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AN EARLY WARNING SYSTEM FOR VECTOR-BORNE DISEASE RISK IN THE AMAZON

NASA PROJECT NNX15AP74G

William Pan, Duke University

Health & Air Quality Applications Program Review, Sept 15 & 21, 2020, Virtualtown, USA

Project Team

William Pan, Duke University

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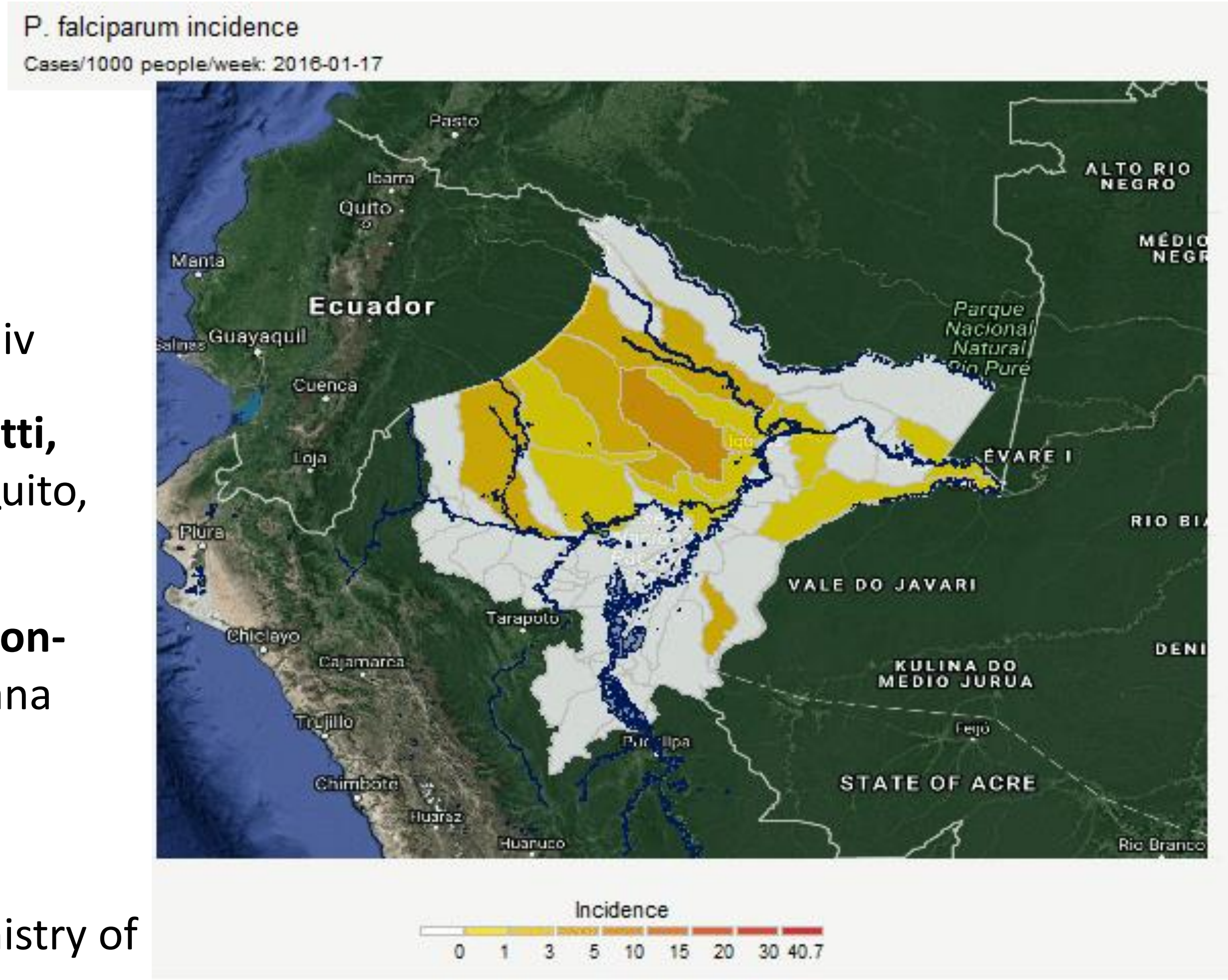

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Project Summary NNH13ZDA001N-Health

OBJECTIVE

Develop an **early warning system for malaria** in the Peruvian Amazon and evaluate the expansion of the system to other diseases and Amazon regions.

