

Contrasting Net Ecosystem Production Across Ecological Succession at Subtropical Dry Forest of Northwestern Mexico

Enrico Yepez¹, Nidia E. Rojas-Robles², Juan C. Alvarez-Yepiz³, Zulia Mayari Sanchez-Mejia³, JAIME GARATUZA-PAYAN³, José M. Madrigal⁴, Miguel A. Rivera-Diaz⁵, and Rodrigo Vargas⁶

¹Instituto Tecnológico de Sonora

²University of California Riverside

³Instituto Tecnológico de Sonora

⁴Centro de Investigación en Geografía y Geomatica, Ing. Jorge L. Tamayo, A.C

⁵Instituto Tecnológico de Sonora

⁶University of Delaware

November 23, 2022

Abstract

Forests are under major pressures due to contemporary land-use, which creates mosaics of stand-stage development that follow different successional paths, that imply ecosystem complexity. The interplay of carbon and water dynamics across succession involves physical and biological interactions that shape net ecosystem production (NEP) and water use efficiency. Here we present 13 years-site of eddy covariance data (2016-2020) from a seasonally dry tropical forest in Northwestern Mexico to elucidate the environmental controls on ecosystem fluxes and explore the interactions with changes in resource availability. Across a successional gradient, an early (9 years since abandonment) and a mid-successional (about 45 years with natural recruitment and regrowth) sites were net carbon sinks (in the order of 100 to 500 g C m⁻² y⁻¹) while an old-growth forest was a chronic net source over the 5 years studied (losing between 100 and 300 g C m⁻² y⁻¹). In contrast evapotranspiration was alike at sites and close to the precipitation input. Ecosystem water use efficiency tended to be higher at the old-growth forest site (ca. 3.0 g C m⁻² / mm H₂O vs. ca. 2.0 g C m⁻² / mm H₂O at the secondary sites). Water availability and radiation were clearly dominant environmental controls across sites, but notably vapor pressure deficit was not a controlling factor for gas exchange at the old-growth forest. Surface characteristics, canopy structure and species composition may explain differences in NEP across succession in TDF at its northernmost extent.

Contrasting Net Ecosystem Production Across Ecological Succession at Subtropical Dry Forest of Northwestern Mexico

Enrico A. Yépez¹; Rojas-Robles, Nidia Elisa^{1,2}; Juan C. Alvarez-Yepiz¹; Zulia Sanchez-Mejía¹; Jaime Garatuzaya-Payán¹; José M. Madrigal¹; Miguel A. Rivera-Díaz¹; Rodrigo Vargas¹
Corresponding authors: nerojasrobles@gmail.com; enrico.yepeza@itson.edu.mx

¹Departamento de Ciencias del Agua y Medio Ambiente, Instituto Tecnológico de Sonora, Ciudad Obregón, Sonora, México.
²Department of Environmental Sciences, University of California, Riverside, CA 92521
³Centro de Investigación en Geografía y Geomática, Ing. Jorge L. Tamayo, A.C. Ciudad de México, México
⁴University of Delaware, 531 South College Avenue, Newark, DE, 19716, USA.

