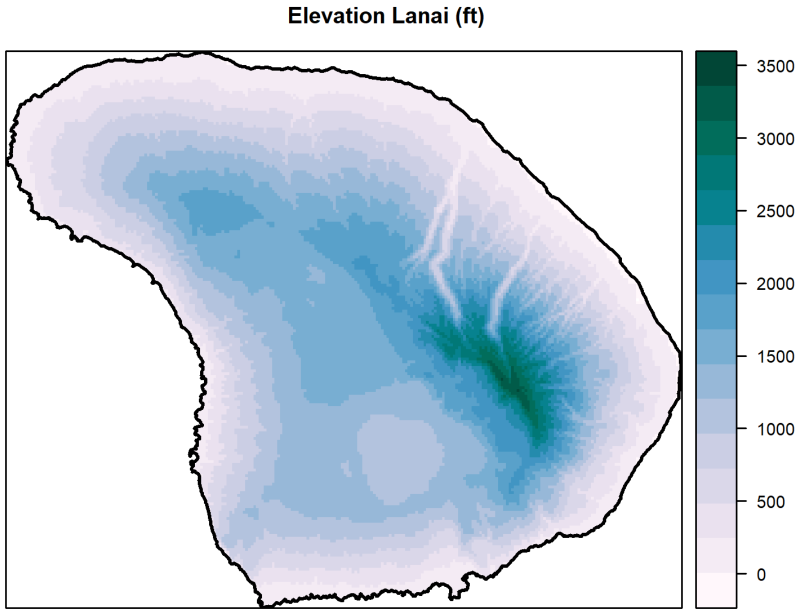


Figure 2. Elevation for the Island of Lanai with Lanai outlined in black.

Landcover

The three most common types of landcover in Lanai are Grass/Shrub, Tree Cover, and Barren. Each landcover type exhibits different climate change impacts and management needs.

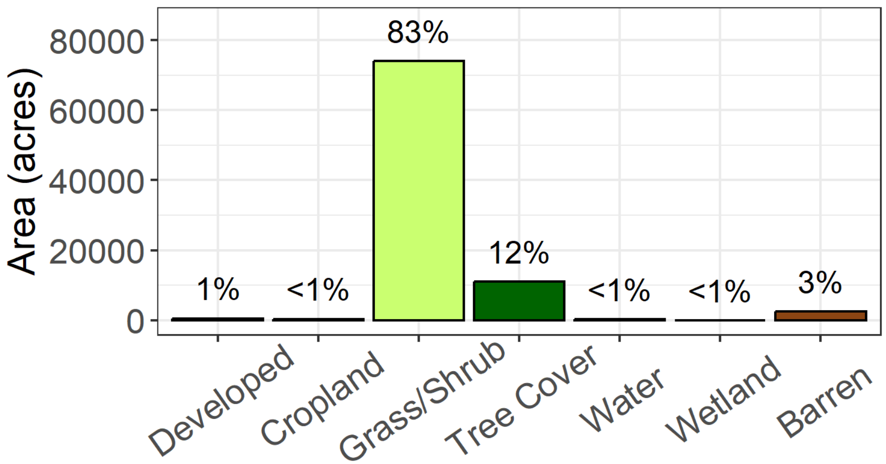


Figure 3. Bar graph showing amount and percent of each landcover type within Lanai.

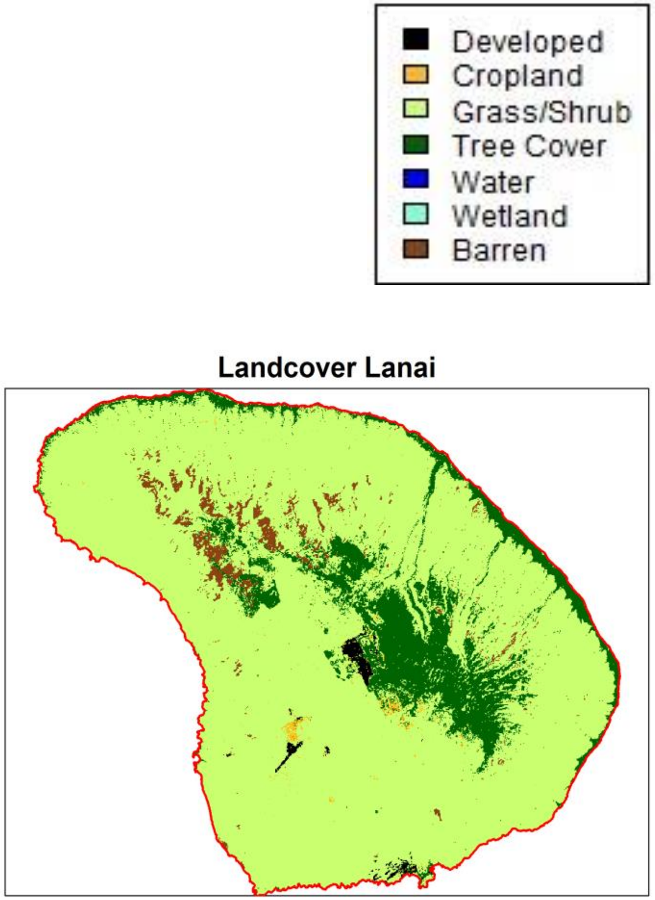


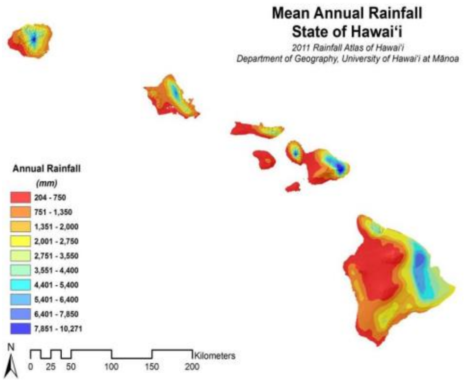
Figure 4. Landcover mapping for the island of Lanai with Lanai outlined in red. The maps shown in the following slides will be for the Lanai area only.

https://www.usgs.gov/special-topics/lcmap

Part 2: Climate Characteristics

Lanai

In developing this Portfolio, we relied on several gridded climate products available for the State of Hawaii. Annual and monthly estimates of rainfall were obtained from the Hawaii Climate Data Portal (HCDP). Gridded estimates of other climate variables were obtained from the UH Manoa Climate of Hawaii data page. We retrieved all the data points that fell within the boundaries of Lanai from our 250 meter resolution state-wide maps to support the presented analyses.



Rainfall Station Locations

Rainfall data for this portfolio were estimated based on measurements made by hundreds of stations across the state.

The closest station to Lanai is LANAI AIRPORT 656, part of the NWS climate station network.

Figure 5. Rainfall station locations across Lanai with Lanai outlined in blue and three closest stations in orange.

Station.Name	Network	Website
LANAI AIRPORT 656	NWS	https://www.weather.gov/hfo/RRA
Lanai City	HydroNet-UaNet	https://www.weather.gov/hfo/hydronet
LANAI 1	RAWS	https://raws.dri.edu/wraws/hiF.html

Figure 6. Three closest stations to Lanai with links to more information on the station network. If there are more than three stations at the site, only three will be listed here.

Annual Climate Characteristics

Climatic conditions in Hawaii can vary greatly across the landscape. These maps show the variation in select climate variables across Lanai and the table below has min. and max. values taken from the maps.

Climate Variable	Min	Max
Rainfall (°F)	15.00	36.0
Air Temperature (°F)	62.90	74.9
Relative Humidity (%)	70.00	86.0
Solar Radiation (W/m2)	163.00	256.0
Soil Moisture (Ratio)	0.23	1.0
Evapotranspiration (°F)	4.00	66.0
Windspeed (mph)	2.50	12.3

Table 1. Minimum and maximum average annual values for selected climate variables from within Lanai.