GEOGRAPHIC SCOPE

Primary : Peru (Loreto), Ecuador (Napo, Orellana, Succumbios)
Secondary locations: Colombia, Western Brazil (Acre)

SOCIETAL BENEFIT

Improved / targeted interventions; Application of components to other diseases and climate events

EARTH OBSERVATIONS / MODELS / TECHNOLOGY

Land Data Assimilation System (LDAS) – MODIS, LandSAT, GRACE, TRMM, GPM, SMAP, GOES

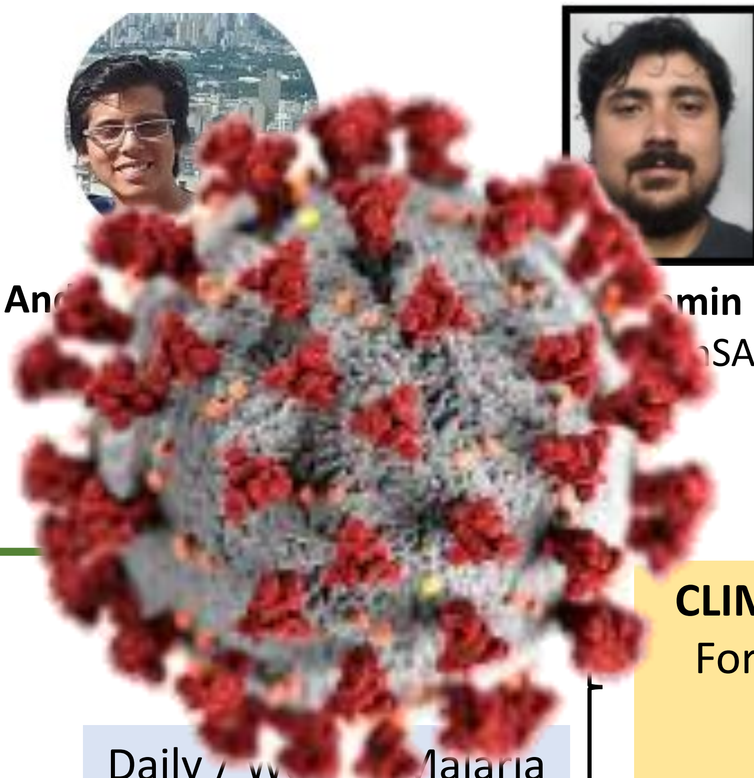
Summary of Accomplishments (overall)

- We forecast malaria outbreaks in small, administrative districts 12 weeks in advance with ~90% sensitivity
  - Two modeling levels: Ecoregion and District
- We have strong government & academic partnerships in Peru & Ecuador that are ready to adopt and implement the system
  - LDAS implementation in Ecuador in the Institute of Geography at USFQ in partnership with the Ministry of Public Health
  - Forecasting capacities to be adopted by CDC-Peru and CLIMA (Climate and Infectious Disease Laboratory at UPCH, Lima)
- Additional Funding:
  - Bi-weekly team telecons to prepare application to EU "Early Warning for Epidemics" prize for vector-borne disease forecasting ($5 million euros)
  - 10% score from NIAID to support technical improvements to MEWS for understanding cross-border malaria risk
- Publications: 3 articles published, 6 in review (4 are COVID-related)
- ARL7 (goal ARL 8)

Accomplishments & Challenges 2019-20

- Implementation & Training program (March – June 2020)

