Performance of a Louvered Screen Fog Gauge as a Proxy for Canopy Throughfall in a Hawaiian Montane Cloud Forest

ERIC HANSEN¹ AND JAMES JUVIK²
¹Tropical Conservation Biology and Environmental Science, University of Hawai`i at Hilo, Hilo, Hi 96720
²Geography and Environmental Studies, University of Hawai`i at Hilo, Hilo, Hi 96720

Abstract: Wind-driven, horizontal cloud water interception (CWI) by vegetation, also known as fog-drip, has been recognized for its important role in the ecology and hydrology of tropical montane cloud forests (TMCF) and coastal fog deserts around the world. In recent years various passive fog gauge designs have been advanced to characterize site specific CWI potential and evaluate the contribution of this “occult” water source to forest canopy throughfall in fog prone areas. Here we demonstrate the performance of a rain-shielded, louvered screen fog gauge (LSFG) in predicting tree canopy (Araucaria columnaris) throughfall along a trade wind exposed, mountain ridge TMCF (~800-1000 m elevation) on the island of Lāna`i. With an exceptionally high incidence of fog dominated precipitation events along this ridge, and a linear array of planted trees with canopy architecture ideally suited to cloud water interception, the open-site LSFG provided a robust characterization of event scale canopy throughfall compared to concurrent open-site rainfall which showed no significant relationship to throughfall.

Keywords: cloud water interception, fog drip, louvered-screen fog gauge, tropical montane cloud forest, Hawai`i

Introduction
Quantifying Tropical Montane Cloud Forest (TMCF) canopy water balance has proved challenging due to the difficult nature of measuring the horizontal cloud water interception (CWI) component of precipitation, and separating this from non-vertical rainfall. Although there is an agreement that fog contributes to the water budget, the degree of this input is uncertain and also tends to exhibit high spatial variability.

In Hawai`i, a cylindrical, LSFG has been used for five decades in mountain fog studies. In the 1950’s a LSFG were deployed for fog collection on the island of Lāna`i (Ekern 1964). Bruce (1966) tested the fog capture efficiency of 13 types of flat screen panels in the Ko`olau Gap region of East Maui, and found that Kaiser louvered aluminum ShadeScreen® (Phifer Wire Products Inc. Tuscaloosa, Alabama USA) used in LSFG construction proved to have comparatively high collection efficiency. From the 1970’s onward a modified form of the LSFG has been utilized extensively for cloud forest research in the Hawaiian Islands (Juvik and Perreira 1974, Juvik and Ekern 1978, Juvik and Nullet 1995a, Delay 2005 and Juvik et al. in press). Outside of Hawai`i, the LSFG has been used in such areas as temperate Sequoia forests of California (Buckard et al. 2003) and TMCF sites in Costa Rica, Mexico and Northern Thailand (Burgess and Dawson 2004, Ward 2007 and Tanaka et al. 2010).

Various other fog gauge designs have been employed for fog capture in different areas worldwide. These include wire harps and a fixed panel, plastic screen fog collector (Schemenauer and Cereceda 1994). However these devices, especially the Schemenauer-Cereceda fog gauge have been noted to exhibit major design limitations (Juvik and Nullet 1995a). The panels have a fixed orientation. In montane regions, both wind direction and speed can be quite variable making it problematic for a single panel with fixed orientation to accurately record cloud water under all wind conditions. Secondly, the panel collector provides no mechanism for separating the horizontal and other non-vertical components of precipitation, a primary objective of a fog gauge. Lastly, the Schemenauer-Cereceda collector is made from a “stretchable” plastic mesh, and thus, depending on how deployed, can present a variable catchment surface area per unit vertical area.