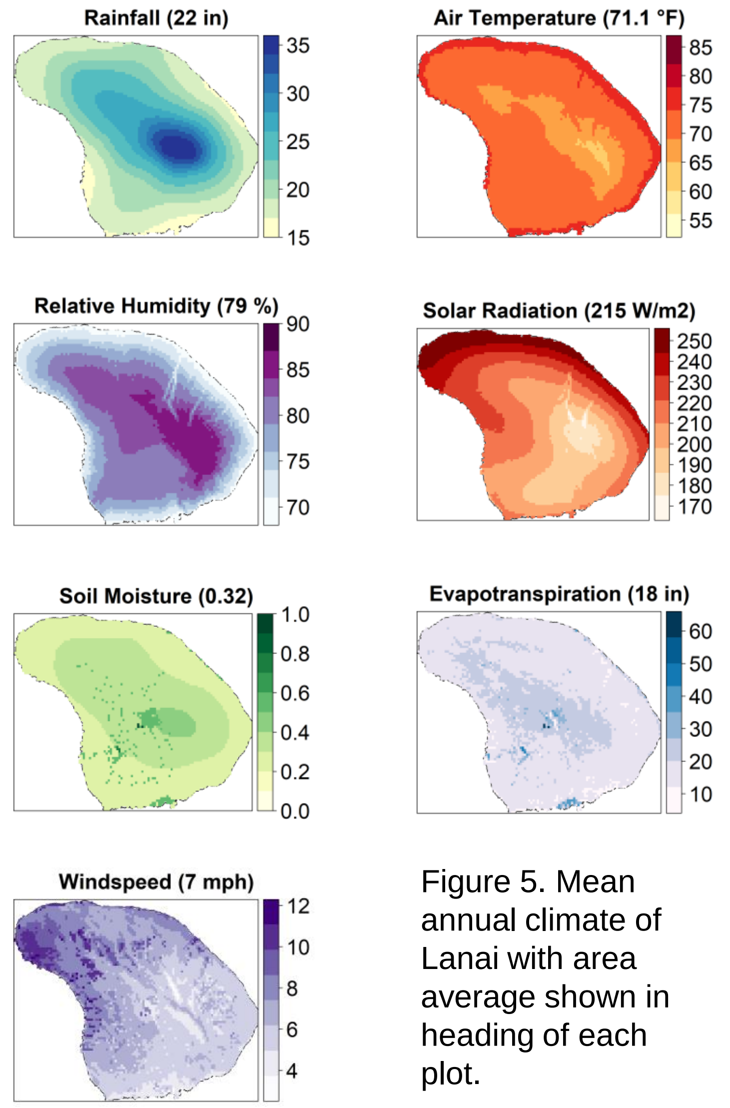


Figure 5. Mean annual climate of Lanai with area average shown in heading of each plot.

Giambelluca et al. (2013;2014)

Average Monthly Rainfall

Average monthly rainfall patterns vary over the course of the year. At Lanai, the highest monthly rainfall is received in January (3 in.) and the lowest monthly rainfall is received in August (1 in.).

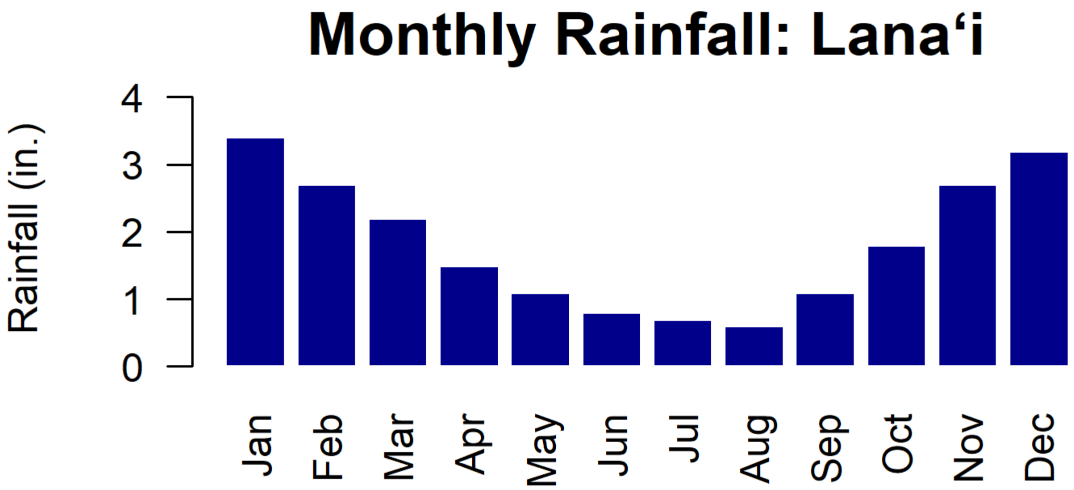


Figure 6. Mean monthly rainfall at Lanai.

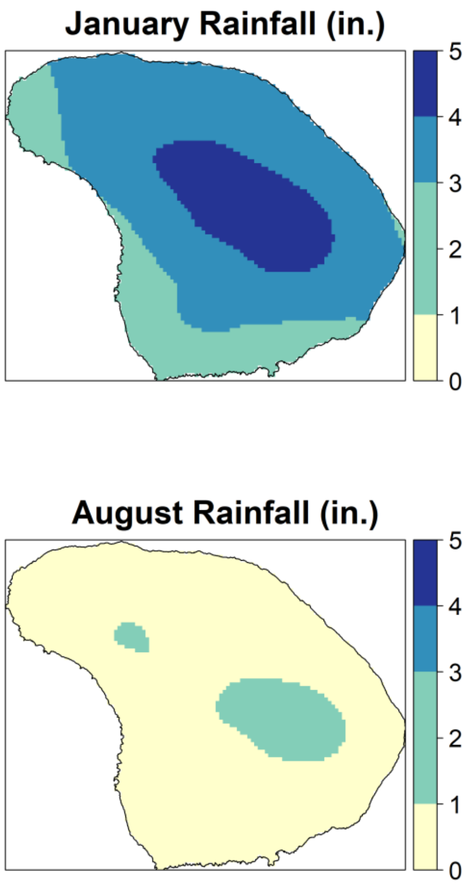
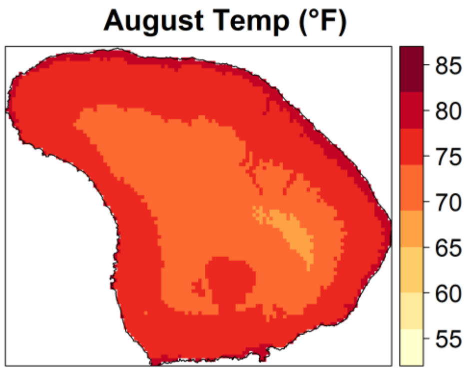


Figure 7. Monthly rainfall maps for the wettest (top) and driest (bottom) months.

Giambelluca et al. (2013;2014)

Average Monthly Temperature

Average monthly air temperature patterns vary over the course of the year. At Lanai there is a 7.1 °F annual variation in temperature, with the warmest month of August (75 °F) and the coolest month in January (68 °F).



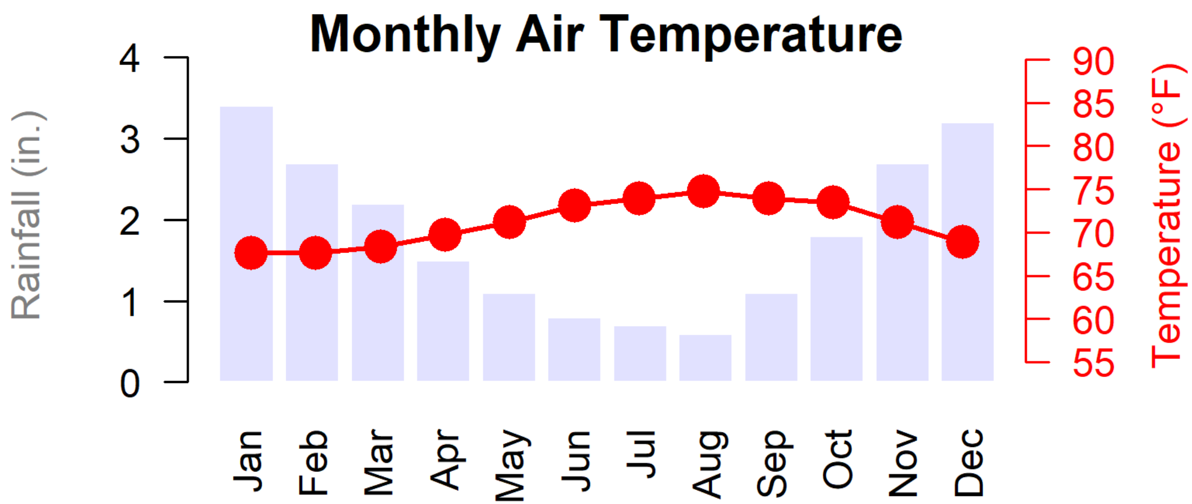


Figure 8. Mean monthly air temperature at Lanai with monthly rainfall in the background.