Carlos Culquichicon
CDC Peru & CLIMA



An

min Narvaez
SALUD

Alonso Bussalleu
CLIMA

USFQ Institute for Geography

CDC-Peru & MinSALUD (Ecuador)

Daily / W Malaria Surveillance & Population Data

CLIMA (USFQ) and CDC-Peru
Forecast model application
Risk Visualization
Outbreak reporting

Supported by Duke

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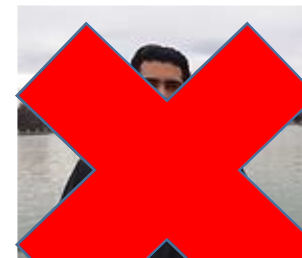
Accomplishments & Challenges 2019-20

- Training was postponed to Fall 2020, then cancelled

Carlo[illegible] Culqui[illegible]con
CDC Peru & CLIMA

Andree Valle Campos
CDC Peru

Manuel Benjamin Narvaez
USFQ & MinSALUD



Alon[illegible]o Bussa[illegible]eu
CLIMA

Began MSPH Program at Emory

Repurposed to COVID-19

Began PhD at Swiss-TPH

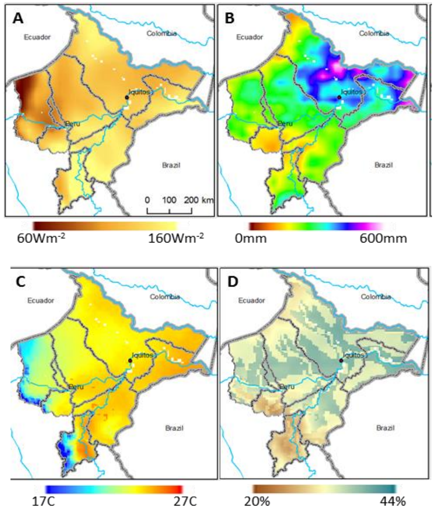
The rest of this presentation …

- How do we achieve 90% sensitivity in detecting malaria outbreaks?
  - LDAS
  - Ecoregion analysis & District level forecast models

- Recent Publications on PAMAFRO and International Migration using our model

LAND DATA ASSIMILATION SYSTEM

Temperature
Precipitation
Soil Moisture
Solar Radiation
Stream Flow



Government Malaria Surveillance, Interventions & Population at Risk

ECO-REGION FORECAST MODEL

12-week forecast in Ecoregions

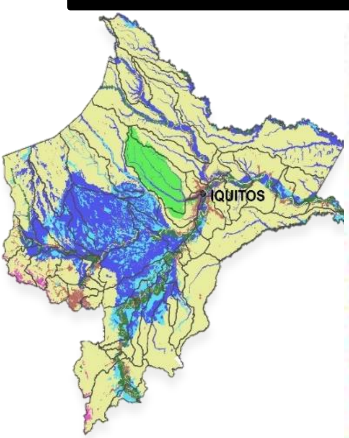
DISTRICT FORECAST MODEL

12-week forecast in Districts

AGENT-BASED MODELS

Intervention & Control Scenarios

LANDSCAPE ECOLOGY



Districts (n=51)
Bodies of Water

Ecoregions

Humid Amazon Forest
Humid Andean Forest
Forest Flooded by Clear-water Rivers
Forest Flooded by Black-water Rivers
Anthropic Areas
Amazonian azonal vegetation (edaphically conditioned)
Upper Amazon alluvial plains marsh

