A hydro-ecological cross-section of Santa Cruz Island, Galapagos Archipelago

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The Galapagos Islands, renown for their endemic species and unique ecosystems, suffer from a lack of freshwater availability. The volcanic origin of the islands and the atypical dry climate have led to little existence of surface water features. The "Galapagos Islands Integrated Water Studies" project (GIIWS) has aimed its efforts towards the understanding of the hydrological processes in the archipelago, especially in Santa Cruz island.

SEASONAL CHARACTERIZATION IN GALAPAGOS ISLANDS

There are two seasons in the year. The hot season occurring from January to May is characterized by high sea and air temperatures and also by the high variability of rainfall. Rains are convective and with high intensity, but of short duration. Mean air temperature can reach 26°C at the coast and decreases with altitude. During the 2011 hot season, mean temperature in the highlands (650 m.a.s.l) was 21°C.

Figure No.1. Satellite image of the Archipelago during the hot season.

Figure No.2. Photo of the highlands of Santa Cruz Island in the hot season (2011).

The cool "garúa" season comes during June to December, when a semi-permanent fog layer is present above 400 m.a.s.l. Precipitation is mostly orographic and consistent from one month to another and from one year to the next (Trueman & d'Ozouville, 2010). Intensity of rainfall is very low. In the coastal zone, air temperatures are around 22°C. In the highlands during the 2010 cool season , mean air temperature was 17°C.

Figure No.3. Satellite image of the Archipelago during "the garúa" season.

Figure No.4. The highlands of Santa Cruz Island in the l"garúa" season (2010).

WEATHER STATIONS & THROUGHFALL MONITORING

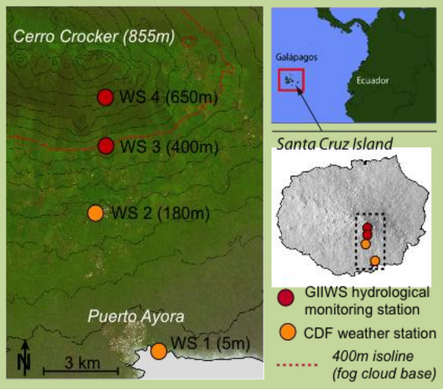

Figure No.5. Map with the location of the four weather stations present in Santa Cruz Island.

Two historical weather stations (WS1 & WS2) are monitored by the "Charles Darwin Research Station". WS1 has a record since 1965 and WS2 since 1987. Recorded variables include: rainfall, sea surface and air temperature and relative humidity.

In addition GIIWS project has installed two more weather stations, **WS3 & WS4,** along the same N-S section on the windward slope of Santa Cruz Island. These stations started their operation in July 2010, during the last "garúa" season. **They include nearby "throughfall" monitoring plots.**

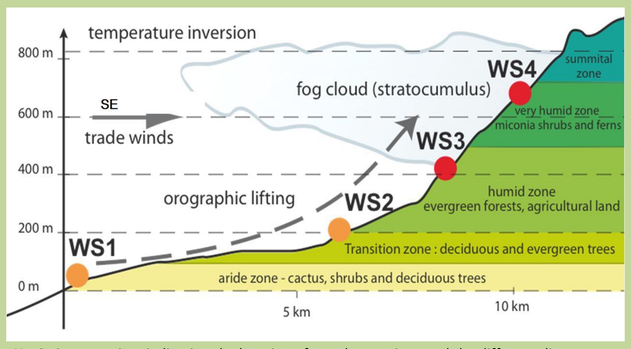

Figure No.6. Cross-section indicating the location of weather stations and the different climate zones by altitude.

Throughfall is the portion of precipitation that goes through the vegetation and reach the soil.

Figure No.7. Photo of the experimentation plot. Troughs and collectors are shown.

Throughfall is measured in a representative plot in two ways:

Troughs dipping to an automatic tipping bucket rain gauge. This set-up requires field dynamic calibration to be carried out.

Collectors consisting of recipients with a funnel on top. These can be used to quantify throughfall spatial variability.