The objective of the passive fog collector is to compliment open-site rainfall data by providing standardized cloud-water measurements for inter-site comparison and an analog measure of CWI by nearby vegetation or artificial catchment structures (Juvik and Nullet 1995 a). The LSFG, with its cylindrical form (wind direction independent profile), definable surface area (rigid, louvered screen structure) and rainfall shielded “hat” meets general design criteria for such measurements. Frumau et al. (2010) tested the performance of various fog gauges (wire harp, louvered gauge and tunnel gauge) under wet and windy conditions in Costa Rica. It was found that the LSFG was most effective, yielding measurements independent of wind speed and direction, and showing excellent screen drainage characteristics.
Besides Ekern’s (1964) seminal study evaluating the fog-drip component of precipitation under planted Cook Pine trees (*Araucaria columnaris*), relatively few studies in Hawai‘i (e.g. Juvik and Nullet 1995b and Juvik and Nullet 1998) have attempted to directly link open-site LSFG output with adjacent forest canopy throughfall. In a recent preliminary trial (145 days during 2000-2001) of the LSFG ability to predict native cloud forest canopy throughfall in the Kohala mountains (1160m) of Hawai‘i, Juvik et al. (2008) demonstrated that even when the overall fog contribution to forest canopy throughfall was only about 20%, the open-site, LSFG was a significantly better event-scale predictor of canopy throughfall ($r^2 = 0.63$) than open-site rainfall measurements alone ($r^2 = 0.53$).

In this study we evaluate the ability of the LSFG in predicting event scale CWI and Cook Pine throughfall at trade wind exposed, ridge-line TMCF sites (800-1000 m elevation) on the Island of Lāna‘i.

**Methods**

**Study Site**

The study site on the Lāna‘ihale summit ridge of Lāna‘i Island (Fig. 1) supports a linear array of Cook Pines (*Araucaria columnaris*) that were planted in the 1930s-50s with the specific expectation of CWI enhancement of local groundwater recharge (Munro 2007). The generally arid island of Lāna‘i lies in the rain shadow (with respect to prevailing NE trade winds) of nearby Maui Island. Consequently the summit area (800-1050 m) of Lāna‘i receives reduced annual rainfall (~1000 mm), but significant cloud immersion and CWI. In this study, precipitation sampling sites along the ridge (Fig. 2) were selected to effectively bracket Ekern’s (1964) earlier single study site (838 m) and additionally characterize CWI at higher elevations. Juvik et al. (2011) provides further details of the study area.

![Fig. 1. Lāna‘ihale summit ridge (elev. ~ 900 m) with trade wind exposed, planted Cook Pine (*Araucaria columnaris*).](image1)

**Rain and Fog Measurements**

The LSFG has been described in detail by Juvik and Nullet (1995a, 1995b). The louvered aluminum screen collector gathers horizontally moving cloud droplets that drip down by funnel and plastic tubing into a covered rain gage (Fig. 3). The LSFG cylinder (12.7 cm dia. x 40.6 cm ht.) presents a vertical silhouette of 516 cm$^2$. Based on open-site rain gage orifice area, a scaler can be applied to convert fog screen output to a “unit vertical catch,” equivalent in the rain gage (Juvik and Ekern, 1978). A conical, stainless-steel, rain exclusion “hat” (dia. 58 cm) shields the fog screen below from vertical rainfall and most wind blown rain drops (> 0.1 mm dia., at wind speeds < 5m/sec.) Under high wind conditions, some non-vertical rainfall will enter the fog gage. However, with simultaneous wind speed, open-site rainfall measurements, and event drop-size estimates available, corrections can be made to the LSFG output. At each ridge-line monitoring site a standard recording rain gauge and LSFG (mounted at 3 m above the ground; Fig. 3) were paired at an open site exposed to the prevailing NE trade winds. Precipitation was logged at hourly intervals.

![Fig. 2. Elevation of fog, rain and Cook Pine throughfall sampling stations along Lāna‘ihale summit ridge.](image2)

**Fig. 3. Rain shielded, louvered screen fog gauge (LSFG) on the Lāna‘ihale summit ridge.**

**Cook Pine throughfall monitoring**

Adjacent to open-site precipitation monitoring sites along the Lāna‘ihale summit ridge (between 762m and 1,021 m; Fig. 2) a mature, isolated and fully exposed Cook Pine was selected for throughfall measurements. At each site trees of similar size (DBH 64-78 cm, height 21-23 m and projected canopy area ~ 25 m$^2$) were chosen to insure a fair comparison of Cook Pine performance at different elevations across the summit ridge. Under each tree an array of rain gauges was randomly placed beneath the center of the conical canopy (Fig. 4). Rain gauges were modified with trough attachments to better capture canopy throughfall.
Results