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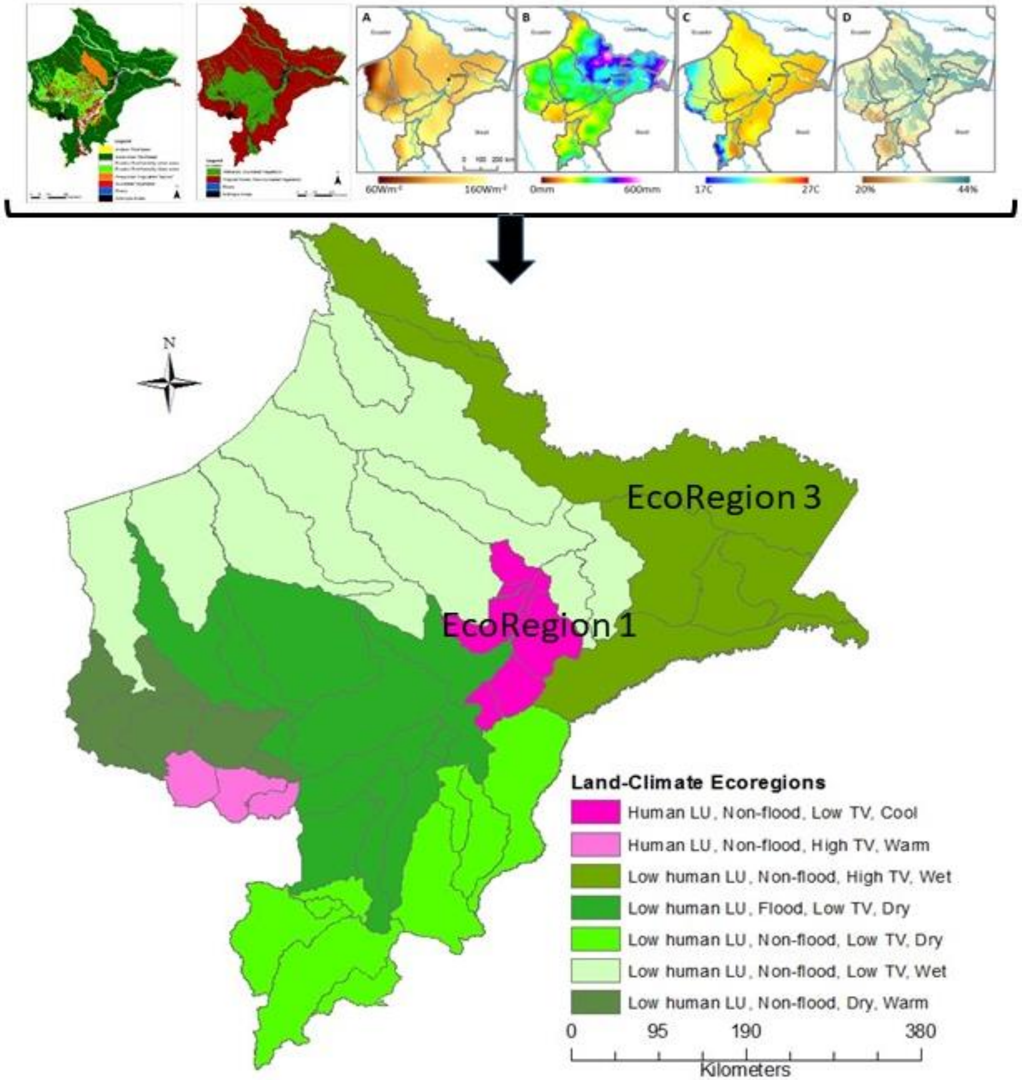
EcoRegion Forecast



- LDAS & Ecosystem data are combined to identify EcoRegions
- Malaria & Population data are aggregated to the EcoRegion level
- Unobserved Component Model (UCM) used to conduct forecasts

$$y_t = \mu_t + \gamma_t + \varphi_t + r_t + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{m} \beta_j x_{jt} + \varepsilon_t$$

y_t ~ malaria cases/1000 during week *t*

μ_t, γ_t,φ_t, and r_t represent the trend, seasonal, cyclical and autoregressive components