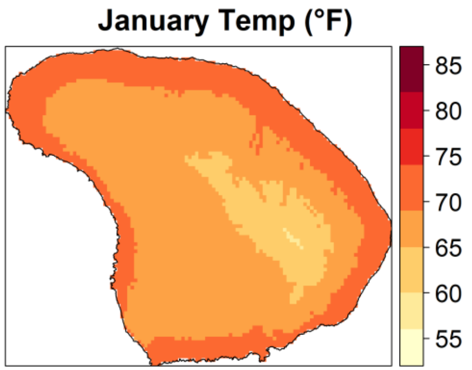


Figure 9. Monthly air temperature maps for the coldest (top) and hottest (bottom) months.

Giambelluca et al. (2013;2014)

Average Monthly Climate

Monthly Rainfall: Lana‘i

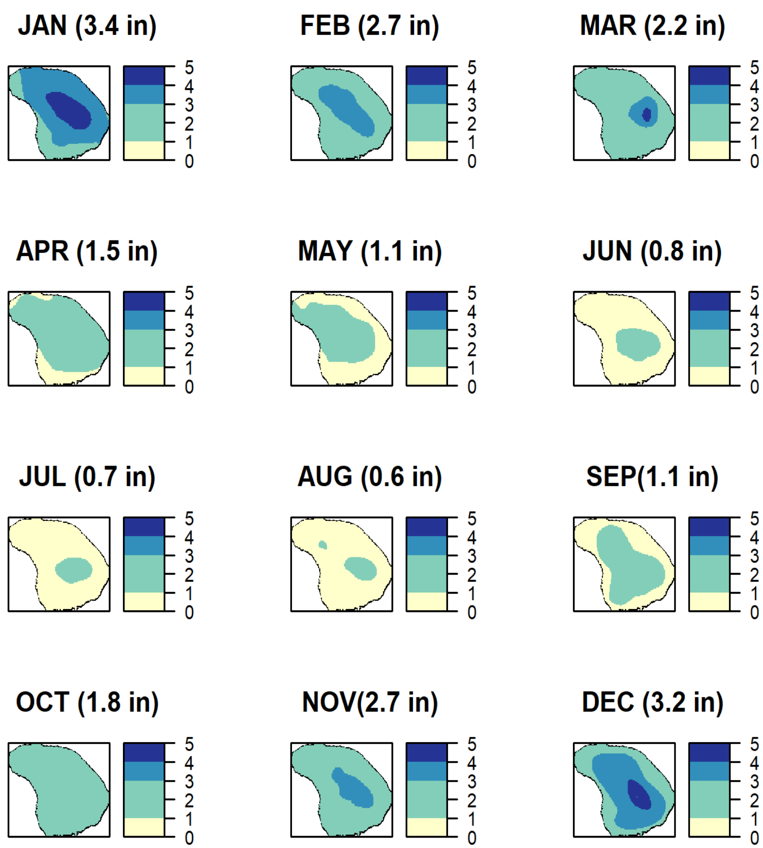


Figure 10. Mean monthly rainfall Lanai with area average shown in heading of each plot.

Monthly TemperaturF: Lana‘i

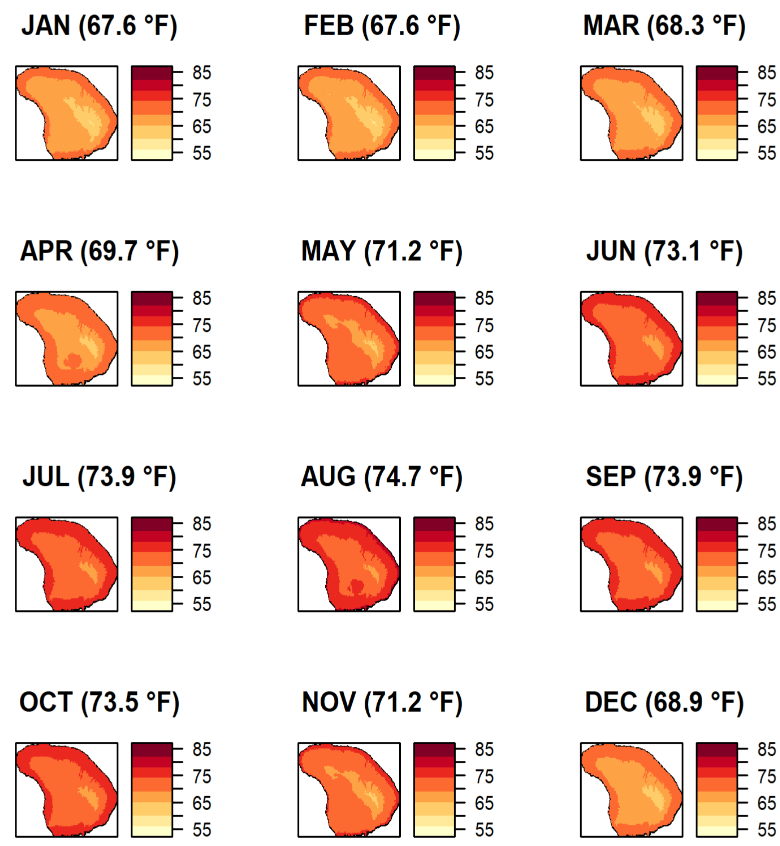


Figure 11. Mean monthly temperature at Lanai with area average shown in heading of each plot.

Giambelluca et al. (2013;2014)

Average Seasonal Rainfall

Hawaii has two distinct 6-month seasons of rainfall: hooilo (Wet season: November to April) and kau (Dry season: May to October). Average Wet season monthly rainfall across Lanai is 2.6 in and Dry season is 1 in. These monthly values are in the 34 and 2 percentiles for rainfall across the whole state, respectively.

Management plans should anticipate and minimize negative impacts of these seasonal rainfall variations.

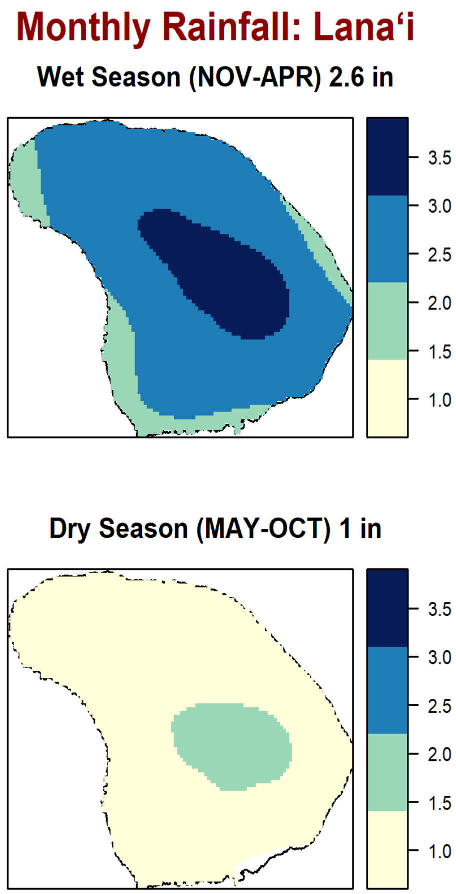


Figure 12. Average monthly rainfall maps for the wet (top) and dry (bottom) seasons. Lanai.

Giambelluca et al. (2013)

Average Monthly Climate Table

Lanai

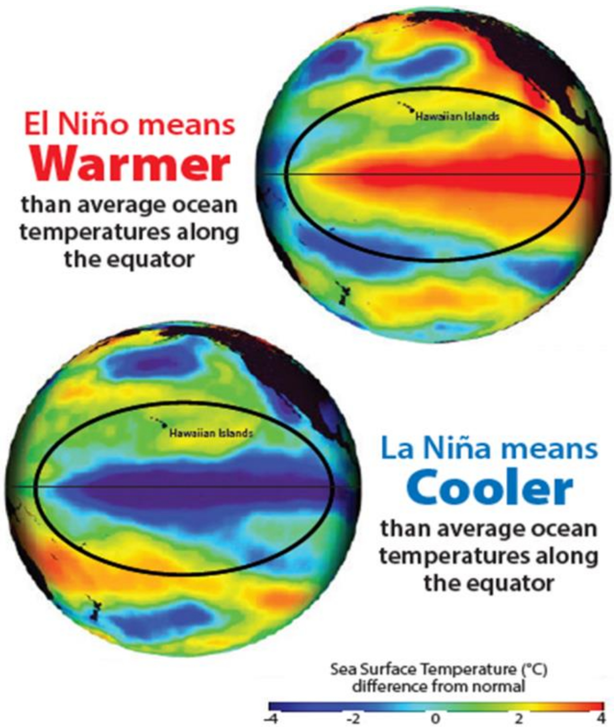
Variable	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
RF [in]	3.4	2.7	2.2	1.5	1.1	0.8	0.7	0.6	1.1	1.8	2.7	3.2	22.0
Min TA [°F]	60.4	60.4	61.2	62.5	63.9	65.7	66.6	67.4	66.7	65.9	64.4	62.0	64.0
Mean TA [°F]	67.6	67.6	68.3	69.7	71.2	73.1	73.9	74.7	73.9	73.5	71.2	68.9	71.1
Max TA [°F]	76.7	76.6	77.0	78.0	79.3	81.2	82.1	82.9	82.8	81.9	79.6	77.5	79.7
RH [%]	79.0	78.0	79.0	79.0	80.0	79.0	79.0	78.0	78.0	79.0	79.0	79.0	79.0
CF [%]	43.0	44.0	50.0	49.0	46.0	42.0	40.0	38.0	32.0	44.0	44.0	41.0	43.0
ET [in]	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	18.0
SM [%]	45.0	44.0	40.0	34.0	27.0	22.0	19.0	15.0	20.0	30.0	38.0	43.0	32.0
S [W m/2]	170.0	199.0	215.0	238.0	241.0	251.0	247.0	245.0	235.0	196.0	173.0	165.0	215.0