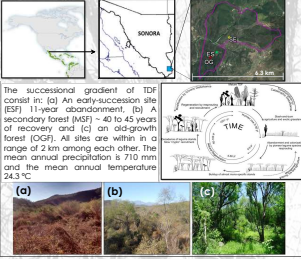


ABSTRACT

Forests are under major pressures due to contemporary land-use, which creates mosaics of stand-stage development that follow different successional paths, that imply ecosystem complexity. The interplay of carbon and water dynamics across succession involves physical and biological interactions that shape net ecosystem production (NEP) and water use efficiency. Here we present 13 years of eddy covariance data (2016-2020) from a seasonally dry tropical forest in Northwestern Mexico to elucidate the environmental controls on ecosystem fluxes and explore the interactions with changes in resource availability. Across a successional gradient, an early (9 years since abandonment) and a mid-successional (about 45 years with natural recruitment and regrowth) sites were net carbon sinks (in the order of 100 to 500 g C m⁻² yr⁻¹) while an old-growth forest was a chronic net source over the 5 years studied (ranging between 100 and 300 g C m⁻² yr⁻¹). In contrast evapotranspiration was alike at sites and close to the precipitation input. Ecosystem water use efficiency tended to be higher of the old-growth forest site (ca. 3.0 g C m⁻² mm H₂O⁻¹ ca. 2.0 g C m⁻² / mm H₂O at the secondary sites). Water availability and radiation where clearly dominant environmental controls across sites. Surface characteristics (canopy structure and species composition) may explain differences in NEP across succession in TDF at its northernmost extent.

Our goal is to investigate the patterns of NEP, GEP, Reco and ET during succession in TDF and explored what biological and environmental drivers control ecosystem fluxes across succession, to ultimately understand how ecosystem function behaves after disturbance

The study site is within the natural protected area "Reserva montana región", within the protected area "Reserva natural protegida de flora y fauna sierra de Alamos-El Cucuchuco".



Flux measurements across succession



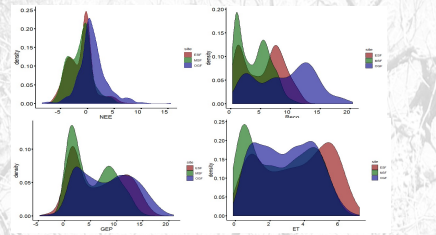
Ecosystem flux measurements at all sites were performed using Eddy covariance (EC) technique and complete meteorological arrangements. The high frequency (10Hz) water vapor and CO₂ concentrations and air temperature measurements were used with the turbulent wind velocities to obtain latent heat flux (LE) or evapotranspiration (ET), sensible heat (H) and net ecosystem exchange (NEE) generally equal to net ecosystem production (NEP).

NEP = GEP - R_g

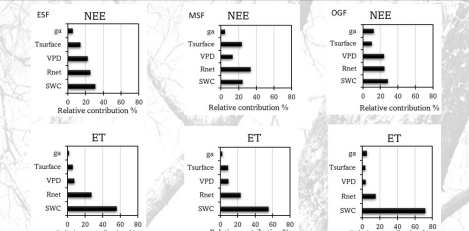
- The flux measurements were corrected for density fluctuations (Webb et al. 1980)
- The data below a threshold of a critical friction velocity were removed (Papale et al. 2006) The μ⁴ filtering (Table 2), data gaps filled, a flux partitioning were performed using the online tool RecoDryProc <https://www.hawaii.edu/maui/maui/RecoDryProc.html>

Site and flux characteristic	ESF	MSF	ESF	MSF	ESF	MSF	ESF
Canopy height (m)	15	12	3	75	137	129	
Above ground biomass (Mg/ha)	35.8 ± 9.0	38.5 ± 6.6	18.6 ± 0.9				
Leaf area index	0.33	0.30	0.29				
Fluxes							
NEP (g C m ⁻² yr ⁻¹)	-113	-111	-209				

RESULTS



Probability density curves (PDF) of daily sums of Carbon and water fluxes showed a bimodal behavior across sites, but a marked difference occurs at the OG site, where NEP and Reco depart from the general trend. Despite the slight differences in the density of GEP across the successional gradient, the peaks are similar. The contrast between GEP and Reco points at the significance of Reco to define the C source or sink strength of TDF across succession.



Result from a bootstrap regression tree analysis to assess the relative contribution of environmental variables on ecosystems fluxes. The factors with the higher relative contribution for flux predictability are Surface Temperature (Surface), Vapor pressure deficit (VPD), Soil Volumetric Water Content (SWC), Net Radiation (Rnet), and aerodynamic conductance (ga), the variables with more influence changed according to the successional stage. For instance, at the ESF and OGF sites SWC and Rnet were the most influential, but for the MSF site Rnet and surface temperature where influential. For ET, important transitions between Rnet and VWC, where noticed.