ϕ_i is an autoregressive term capturing the momentum of infections

β_j is the unknown effect for explanatory factors

ε_t is the error term

- **MINSA-defined outbreak level**

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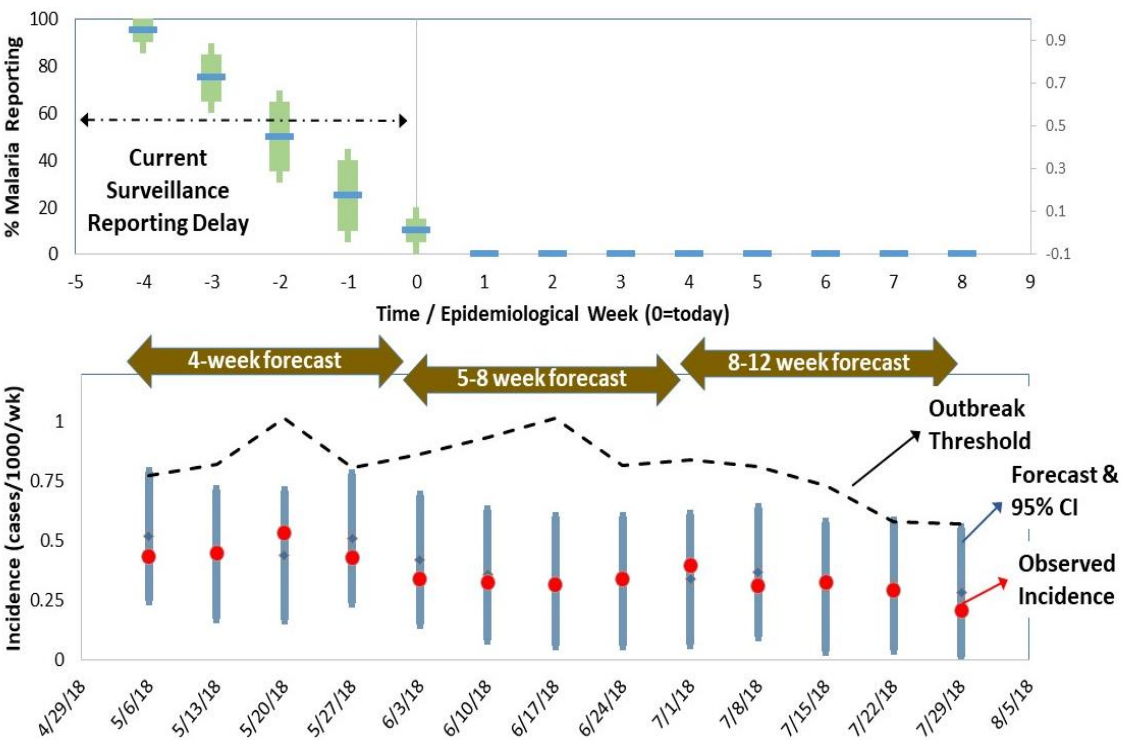
EcoRegion Forecast

Real-time data reporting (top) and forecast (bottom) for EcoRegion 1 from May-July 2018 in Loreto, Peru



Forecast Performance, 2016

	Forecast weeks	TP	FN	FP	TN	Se	Sp
Eco-Region 1	1-4	3	0	0	10	100%	100%
	5-8	3	0	1	9	100%	90%
	9-12	3	0	3	7	100%	70%
Eco-Region 3	1-4	1	1	1	10	50%	91%
	5-8	1	1	1	10	50%	91%
	9-12	2	0	3	8	100%	73%

TP=True Pos; FN=False Neg; FP=False Pos.; TN=True Neg.