Table 2. Average monthly climate variables characteristics at Lanaʻi. Where, RF is rainfall; Min TA is average minimum air temperature Mean TA is average air temperature; Max TA is average maximum air temperature; RH is relative humidity; CF is cloud frequency; ET is evapotranspiration; SM is soil moisture; S is shortwave downward radiation: ANN, is annual total for rainfall and annual average for all other variables.

Giambelluca et al. (2013;2014)

Part 3: Climate Variability

Rainfall and temperature in Hawaii can vary greatly from year-to-year due to natural climatic systems such as the El Niño-Southern Oscillation (ENSO). ENSO is a periodic fluctuation of ocean temperatures in the tropical Pacific, and this has a strong influence on rainfall variability. ENSO consists of five phases, as shown in the graph below.



https://www.climate.gov/enso

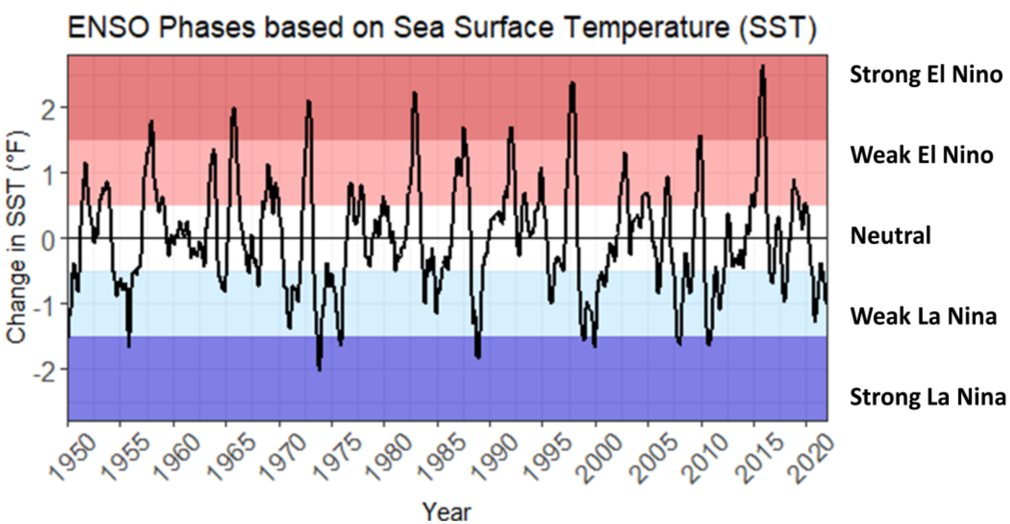


Figure 13. Timeseries of changes in sea surface temperature (SST) and associated ENSO phase from 1950 - 2022. Lanai.

https://origin.cpc.ncep.noaa.gov/

Seasonal Rainfall and ENSO

In Hawaii, the Warm (El Niño) phase typically brings below average rainfall during the wet season, and above average rainfall in the dry season. This pattern is reversed for the Cool (La Niña) phase.

At Lanai, the wet season during a Strong El Niño is 33% dryer than the long-term wet season average, and the dry season during a Strong La Niña is 60% dryer than average. These patterns influence drought conditions and wildfire susceptibility, and management activities can benefit from incorporating this ENSO-influenced seasonal rainfall variability.

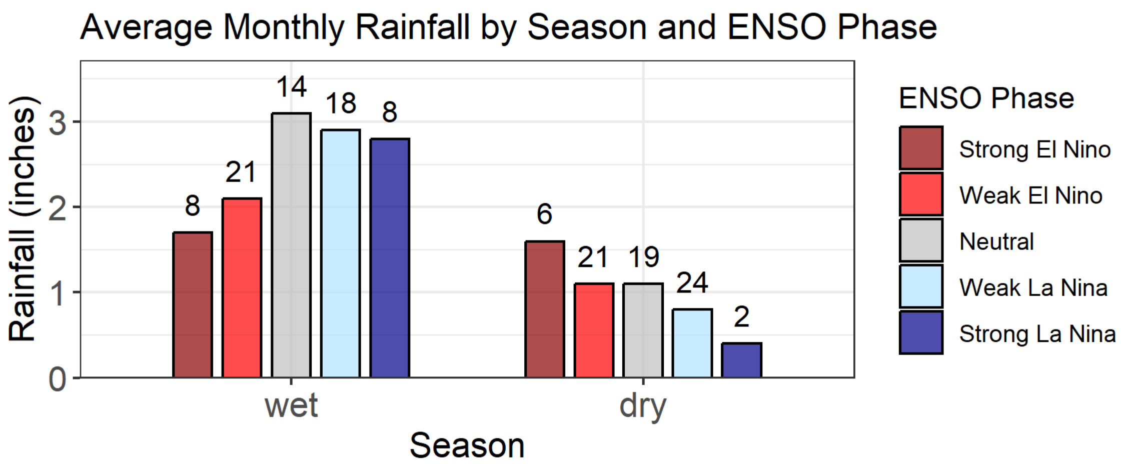


Figure 14. Barplot of average monthly rainfall grouped by season and ENSO phase. Numbers above the bars are how many seasons from 1950 to 2022 fell within each ENSO phase.

Long-Term Trends in Rainfall

Linear trends in annual and seasonal rainfall at Lanai have been calculated over three different periods since 1920 to show long, mid, and short-term trends. The directions of change for the annual plot are shown below.

Period	Trend
1920 - 2022	Decrease
1980 - 2022	Decrease
2010 - 2022	Increase

Table 3. Direction of trendline for annual average monthly rainfall over three periods within the record.

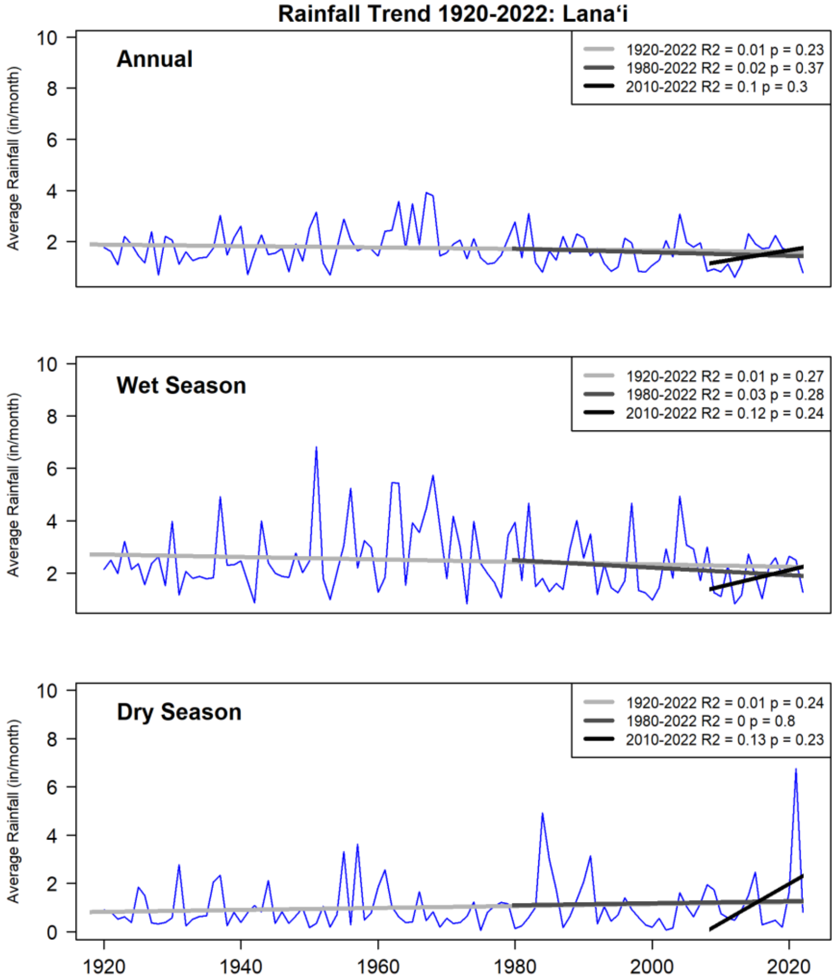


Figure 15. 102-year (1920-2022) rainfall time series at Lanai with linear trends. Trendlines with p-value < 0.05 are statistically significant.

