Correlation of hurricane damage to coral reefs with the features of both of them.
Iniciativa Mesoamericana de Rescate de Arrecifes (RRI)

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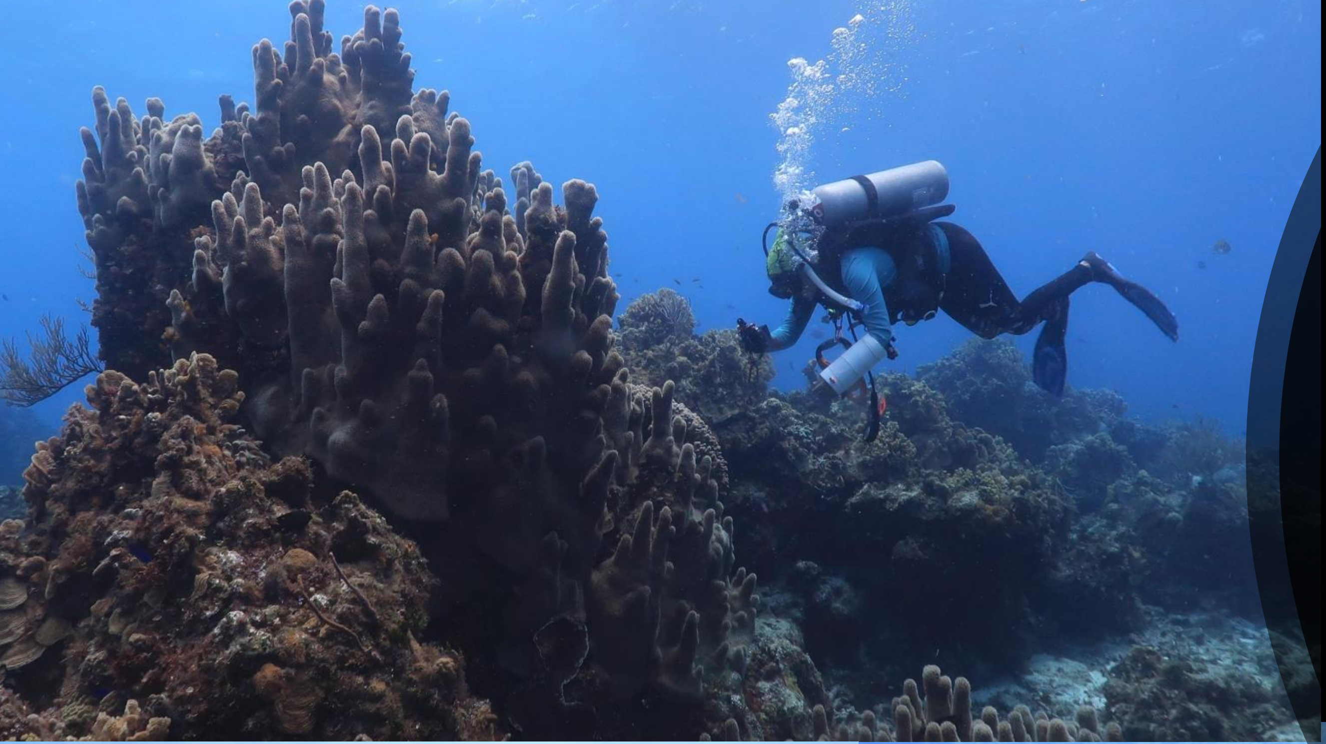
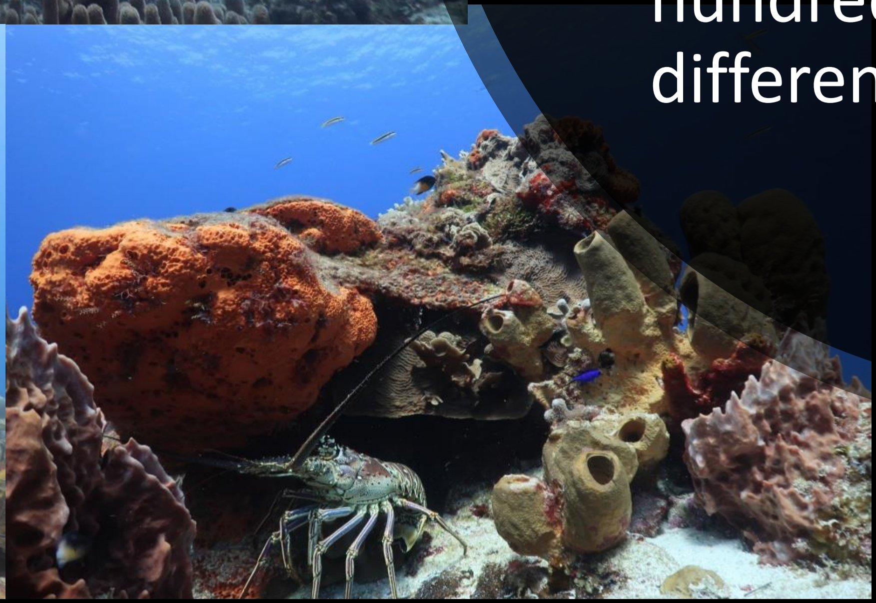