YEAR	OGF		MSF		ESF		PPT
	NEE	ET	NEE	ET	NEE	ET	
	(g C m ⁻² yr ⁻¹)	(mm yr ⁻¹)	(g C m ⁻² yr ⁻¹)	(mm yr ⁻¹)	(g C m ⁻² yr ⁻¹)	(mm yr ⁻¹)	(mm yr ⁻¹)
2016	181	752	-428	614	-149	742	725
2017	295	675	-566	548	-195	682	580
2018	208	790	-468	654	-308	816	860
2019	193	638	-267	532	--	--	614
2020	233	669	-197	551	--	--	452

CONCLUSION AND FURTHER HYPOTHESIS

The OGF consistently lost more carbon than gained at a five year-long period following a strong el Niño event and a prior extreme frost, while the secondary forests remained as net C sinks during this same 5-year period. In 2011 there was a remarkable frost affecting the TDF at the study site (Borjaquez et al., 2019) and further drought effects in 2015 from El Niño. Therefore, we hypothesize that net C sources to the atmosphere observed during the reported five years at the OGF site, in contrast to the sites in secondary succession, respond to the decomposition of accumulated organic matter from stress and plant mortality following extreme climate events in the region.

ACKNOWLEDGEMENTS

Financial support for this project came from CONACYT Mexico project (2013-01-22014) and a graduate scholarship to E. E. Yépez (2019). E. Yépez is supported by grants from NASA Carbon Monitoring System (CMS) and SBIR/STTR (NSF 19-01498) for additional funding.

REFERENCES

Alvarez-Yepiz et al. (2008). Forest Ecol Manag. 254:305-314.
Borjaquez et al. (2019). Global Change Biol. 25: 3817-3828
Rojas-Robles et al., 2020. GCR Biogeochemistry, 17(1): 1029-1050/DOI:10.1007/s10533-019-00611-9
Vankar et al. (2015). JGR Biogeosci. 120: doi:10.1002/2015JG003119.



ITSON
Educar para
Trascender

Contrasting Net Ecosystem Production Across Ecological Succession at Subtropical Dry Forest of Northwestern Mexico

Enrico A. Yépez¹; Rojas-Robles, Nidia Elisa^{1,2}; Juan C. Alvarez-Yepiz¹; Zulia Sanchez-Mejía¹, Jaime Garatuza-Payán¹ José M. Madrigal³, Miguel A. Rivera-Díaz¹, Rodrigo Vargas⁴
Corresponding authors: nerojasrobles@gmail.com; enrico.yopez@itson.edu.mx

¹Departamento de Ciencias del Agua y Medio Ambiente, Instituto Tecnológico de Sonora, Ciudad Obregón, Sonora, México.
²Department of Environmental Sciences, University of California, Riverside, CA 92521
³Centro de Investigación en Geografía y Geomática, Ing. Jorge L. Tamayo, A.C. Ciudad de México, México
⁴University of Delaware, 531 South College Avenue. Newark, DE, 19716, USA.