Frazier et al. (2016); Lucas et al. (2022); See Annex I

Trends in Air Temperature

Trends in air temperature have been calculated over a 32-year record at Lanai. From 1990 to 2022 average annual air temperature has increased by 1°F.

At this site there is an average range of 18.2°F between the hottest and coldest months within a single year. The highest monthly temperature of 82.1°F was recorded in September 2019.

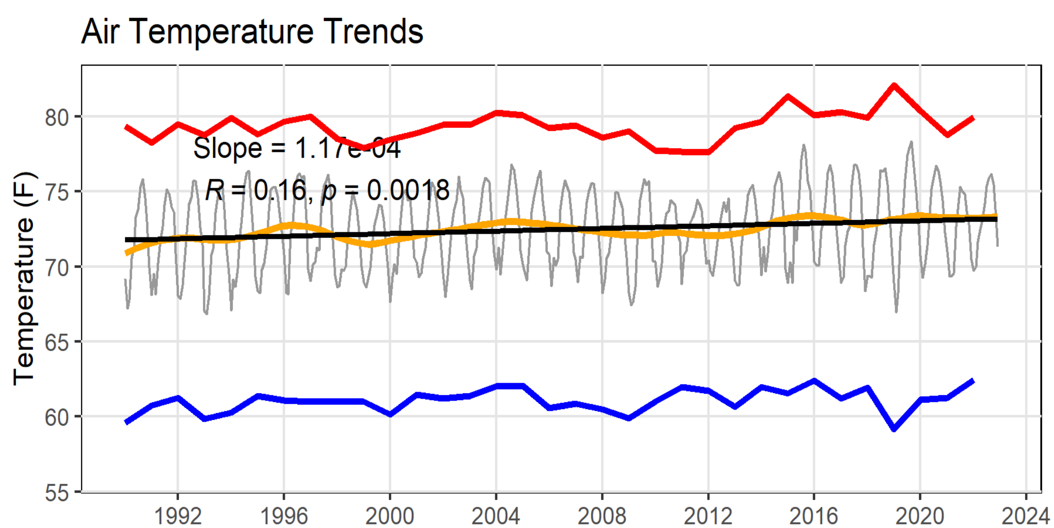


Figure 16. 32-year (1990 ?? 2022) monthly air temperature time series at Lanai. The linear trend is determined to be statistically significant when the p-value is less than 0.05.

https://www.hawaii.edu/climate-data-portal/

Part 4: Drought and Fire History

Lanai

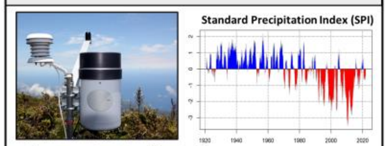
Drought is a prominent feature of the climate system in Hawaii and can cause severe impacts across multiple sectors. Droughts in Hawaii often result in reduced crop yields, loss of livestock, drying of streams and reservoirs, depletion of groundwater, and increased wildland fire activity. These impacts can cause substantial economic losses as well as long-term damage to terrestrial and aquatic habitats.

Five Types of Drought

There are five major types of drought. During droughts there is sometimes a progression from one type to the next. Depending on local factors, these drought types can also happen simultaneously and at different levels of severity.

Time (duration of drought) →

Meteorological



Climate station; Monthly rainfall measurements

Measurements of rainfall amount and duration fall below their normal amount.

Factors of Severity:

- Natural climate variability
- Climate change

Agricultural

Dry coffee plant; Cattle grazing in drought conditions

Agricultural yield is reduced (biomass, quality) due to insufficient water.

- Fresh water sources
- Crop suitability and timing

Hydrological

Dry stream bed; Reservoir with low water level

Less water in streams, lakes, reservoirs, or aquifers.

- Surface water management
- Groundwater recharge

Ecological

Water-stressed plants and landscape; forest fire

Degradation of nature. Plant/animal mortality, wildfire, habitat change.

- Biodiversity
- Fire management

Socioeconomic

Negative impacts to social and economic systems. Increased costs, reduced public health and safety.

Factors of Severity:

- Community awareness
- National/global support

Drought-stricken rural landscape; Wildfire next to residences.

Frazier et al. (2019)

Identifying Droughts Using the Standard Precipitation Index

The Standardized Precipitation Index (SPI) is one of the most widely used indices for meteorological drought. SPI compares current rainfall with its multi-year average, so that droughts are defined relative to local average rainfall. This standardized index allows wet and dry climates to be represented on a common scale. Here, 100+ years of monthly rainfall are used to used to calculate SPI-12, which compares how a 12-month period compares with all 12-month periods in the record. SPI-12 is a good measure of sustained droughts that affect hydrological processes at Lanai.

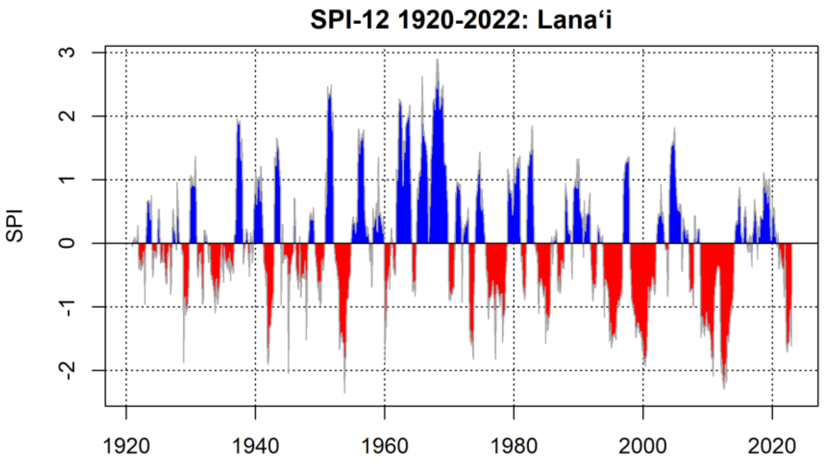


Figure 18. 102-year (1920-2022) SPI-12 time series at Lanai. Positive SPI (blue) indicate wet periods, negative SPI (red) indicate dry periods.

Frazier et al. (2016); Lucas et al. (2022)

A 100+ Year History of Drought

Negative SPI values (dry periods) are inverted to show a complete drought timeseries at Lanai. Dashed lines and corresponding color coding indicates instances of Moderate (SPI > 1), Severe (SPI > 1.5), and Extreme (SPI > 2) drought.

A total of 14 droughts were observed over the entire record with a total of 13 drought events of severe strength or greater. The longest drought lasted for a total of 64 months (see Annex III).

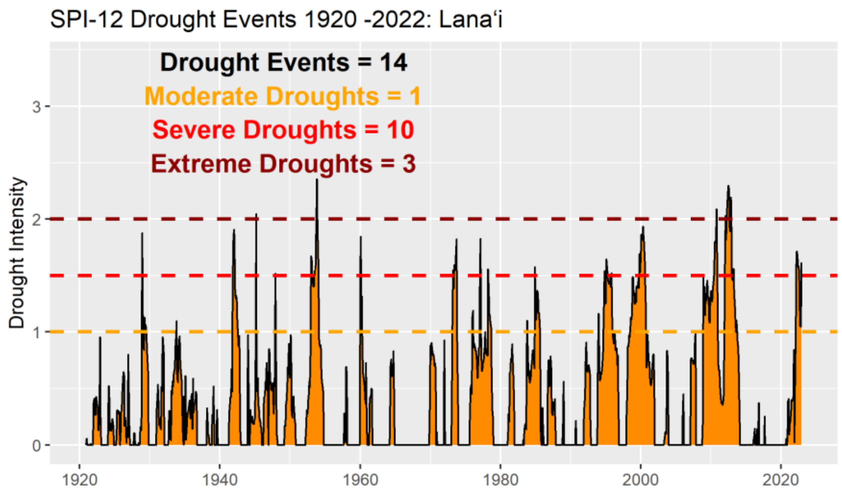


Figure 19. 102-year (1920-2022) SPI time series (reversed axis) at Lanai. Dashed lines show, moderate (yellow), severe (red), and extreme (dark red), drought thresholds.