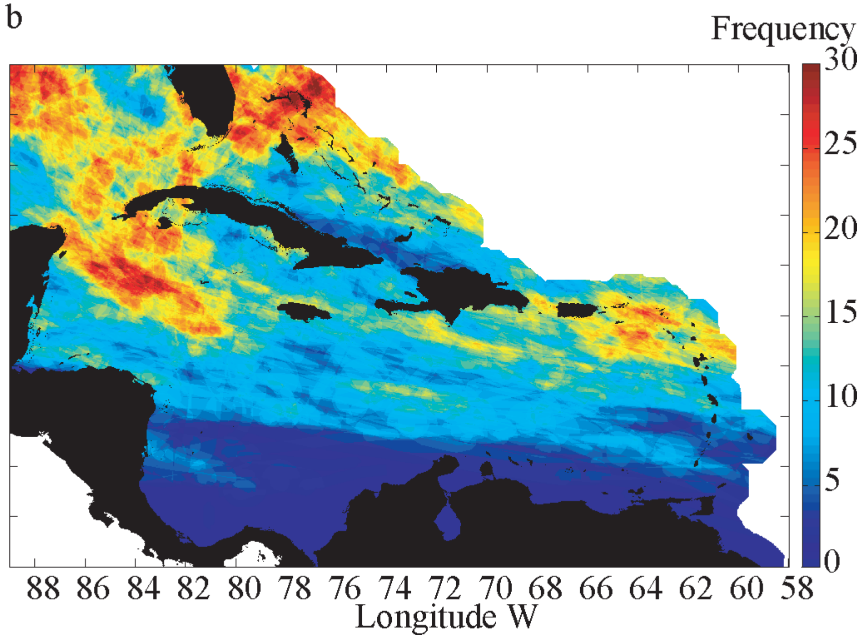


- Coral reefs are the most diverse of all marine ecosystems:
  because of their 3D-architecture they can house hundreds of thousands of different species.

Pictures: Álvarez-Filip L.

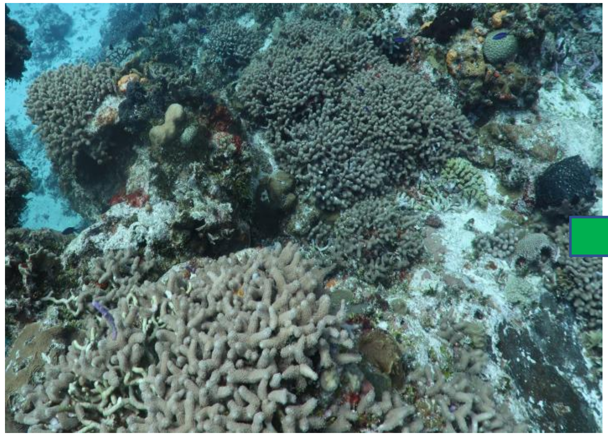
Hurricanes are natural disasters that commonly affect the Caribbean Sea: every year, the Caribbean zone receives an average of 6.2 hurricanes between June and November.

Frequency of category 1-5 hurricanes from 1851 to 2008 in the Caribbean.