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District Level Forecast

- Probability of District outbreak = (Ecoregion Outbreak Prob) * (District Outbreak Prob)
- Hierarchical Bayesian spatio-temporal logistic model

$$y(s,t) = \boldsymbol{x}^T(s,t)\beta + \theta(s,t)$$

$y(s,t)$ ~ # malaria cases in district s during week t
$\boldsymbol{x}(s,t)$ ~ vector of covariates & lagged predictors
$\theta(s,t)$ ~ spatio-temporally correlated random effects

  - The Model estimates Malaria incidence rate during week t in district s

- **MINSA thresholds used to define an outbreak**

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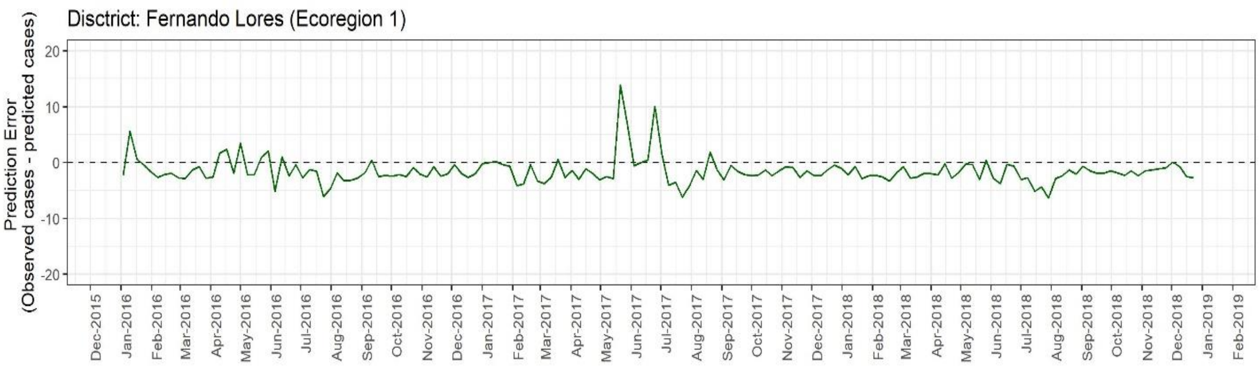
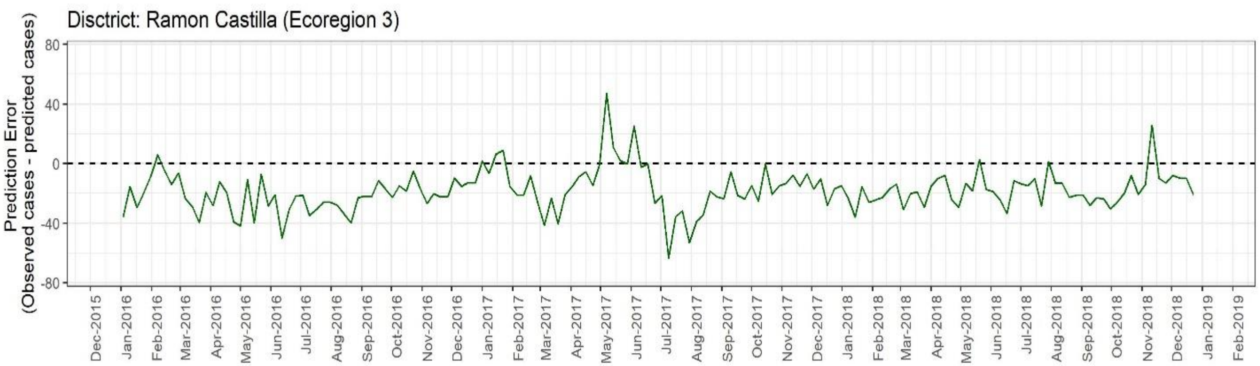
District Level Forecast

Root-mean square prediction error, Fernando Lores and Ramon Castilla districts, 2016-19





Sensitivity & Specificity of 8-week district forecasts, 2007-2019

District	Se	Sp
Ecoregion 1		
Iquitos	88%	84%
Fernando Lores	51%	84%
Punchana	89%	74%
Belen	79%	70%
San Juan Bautista	97%	67%
Jenaro Herrera	94%	98%
EcoRegion 3		
Ramon Castilla	57%	79%
Pebas	54%	68%
Yavari	55%	63%
San Pablo	60%	76%