Frazier et al. (2016); Lucas et al. (2022)

Short-term vs Long-term Droughts

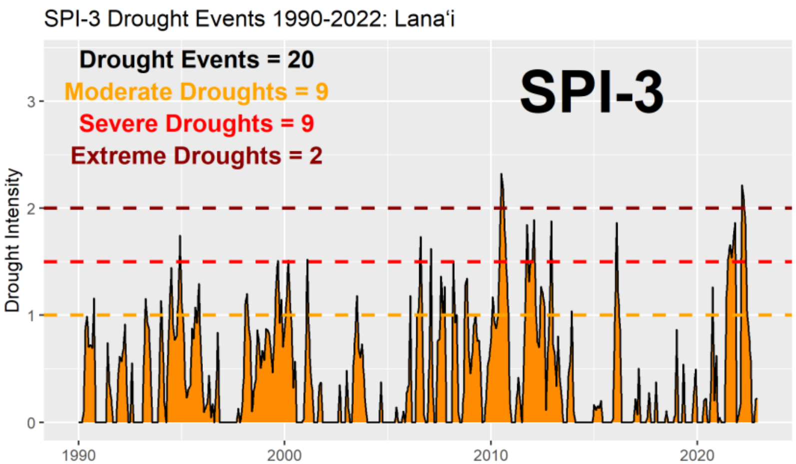


Figure 20. SPI-3 time series (reversed axis) at Lanaʻi.

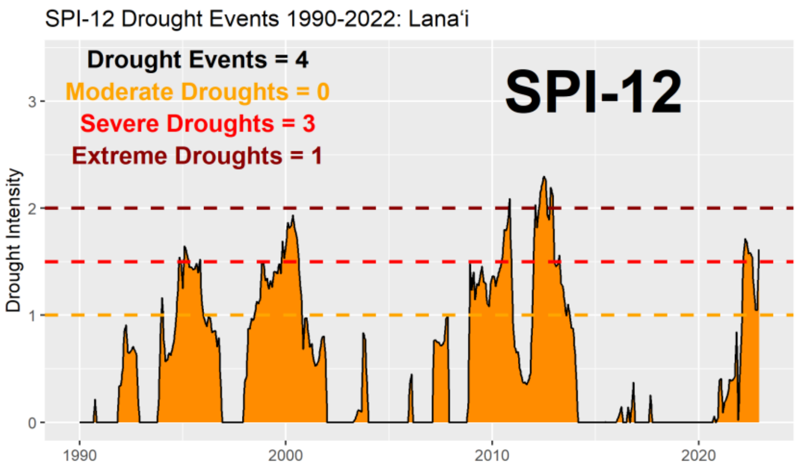


Figure 21. SPI-12 time series (reversed axis) at Lanaʻi.

SPI-3 provides a comparison of rainfall over a specific 3-month period and reflects short-term conditions. SPI-12 provides 12-month comparisions and reflects long-term conditions. It is important to consider both timescales for planning.

As of December 2022 the most recent drought events are as follows:

SPI-3: Currently not in drought. Most recently there was extreme drought from Jan 2022 - Aug 2022. Current SPI-3 value 0.2.

SPI-12: Currently in severe drought since Jan 2021. Current SPI-12 value -1.6.

Fire Occurrence in Lanai

Ecological drought often drives an increase in wildfire occurrence. In Hawaii, wildfires are most extensive in dry and mesic non-native grass and shrublands. During drought events, wildfire risk in these areas increases rapidly. Currently, agricultural abandonment is resulting in increased grass and shrublands. This combined with recurring incidences of drought is expected to increase the risk of future wildfire in Hawaii.

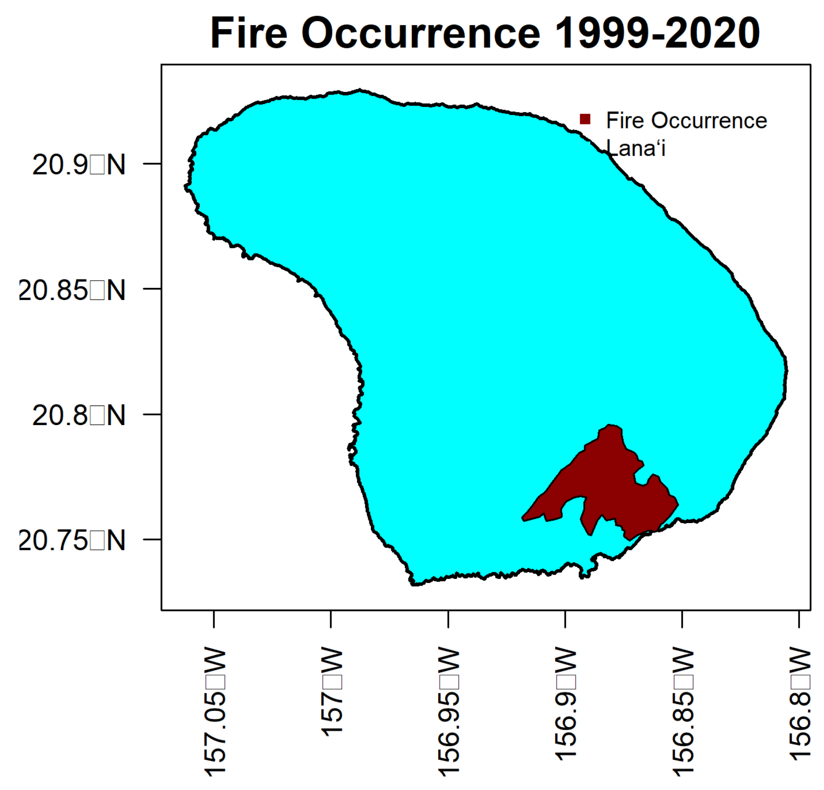


Figure 22. The map shows wildfires that have occurred on the island of Lanai between 1999 and 2020.

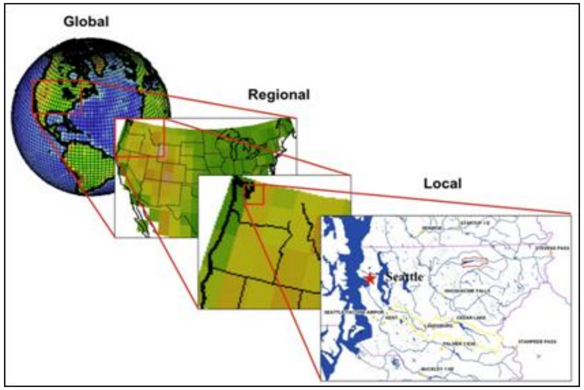
Trauernicht, 2019; Frazier et al. (2022)

Part 5: Future Climate
Lanai

Global Climate Models are used to predict future changes in rainfall and temperature, simulating future conditions under different scenarios for how much carbon dioxide we emit into the air. Two common scenarios are RCP 4.5 which assumes we reduce our carbon emissions, and RCP 8.5, which is an increased emissions scenario.

Data downscaling is used make these models useful at the local management level. In Hawaii, two types of downscaled projections are available:

Statistical: Available for Mid & End-of-Century
Dynamical: Only available for End-of-Century



Both downscaling projections are presented here. These two projections sometimes agree with each other, and other times they provide conflicting results. When viewing the maps, we can observe where these similarities and differences are, for example which areas show reduced rainfall under both projections.

See Annex II

Average Rainfall Change Mid-Century (2040-2070)

Rainfall for Years 2040-2070

Change in Annual Rainfall
-5 to -6 in/year
-22 to -25% change from present

These Statistical Downscaling maps show the projected change in rainfall under RCP 4.5 and 8.5 conditions. At Lanai, annual rainfall is projected to decrease by 5 inches (RCP 4.5), or decrease by 6 inches (RCP 8.5) by mid-century.