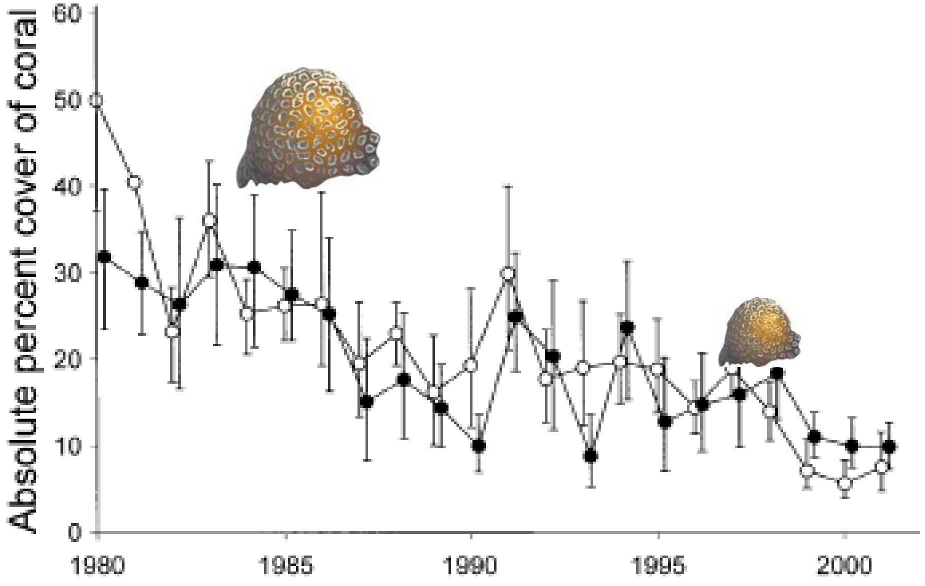
(Chollett *et. al.*, 2012).

Hurricane Emily 2005



(Álvarez-Filip *et. al.*, 2006)

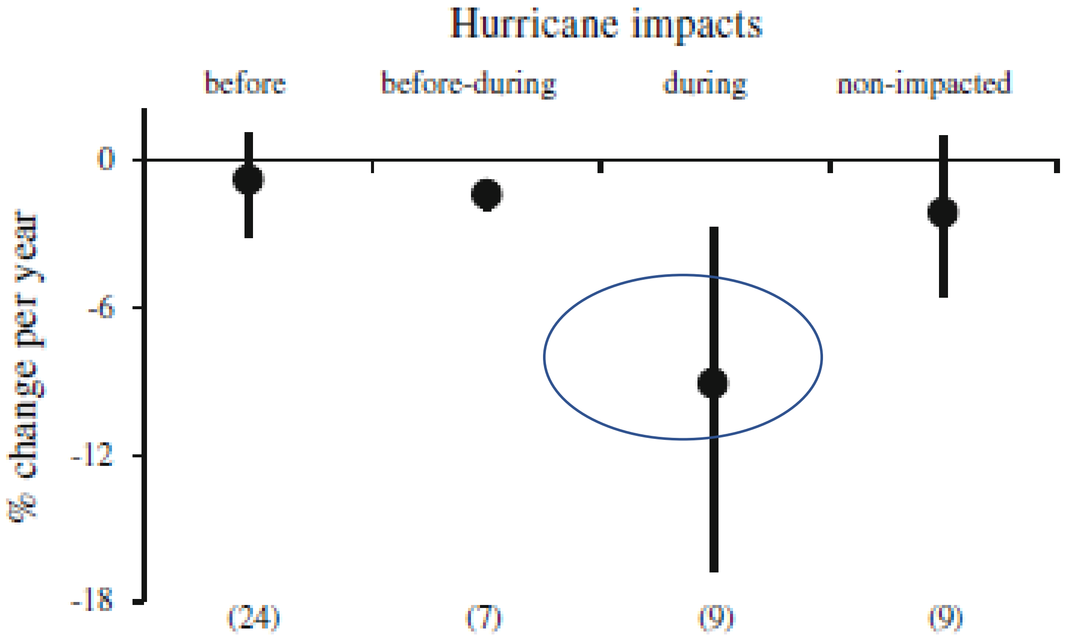
Coral percent cover at impacted (solid circles) and nonimpacted (open circles) sites across the Caribbean Basin from 1980 to 2001.