Publications / Manuscripts in Review 2019-20

Recalde Coronel, C., B. Zaitchik, WK Pan (2020) “Madden-Julian oscillation influence on sub-seasonal rainfall variability on the west of South America” *Climate Dynamics*, in-press, DOI: 10.1007/s00382-019-05107-2

Pizzitutti F, CF Mena, B Feingold, WK Pan, (2019) Modeling asymptomatic infections and work-related human circulation as drivers of unstable malaria transmission in low-prevalence areas: a study in the Northern Peruvian Amazon. *Acta Tropica*: 2019 Jan 28. pii: S0001-706X(18)31234-8. doi: 10.1016/j.actatropica.2019.01.022

Gunderson, A., R Kumar, C Recalde-Coronel, LE Vasco, A Valle-Campos, CF Mena, BF Zaitchik, AG Lescano, WK Pan, MM Janko “Malaria transmission and spillover across the Peru-Ecuador border: a spatio-temporal analysis” *International Journal of Environmental Research and Public Health*, in-review

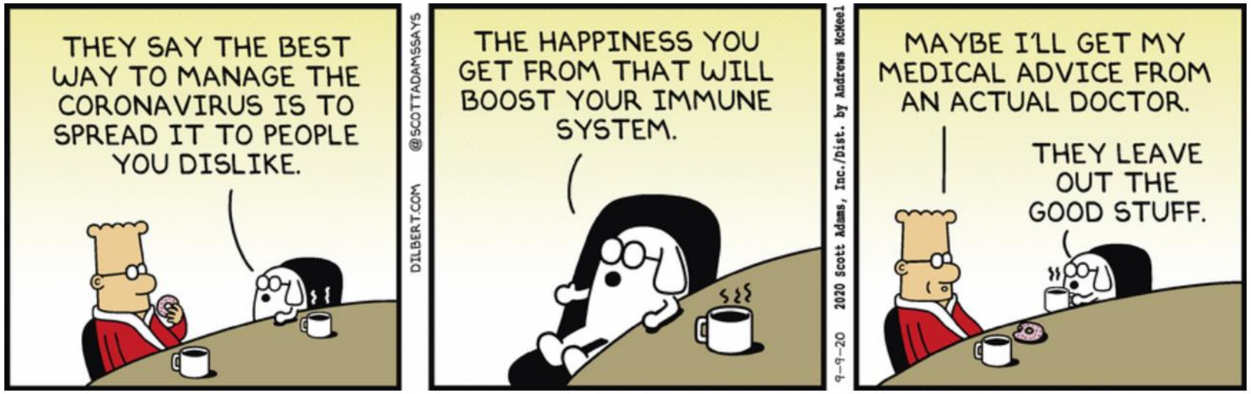
Janko, MM, C Recalde-Colonel, AG Lescano, G Salmón-Mulanovich, BF Zaitchik, WK Pan “Sustained malaria control and its withdrawal in the Loreto region of Peru: A retrospective, observational study of the potential impact of the PAMAFRO program”, *LANCET*, in-review

(COVID-19 related)

Pan, WK, S Tyrovolas, GV Iago, RR Dasgupta, D Fernandez, B Zaitchik, P Lantos, CW Woods “Heterogeneity of non-pharmaceutical intervention effectiveness in the US before phased reopening” https://www.medrxiv.org/content/10.1101/2020.08.18.20177600v1

Turner, NA, WK Pan, VS Martinez-Bianchi, GM Maradiaga Panayotti, AM Planey, CW Woods, PM Lantos, (2020) “Racial, Ethnic, and Geographic Disparities in Novel Coronavirus (SARS-CoV-2) Test Positivity in North Carolina” *Open Forum Infectious Diseases*, ofaa413, https://doi.org/10.1093/ofid/ofaa413

THANK YOU!



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