Changes in Annual Rainfall by Mid-Century

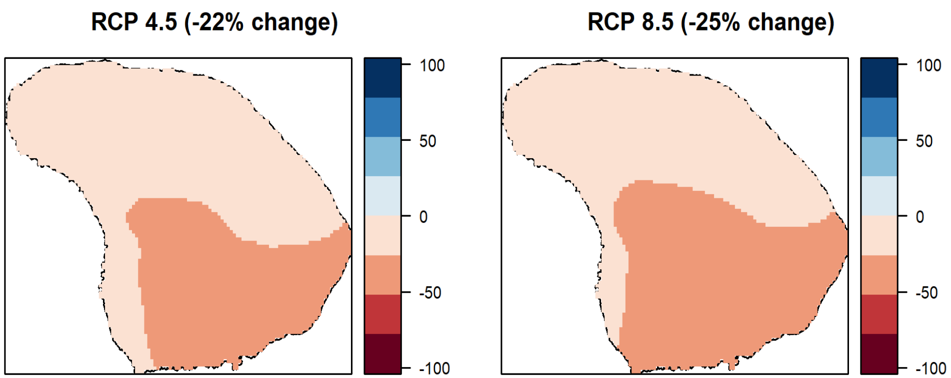


Figure 23. Downscaled future rainfall projections (% change from present) at Lanai by mid-century (2040-2070) using Statistical Downscaling. RCP 4.5 (left) and RCP 8.5 (right).

Timm et al., 2015; See Annex II

Average Rainfall Change End-of-Century (2100)

Rainfall in the Year 2100

Annual

-5 to -8 in/year

-35 to -6 % change from present

These Dynamical and Statistical Downscaling maps show the projected change in rainfall under RCP 4.5 and 8.5 conditions. At Lanai, annual rainfall is projected to decrease by 5 inches (RCP 4.5), or decrease by 8 inches (RCP 8.5) by end-of-century.

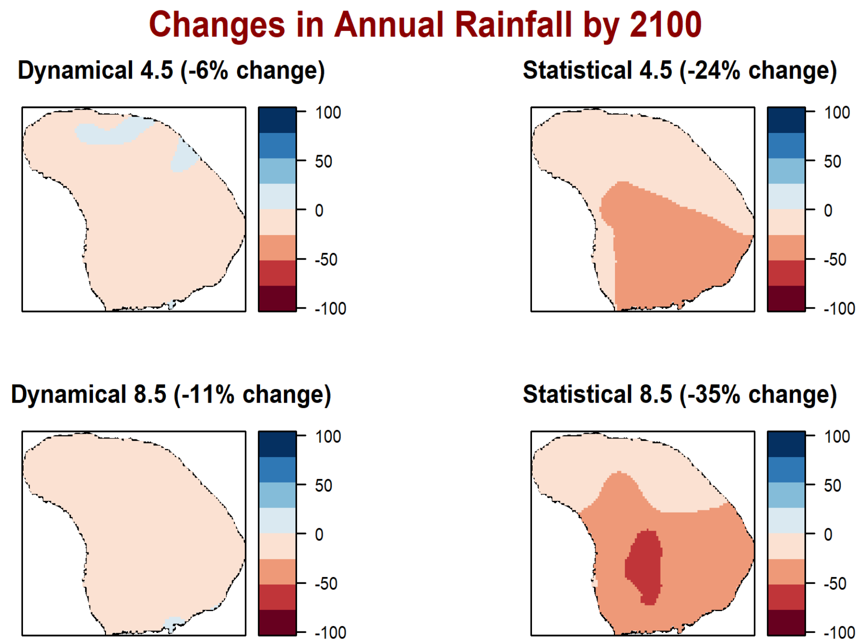


Figure 24. Downscaled future rainfall projections (% change from present) at Lanai by end-of-century (2100), using both Dynamical and Statistical downscaling. RCP 4.5 (top row) and RCP 8.5 (bottom row).

Timm et al., 2015; Zhang et al., 2016; See Annex II

Average Air Temperature Change Mid-Century (2040-2070)

Air Temp. for Years 2040-2070

Change in Air Temperature
2.3 to 3.2°F
3 to 5% change from present

These Statistical Downscaling maps show the projected change in air temperature under RCP 4.5 and 8.5 conditions. At Lanai, air temperature is projected to increase by 2.3°F (RCP 4.5), or increase by 3.2°F (RCP 8.5) by mid-century.

Changes in Air Temperature by Mid-Century

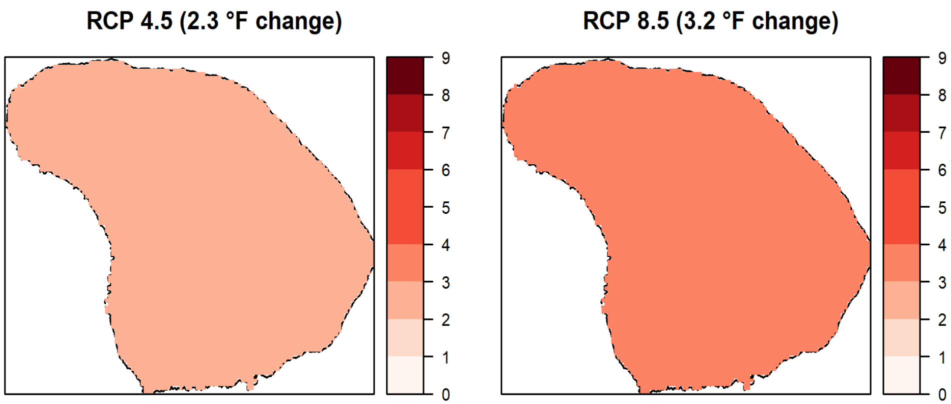


Figure 25. Downscaled future temperature projections (°F change from present) at Lanai by mid-century (2040-2070) using Statistical Downscaling. RCP 4.5 (left) and RCP 8.5 (right).

Average Air Temperature Change End-of-Century (2100)

Air Temp. in the Year 2100

Change in Air Temperature
2.9 to 5.6°F
4 to 8 % change from present

These Dynamical and Statistical Downscaling maps show the projected change in air temperature under RCP 4.5 and 8.5 conditions. At Lanai, air temperature is projected to increase by 2.9°F (RCP 4.5), or increase by 5.6°F (RCP 8.5) by end-of-century.

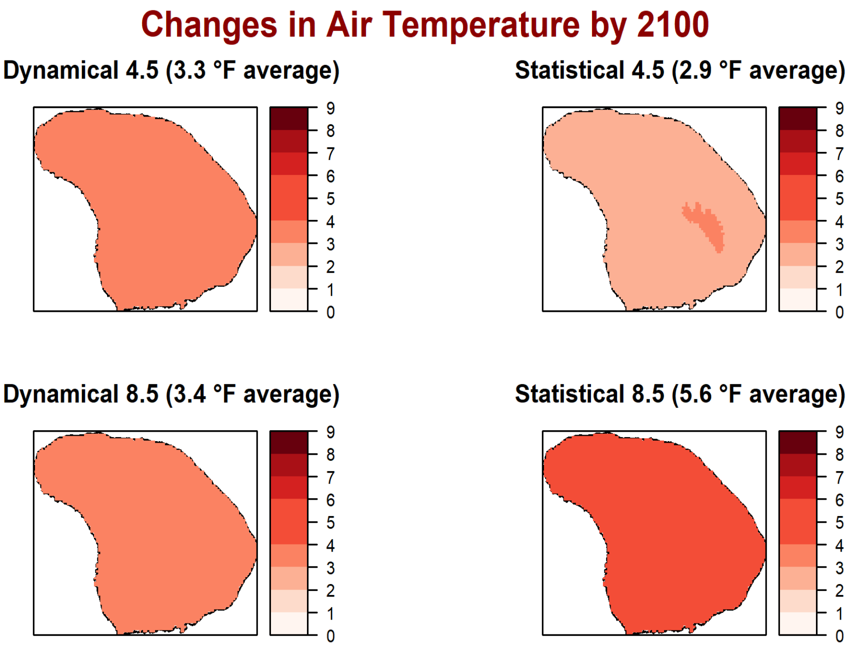


Figure 26. Downscaled future rainfall projections (% change from present) at Lanai by end-of-century (2100), using both Dynamical and Statistical downscaling. RCP 4.5 (top row) and RCP 8.5 (bottom row).

Timm 2017; Zhang et al., 2016;
See Annex II

Part 6: CCVD Summary

Lanai

Lanaʻi (Lanai) is located on the island of Lanai at mean elevation of 1037 ft (rangF: 0 to 3382 ft). Rainfall varies over the course of the year with a maximum of 3°F occurring in January and a minimum of 1°F occurring in August. On average, wet season months (Nov-Apr) receive 1.6 in more rainfall than dry season months (May-Oct). Seasonal rainfall can vary within the unit as well, with dry season rainfall ranging from 4 to 13°F and wet season rainfall ranging from 11 to 23°F across the 3382 ft elevation gradient. Rainfall can also vary considerably from year-to-year with the driest years occurring during a Strong El Niño event, when on average, 33% less rainfall is received, relative to the long-term average. The average temperature at Lanai is 71.1°F but temperature ranges from 68°F to 75°F over the course of the year. Drought is a reoccurring feature in the climate system of Lanai with a total of 14 occurring over the record which is approximately 1.4 per decade. A total of 13 drought events were at severe strength or greater and the longest drought lasted for a total of 64 consecutive months. Future projections of rainfall are uncertain, with end-of-century annual changes ranging from -35 to -6. Future projections of temperature suggest an increase of 2.3°F to 3.2°F by mid century (2040-2070) and an increase of 2.9°F to 5.6°F by the end of the century (2100).