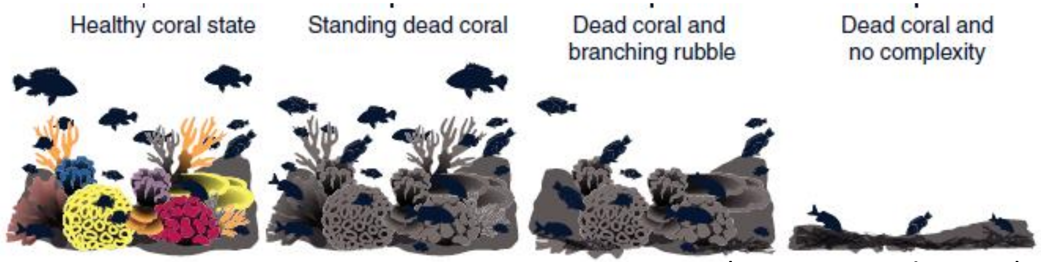
Coral cover at sites impacted by a hurricane has declined at a significantly faster rate (6% per annum) than nonimpacted sites (2% per annum

(Gardner et. al., 2005)

Effect of hurricane impacts on rates of architectural complexity change in the Caribbean



(Álvarez-Filip *et. al.* 2011)



(Rogers et. al. 2018)

Objetive

- Present the analysis of the correlation of hurricane damage to coral reefs with the features of both of them, in the Caribbean and Mesoamerican Reef (MAR) regions.
- And present a list of features that are Correlated with this damage, and so they can be useful indicators to trigger a parametric insurance for coral reefs.

Álvarez-Filip L.