	#	D[1] (m)	L[2] (m)	A[3] (m^2)	Perc[4] (%)
Plot	1	-	6.5	42.25	100
Troughs	4	0.15	3.1	1.86	4.4
Collectors	49	0.25	-	2.41	5.69

[1] diameter of troughs and collectors respectively. [2]length of troughs and side for the square experimentation plot. [3]effective area of plot, troughs and collectors. [4]percentage from total plot area.

Table No.1. Design of the experimentation plot for throughfall measurement in WS3 .

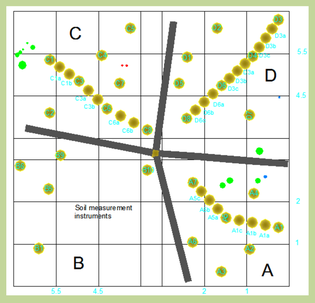

Figure No.8. Distribution of collectors of throughfall for WS3 station.

Figure No.9. Photo of the experimentation plot in WS4. Measurements are made by troughs only.

	#	D[1] (m)	L[2] (m)	A[3] (m^2)	Perc[4] (%)
Plot	1	-	5	25	100
Troughs	3	0.15	3.1	1.4	5.58

Table No.2. Summary of throughfall plot design in WS4.

WS3 plot (troughs and collectors): located below mixed introduced forest.

WS4 plot (troughs only): located below endemic Miconia schrubs.

ALONG THE CROSS-SECTION, RAINFALL AND THROUGHFALL

Analyzing historical time series data from WS1 and WS2, median rainfall is 277 mm/year and 803 mm/year respectively. In Puerto Ayora (WS1) most of the precipitation occurs during the hot season, it is about 70% of the yearly total rainfall. On the other hand at higher altitudes like Bellavista village (WS2), 56% of yearly rainfalls occurs during cool "garúa" season.

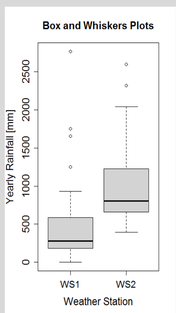

Figure No.10. Yearly rainfall in WS1 and WS2 stations.

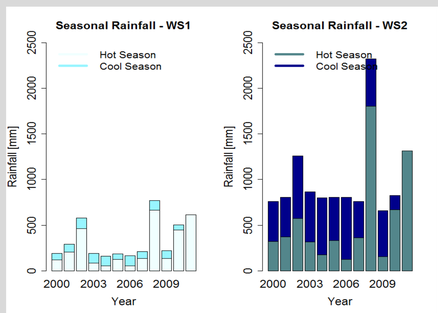

Figure No.11. High variability is observed during the hot season while in the cool season rainfall is very consistent.

The rainfall cross-section along the windward slope of Santa Cruz, from July 2010 to June 2011, covering the hydrological year, shows the marked seasonal differences.

During cool season an orographic gradient of precipitations is well defined while high spatial rainfall variability characterizes the hot season.

At WS4, data is only available since September 2010.

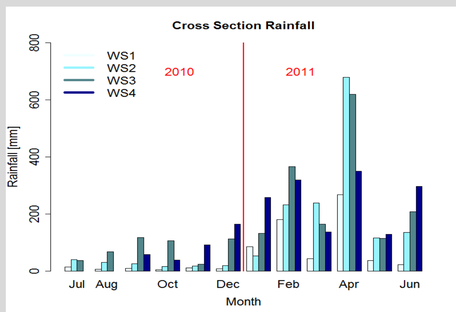

Figure No.12. Rainfall cross-section of Santa Cruz Island windward slope. Data from the 2010 cool season and 2011 hot season.

Throughfall was monitored simultaneously at both WS3 and WS4 stations for a period of 50 days between January and May 2011, covering the hot season. The results indicate that throughfall was 75% and 71% of precipitation respectively.

At WS3 a total of 31 rainfall events were monitored with 49 manual collectors. The results indicate a mean relative throughfall of 80%, which is the same percentage as obtained by automatic rain gauge and troughs once they have been calibrated.

Collectors therefore allowed the validation of measurements performed by troughs.