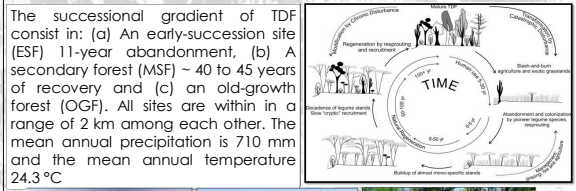


ABSTRACT

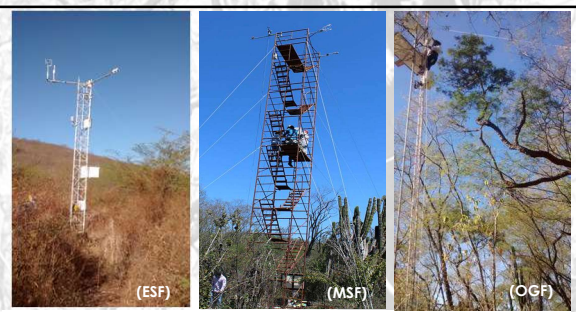
Forests are under major pressures due to contemporary land-use, which creates mosaics of stand-stage development that follow different successional paths, that imply ecosystem complexity. The interplay of carbon and water dynamics across succession involves physical and biological interactions that shape net ecosystem production (NEP) and water use efficiency. Here we present 13 years-site of eddy covariance data (2016-2020) from a seasonally dry tropical forest in Northwestern Mexico to elucidate the environmental controls on ecosystem fluxes and explore the interactions with changes in resource availability. Across a successional gradient, an early (9 years since abandonment) and a mid-successional (about 45 years with natural recruitment and regrowth) sites were net carbon sinks (in the order of 100 to 500 g C m⁻² y⁻¹) while an old-growth forest was a chronic net source over the 5 years studied (losing between 100 and 300 g C m⁻² y⁻¹). In contrast evapotranspiration was alike at sites and close to the precipitation input. Ecosystem water use efficiency tended to be higher at the old-growth forest site (ca. 3.0 g C m⁻²/mm H₂O vs. ca. 2.0 g C m⁻²/mm H₂O at the secondary sites). Water availability and radiation where clearly dominant environmental controls across sites. Surface characteristics, canopy structure and species composition may explain differences in NEP across succession in TDF at its northernmost extent.

Our goal is to investigate the patterns of NEP, GEP, Reco and ET during succession in TDF and explored what biological and environmental drivers control ecosystem fluxes across succession, to ultimately understand how ecosystem function behaves after disturbance

The study site is within the natural protected area "Reserva monte mojino", within the protected area "Área natural protegida de flora y fauna sierra de Alamos-Río Cuchujaqui"



Flux measurements across succession



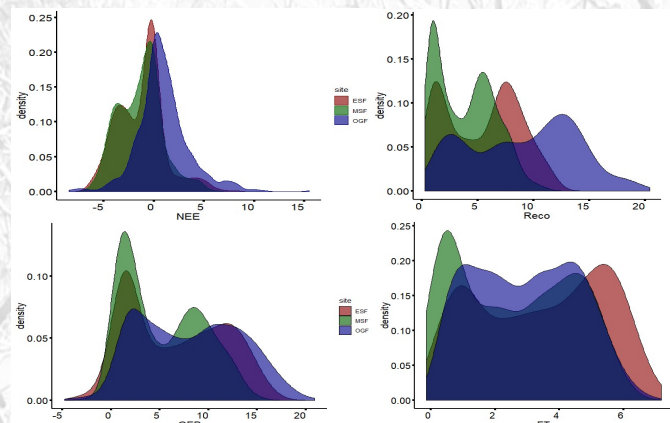
Ecosystem flux measurements at all sites were performed using Eddy covariance (EC) technique and complete meteorological arrangements. The high frequency (10Hz) water vapor and CO₂ concentrations and air temperature measurements were used with the turbulent wind velocities to obtain latent heat flux (LE) or evapotranspiration (ET), sensible heat (H) and net ecosystem exchange (NEE) generally equal to net ecosystem production (-NEP).

$$NEP = GEP - R_{eco}$$

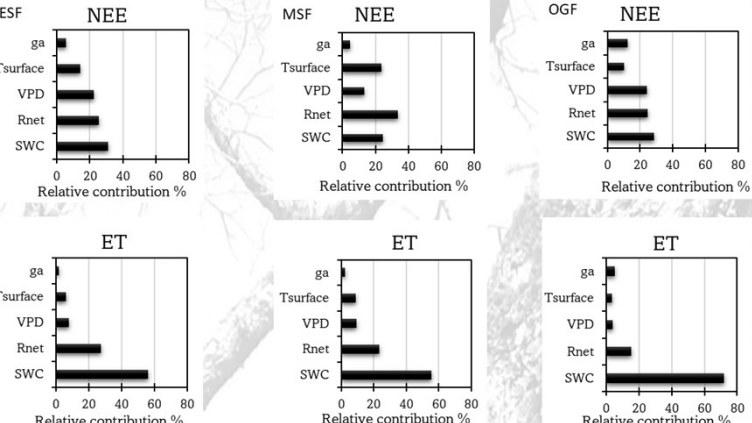
- The flux measurements were corrected for density fluctuations (Webb et al. 1980)
- The Data below a threshold of a critical friction velocity were removed (Papale et al. 2006) The μ^* filtering (Table 2), data gaps filled, an flux partitioning were performed using the online tool Reddyproc (<http://www.bgc-jena.mpg.de/REddyProc/Free/REddyProc.html>)