Process Overview

1. Literature review and data collection: for coral reef sites and hurricanes

2. Integration of the dataset for performing the analyses.

3. Exploratory data analysis

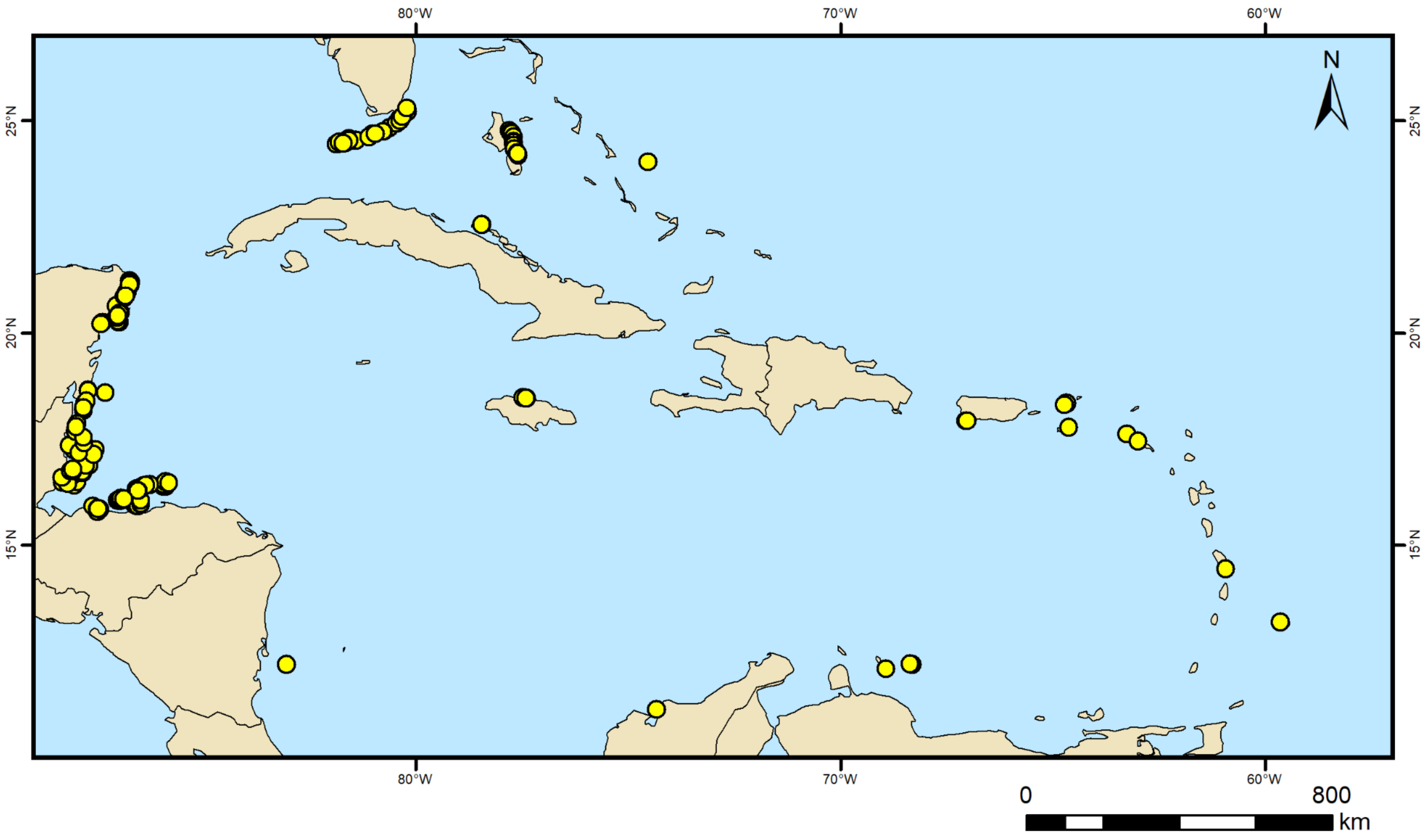
4. Inferential analyses

1. Literature review and data collection: for coral reef sites and hurricanes

- **Literature review**