External Resources

For more Information

US Drought Monitor
https://droughtmonitor.unl.edu/

NIDIS Current Hawaii Drought Maps
https://www.drought.gov/states/hawaii

State of Hawaii Drought Plan
https://files.hawaii.gov/dlnr/cwrm/planning/HDP2017.pdf

Hawaii Climate Data Portal
https://www.hawaii.edu/climate-data-portal/

ENSO Current Phase and Discussion
https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml

Pacific Drought Knowledge Exchange
http://www.soest.hawaii.edu/pdke/

Pacific Fire Exchange
https://www.pacificfireexchange.org/

Ahupuaa GIS Layer Storymap
https://storymaps.arcgis.com/stories/1ad9fcf7f2c345a58adef0997fce9b5d

Acknowledgements

Ryan Longman, Abby Frazier, Christian Giardina, Derek Ford, Keri Kodama, Alyssa Anderson (PDKE), Mari-Vaughn Johnson, Heather Kerkering, Patrick Grady, Elliott Parsons (PI-CASC), Clay Trauernicht, Melissa Kunz, Cherryle Heu (NREM, UH Manoa), Amanda Sheffield, Britt Parker, John Marra (NOAA), Sean Cleveland, Jared McLean (ITS, UH Manoa), Katie Kamelamela (Arizona State University), Thomas Giambelluca (WRRC, UH Manoa), Jim Poterma (SOEST, UH Manoa), Carolyn Auweloa (NRCS), Nicole Galase (Hawaii Cattlemen's Council), Mark Thorne (CTAHR, UH Manoa)

Suggested Citation

Longman, R.J., Ford, D.J., Anderson, A., Frazier, A.G, Giardina, C.P (2023). Climate Change, Climate Variability and Drought Portfolio Lana'i Pacific Drought knowledge Exchange CCVD Series Version 4.5.

For the most up-to-date version of this portfolio contact Derek Ford: fordd@eastwestcenter.org for more information.

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Annex I: 100+ Year Rainfall

The 100+ year monthly rainfall dataset was drawn from two unique gridded products. We used data from Frazier et al. (2016) for the period 1920-1989 and Lucas et al. (2022) for the period 1990-2022. Given that two unique data sets and methods were used to make these two products we show the 1:1 Statistical relationship between the two products for a 23-year overlap (1990-2012) with the datasets and associated error metrics.

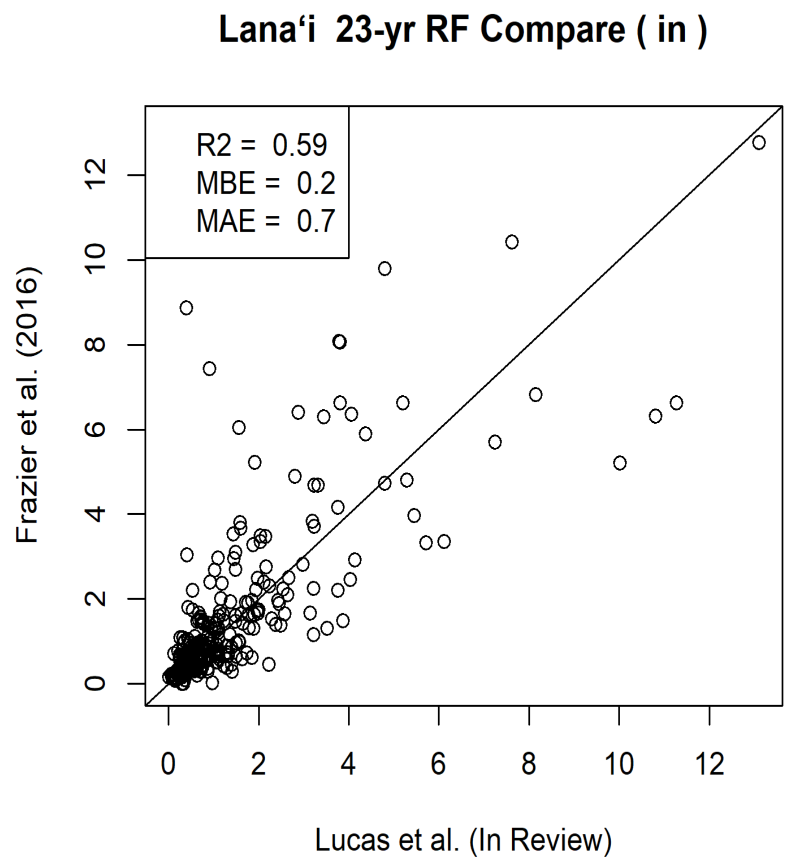
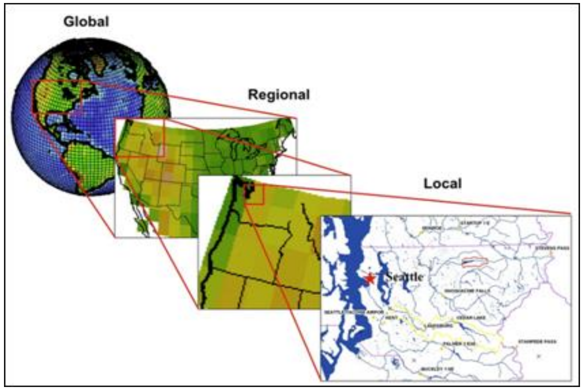


Figure A1: One to one comparison of 23-years (1990-2012) of monthly rainfall from two unique datasets for Lanai, and associated error metrics; R2, is the coefficient of determination, MBE, is the mean bias error, MAE, mean absolute error.

Frazier et al., 2016; Lucas et al., (2022)

Annex II: Climate Downscaling in Hawaii

Two types of downscaling products were used in this analysis. Here we explain some of the nuances between the two. Dynamical Downscaling (Zhang et al., 2016), feeds GCM output into a regional model that can account for local topographic and atmospheric phenomena at much finer resolutions (e.g. 1 km). End-of-century projections (2100) encompass the period 2080-2099. Statistical Downscaling (Timm et al., 2015, Timm, 2017), develops a relationship between GCM model output and station data for a historical period and then uses this established relationship to make projections for two future scenarios. End-of-century projections (2100) encompass the period 2070-2099 (2100), Mid-century projections encompass the period 2040-2070.



Annex III: Drought Events (1920 - 2022)

Start Date	End Date	Duration (months)	Average Intensity	Peak Intensity	Magnitude
1928-09-01	1929-11-01	15	0.7915726	1.877839	11.873589
1932-10-01	1936-10-01	49	0.4468154	1.098872	21.893953
1941-06-01	1943-01-01	20	0.9753147	1.907155	19.506295
1944-06-01	1946-01-01	20	0.3897759	2.047553	7.795519
1947-02-01	1948-04-01	15	0.5818200	1.518361	8.727301
1952-05-01	1954-11-01	31	1.0397095	2.356203	32.230995
1960-02-01	1961-01-01	12	0.8452711	1.847333	10.143253
1973-03-01	1974-01-01	11	1.3199708	1.824758	14.519679
1975-10-01	1979-01-01	40	0.8653388	1.826498	34.613552
1983-07-01	1985-11-01	29	0.8001521	1.576932	23.204412
1993-12-01	1996-12-01	37	1.0418495	1.646453	38.548431
1998-02-01	2002-01-01	48	1.1556517	1.935751	55.471283

Table A1. SPI-12 drought characteristics at Lanaʻi identified in the SPI-12 timeseries. Duration is the number of months the drought persisted; Average Intensity is the average absolute SPI; Peak Intensity is the highest SPI value calculated during the drought Magnitude is sum of absolute SPI values during the drought.

Annex III: Drought Events (1920 - 2022)

Start Date	End Date	Duration (months)	Average Intensity	Peak Intensity	Magnitude
2008-12-01	2014-03-01	64	1.289715	2.297941	82.54178
2021-01-01		25	0.805881	1.715124	20.14702

Table A1. SPI-12 drought characteristics at Lana‘i identified in the SPI-12 timeseries. Duration is the number of months the drought persisted; Average Intensity is the average absolute SPI; Peak Intensity is the highest SPI value calculated during the drought Magnitude is sum of absolute SPI values during the drought.

Pacific Drought Knowledge Exchange