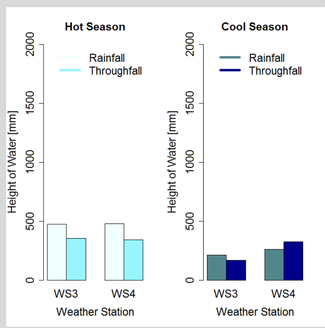

Figure No.13. Throughfall measurements for hot season (n=50) and cool season (n=75). n: days of simultaneous data monitoring at both stations.

	Hot Season	Cool Season
Collectors Measurements		
# Collectors	49	33
Mean ± SE[1]	80 ± 4	81 ± 11
E[2]	5%	14%
CV[3]	25%	38%
Troughs Measurements		
Mean[4]	80	80

[1]Mean relative throughfall for the 95% confidence interval [2]Error expressed as a percentage of the mean [3]Median Coefficient of Variation for 31 throughfall events [4]Mean relative throughfall for the same period than collectors

Table No.3. WS3 summary of throughfall statistics.

These results are compared to the 2010 "garúa" season throughfall data (Dominguez, 2011), when relative throughfall was determined as 79% and 122% of precipitation for WS3 and WS4 respectively.

At WS3, throughfall ratio appears constant all along the year even though there is a different regime of precipitation existing for each season.

At WS4, in the hot season relative throughfall doesn't vary in relation with lower altitudes, while during the "garúa", the incidence of fog in highlands represents an additional input of water, making throughfall to be greater than total precipitation.

Throughfall spatial variability during the hot season, was determined by the Coefficient of Variation, i.e. the standard deviation as a proportion of the mean. This was only carried out at WS3, based on the data obtained by the collectors.

For the 31 events registered, median Coefficient of Variation was 25%. The spatial variation is relative low, which means that distribution of throughfall is uniform. This variation gets even lower when rainfall amount increase reaching values of less than 20%.

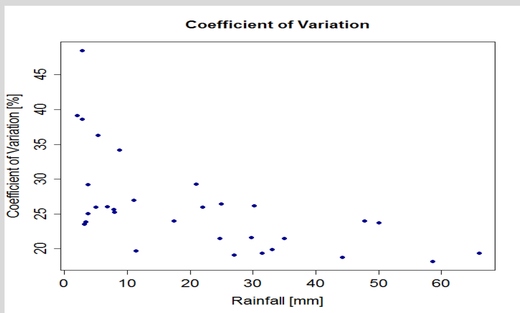

Figure No.14. Decline of the spatial coefficient of variation (%) of throughfall with increasing rainfall amount

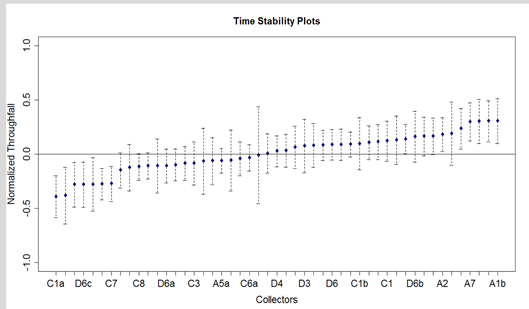

Figure No.15. Time stability plots of throughfall collectors in WS3. They represent the mean relative difference of throughfall collected over the time for each collector.

Time stability plots, i.e, "for *m* periods and *n* locations the mean relative difference over time of the throughfall collected at location *j*" (Staelens et al, 2006).

The collectors with max. throughfall are spatially adjacent (see fig. No.8.). Large deviations from the mean are not observed, which differs from "garúa" season data (Dominguez, 2011).

CONCLUSIONS, ACKNOWLEDGEMENTS & REFERENCES

- Despite the differences in precipitation type, at mid elevations (WS3), where the incidence of fog is almost null, throughfall percentage does not vary between seasons. This could be explained by the fact that the mixed forest canopy structure does not change.
- During the "garúa" season, there is a net input of water entering the hydrological balance by the interception of fog by vegetation in the highlands (WS4), giving an additional 22% of water to the system. During the hot season, the highlands vegetation behaves the same as the mid-highlands vegetation.
- The effect of evaporation on the amount of throughfall should be studied especially in the hot season when temperatures and solar radiation are very high.

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