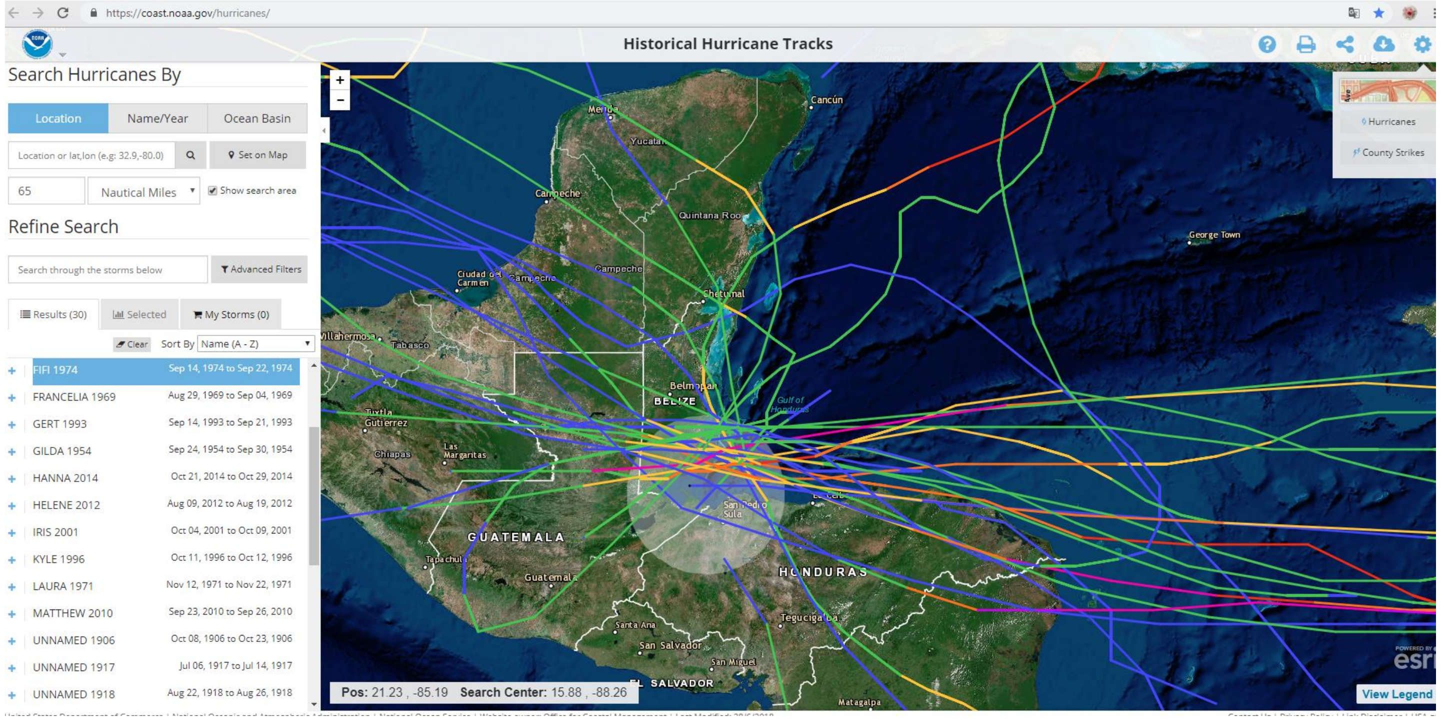
- **Data collection**

Coral reef data collection: map of sites



Hurricane data collection

The National Hurricane Center (NHC) conducts a post-storm analysis of each tropical cyclone in its area of responsibility to determine the official assessment of he cyclone's history. In the database HURDAT.