We first evaluated LSFG performance in predicting Cook Pine throughfall under conditions with low open-site rainfall but frequent cloud immersion. Precipitation parameters for the unseasonably dry (rainfall) month of October 2007 (at Station #2) are presented in Table 1. With only 2 days during the month recording measurable open-site rainfall, compared to 21-23 days exhibiting fog catch and throughfall, it is obvious that rainfall must necessarily be a poor predictor of the overall precipitation environment. Fig. 5 plots open-site rain (5A) and open-site fog catch (5B) respectively against Cook pine throughfall. With only 2 data points for rain during the entire month there is clearly no significant relationship with Cook Pine throughfall. By contrast the LSFG catch provided a robust prediction ($r^2 = 0.921$) of Cook Pine throughfall over this same period. Compared to the total monthly rainfall (3.3 mm), Cook Pine throughfall totaled 296.4 mm, or nearly 90 times greater than rainfall (Table 1).

Wind speeds during precipitation events typically averaged >6 m$s^{-1}$. Fig. 6 plots open-site rainfall (6A) and fog catch (6B) against Cook Pine throughfall. Because open-site rainfall measurements were usually associated with additional substantial fog input, rainfall alone yielded no significant relationship ($r^2 = 0.015$; Fig

<table>
<thead>
<tr>
<th>Precipitation Characteristics</th>
<th>Rainfall (RF)</th>
<th>Fog Catch (FC)</th>
<th>Canopy Throughfall (TF)</th>
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<tbody>
<tr>
<td>Days with Precipitation</td>
<td>2</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Total Monthly Precipitation (mm)</td>
<td>3.3</td>
<td>104.9</td>
<td>296.4</td>
</tr>
<tr>
<td>Ratio of FC and TF to RF</td>
<td>31.8</td>
<td>89.9</td>
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</tbody>
</table>

Table 1. Lāna’ihale summit ridge precipitation, October 2007 (Station #2, Elevation 944 meters). Open-site rainfall (RF) and fog catch (FC) compared with adjacent Cook Pine throughfall.
6A) with Cook Pine throughfall. By contrast the open-site fog catch proved a highly significant predictor ($r^2 = 0.780$; Fig 6B) of throughfall for these mixed precipitation events.

![Graph](image)

**Fig. 6. Summer 2007 – 2008 (236 days) open-site rain fall, fog catch and Cook Pine throughfall, Station #4 (elev. 1021 m).** A: rainfall vs. throughfall. B: fog catch vs. throughfall (data log-transformed to normalize distribution).

**Discussion and Conclusions**

The LSFG performs well in estimating Cook Pine canopy throughfall at Lāna‘ihale. A modest time lag in event scale throughfall gauge output as compared to the LSFG was observed but could be expected give the higher storage capacity of the tree canopy. Overall the LSFG provided a much better characterization of precipitation-vegetation linkage at this unique TMCF site than open-site rainfall measurements alone. However it should also be noted that this study dealt with a linear array of fully exposed trees on a narrow ridge-line (effectively “leading-edge” trees) and is not likely to represent the magnitude of throughfall conditions to be found within a closed forest canopy (reduced wind speeds and laminar flow). In future, the monitoring and management of Hawaiian and TMCF watersheds elsewhere should benefit from supplemental use of the LSFG (in addition to standard open-site rainfall measurements) to calibrate CWI and related throughfall estimates for different montane forest structural types. This could potentially lead to significant improvement in refining estimates of forest water balance and ground water recharge.

**Acknowledgements**

This work was supported by the Lāna‘i landowner Castle and Cooke LLC, in an effort to better understand watershed hydrology and improve forest management on the island. We particularly thank John Shimizu, Clay Rumbaoa and John Stubbart. A special mahalo to Ethan Bogar and Kimberly and Edward Oyama for their indefatigable data collection and field logistic efforts.

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