Site and flux characteristics			Data				
Site Attributes	OGF	MSF	ESF	Attributes	OGF	MSF	ESF
Canopy height (m)	15	12	5	Footprint (m)	73	137	120
Above ground biomass (Mg/ha)	33.0 ± 10	18.5 ± 6	18.0 ± 10	E.Cloas. (r ²)	0.77	0.65	0.77
Albedo	0.13	0.10	0.20	Fricc. Vel. μ^* (m/s)	0.15	0.11	0.059

RESULTS



Probability density curves (PDF) of daily sums of Carbon and water fluxes showed a bimodal behavior across sites, but a marked difference occurs at the OG site, where NEE and Reco depart from the general trend. Despite the slight differences in the density of GEP across the successional gradient, the peaks are similar. The contrast between GEP and Reco points at the significance of Reco to define the C source or sink strength of TDF across succession.



Results from a bootstrap regression tree analysis to assess the relative contribution of environmental variables on ecosystems fluxes. The factors with the higher relative contribution for flux predictability are Surface Temperature (Tsurface), Vapor pressure deficit (VPD), Soil Volumetric Water Content (SWC), Net Radiation (Rnet), and aerodynamic conductance (ga). The variables with more influence changed according to the successional stage. For instance, at the ESF and OGF sites SWC and Rnet where the most influential, but for the MSF site Rnet and surface temperature where influential. For ET, Important transitions between Rnet and VWC where noticed.

Cumulative amounts of carbon and water fluxes and annual precipitation

YEAR	OGF		MSF		ESF		PPT (mm yr ⁻¹)
	NEE (g C m ⁻² yr ⁻¹)	ET (mm yr ⁻¹)	NEE (g C m ⁻² yr ⁻¹)	ET (mm yr ⁻¹)	NEE (g C m ⁻² yr ⁻¹)	ET (mm yr ⁻¹)	
2016	181	752	-428	614	-149	742	725
2017	295	675	-566	548	-195	682	580
2018	208	790	-468	654	-308	816	860
2019	193	638	-267	532	--	--	614
2020	233	669	-197	551	--	--	452

CONCLUSION AND FURTHER HYPOTHESIS

The OGF consistently lost more carbon than gained at a five year-long period following a strong el Niño event and a prior extreme frost, while the secondary forests remained as net C sinks during this same 5-year period. In 2011 there was a remarkable frost affecting the TDF at the study site (Bojorquez et al., 2019) and further drought effects in 2015 from El Niño. Therefore, we hypothesize that net C sources to the atmosphere observed during the reported five years at the OGF site, in contrast to the sites in secondary succession, responded to the decomposition of accumulated organic matter from stress and plant mortality following extreme climate events in the region.

ACKNOWLEDGEMENTS

Financial support for this project came from CONACYT México project CB-2013-01/221014 and a graduate scholarship to N. E. R. R. (278991). R. V. was supported by grants from NASA Carbon Monitoring System (NNX13AQ06G and 80NSSC18K0173). EAY thank PROFAP-ITSON for additional funding.

REFERENCES

Alvarez-Yepiz et al. (2008). Forest Ecol Manag. 256,355-366.
Bojorquez et al. (2019). Global Change Biol. 25, 3817-3828
Rojas Robles et al. 2020 JGR Biogeosciences, 125, 1029/2020JG005666
Verduzco et al. (2015) JGR Biogeosci. 120, doi:10.1002/2015JG003119.