Database HURDAT2

The revised Atlantic hurricane database (HURDAT2). From the NOAA (*National Oceanic and Atmospheric Administration:*

- Is a comma-delimited text format with six-hourly information on the location
- Maximum winds.
- Central pressure, and (beginning in 2004) size of all known tropical cyclones and subtropical cyclones.

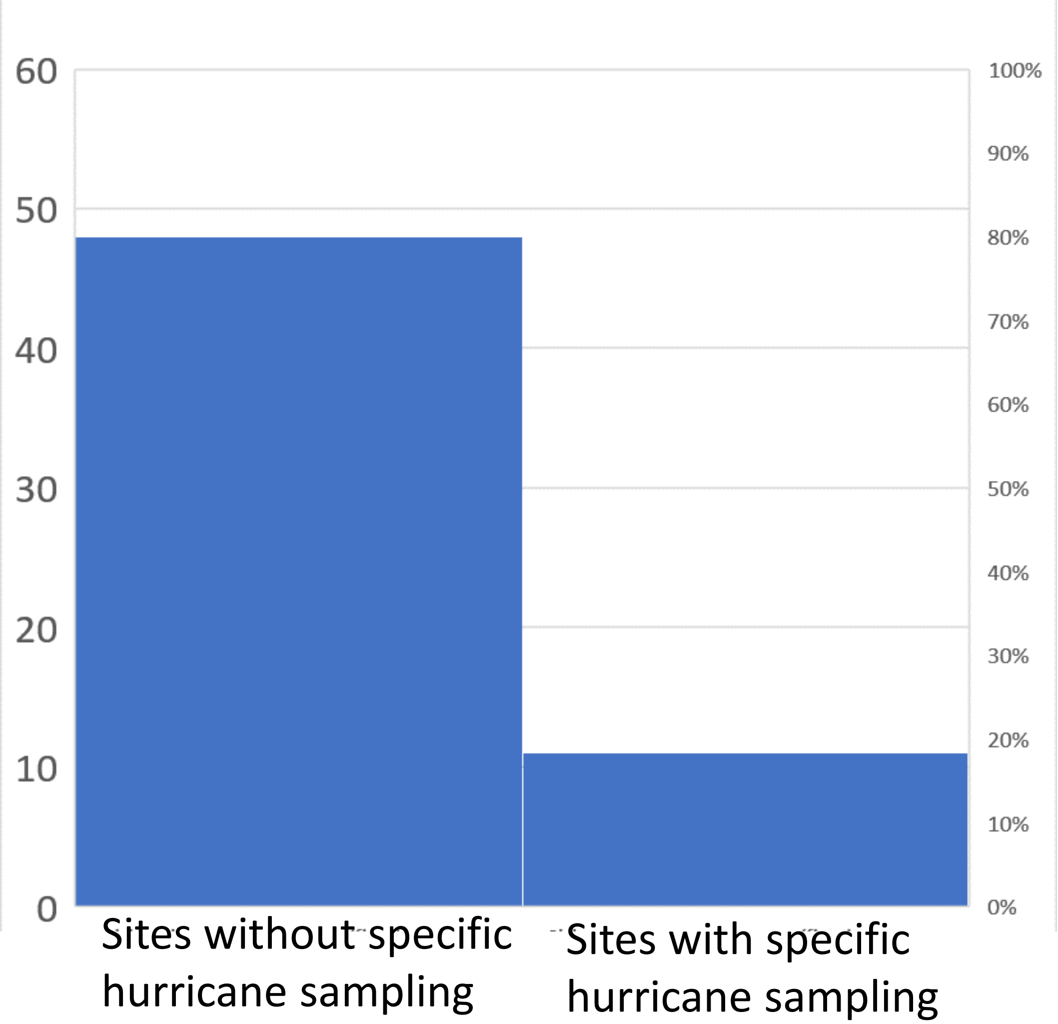
2. Coral cover dataset integration

Contact	Country	Day	Coral sampling method	Rugosity sampling method
email	MPA	Month	Detail of coral sampling method	Detail of rugosity sampling method
Reference	Location	Year	Number of replicates	Number of replicates
Institution	Site		Average coral cover	Chain size meters
Protocol	Reef type		Standard deviation	Average rugosity
Are your data open?	Reef Zone		Standard error	Standard deviation
	Reef subtype			Standard error
	Latitude			Formula used
	Longitude			Notes
-	Coordinate units			
	Depth (m)			
	Temperature (Celsius)			

59 sites compiled for analysis with rugosity data.

Document type	No. SITES
Scientific article	29
Database	27
Report	3

Sites with specific hurricane sampling	11
Sites without specific hurricane sampling	48

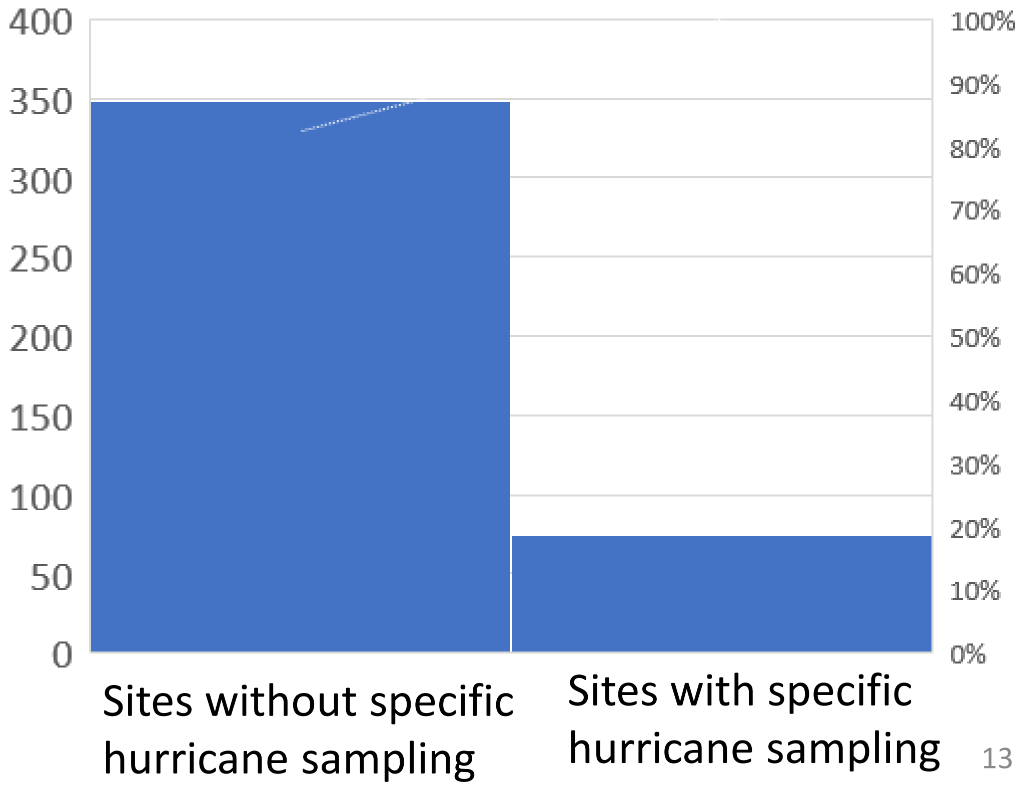


414 sites compiled for analysis with coral cover data

Document type	No. SITES
Scientific article	48
Database	356
Report	5
Bachelor Thesis	5

Sites with specific hurricane sampling → 75

Sites without specific hurricane sampling → 349



Countries with data in the Caribbean of 1973-2017 from 414 sites.

COUNTRIES	1973	1974	1978	1979	1980	1981	1982	1983	1985	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Belize																	4	4	2	2									84		18	68		44	4	18	48			
Guatemala																													6						4	5				
Mexico									5		15	5	15			2	2	1	1	1	1						6	111	63	24	24	48	18	32	16	14	14			2
Honduras																													78			18	16	52	34	12	70			
Bahamas																														33	23	34		35	1					
Barbados																1	2																							
Bermuda																2	2	2		1	2																			
Bonaire		4						4						3	1		2	2	2	6		1		3	4						4				4					
Colombia																4	2	2	2	2	2																			
Cuba																	4	2	2	2				8						8										
Curaçao	4							4						3	1		1	4		4					4						4				4					
United States																			32	31	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32		
Great Corn Island																1		1		1	1																			
Cayman Islands																		2		2																				
U. S. **Virgin Islands**				3	6	3				9	16	11	12	4	4	4	4	4	4	4	4	6	7	7	7	8	8	9	9	9	9	9	9	7	7	7	7	7		
Jamaica			7		5		2									1	1	1	2	2																				
Martinique																														2										
Puerto Rico																	2	3	3	2	2																			
Dominican Republic																			2	1																				
Saba																1	2	2	2		2																			
Saint Eustatius																						1						1		1	1							1	1	
San Salvador																	2	4	2	2	2																			
Tobago																	2	2	2	2	1																			
Venezuela																		4	6	2	2																			
Total SITES	4	4	7	3	11	3	2	8	5	9	31	16	27	10	6	16	32	40	64	67	51	40	39	50	47	40	46	153	272	109	115	209	75	202	106	97	171	40	1	2

3. Exploratory data analysis: purpose

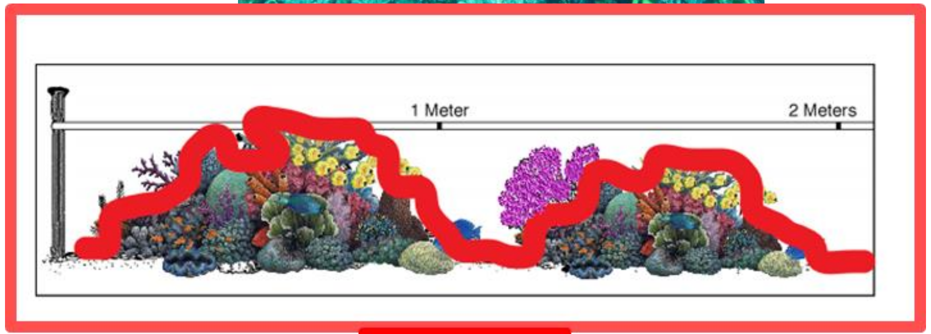
Get a clear picture of the relation of different features with hurricane damage to coral reefs, in order to guide and improve the modelling phase.

3. Exploratory data analysis: methods

Quantification of coral reef damage: coral cover

Coral cover refers to the proportion of hard coral area in the benthic floor. We will consider this variable, before and after the hurricane as a mesure of reef damage.

Quantification of coral reef damage: Rugosity



Cadena

Given a known linear distance, we use a chain to measure the corresponding contour difference over the reef. The quotient between the contour length and the linear distance is the rugosity index.

3. Exploratory data analysis: methods

Independent variable: Effective rate of change

We used the effective rate to quantify coral cover damage after a hurricane impact. A negative rate means coral cover loss and a positive rate, coral cover gain.

Rate of change	$\delta = \frac{\log(V_f) - \log(V_0)}{t}$
Effective rate of change	$\boldsymbol{i = e^{\delta} - 1}$

V_f = final value of a *process* (coral cover or rugosity).

V_0 = initial value.

t= time.

log=logarithm.

e= exponential (2,71828)

δ= Rate of change

$\boldsymbol{i}$= Effective rate of change.

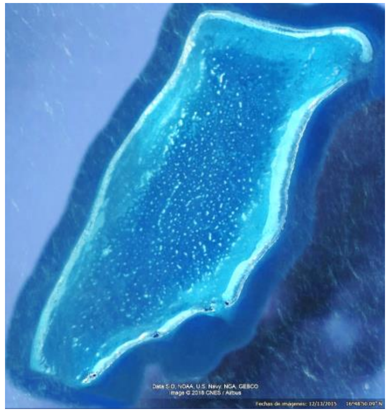
3. Exploratory data analysis: reef covariates

Reef covariates considered at this stage:

1. Initial coral cover (%)
2. Initial rugosity
3. Reef type
4. Reef zone
5. Reef depth (m)
6. Reef exposure.
7. Reef size
8. Fetch

3. Exploratory data analysis: description of categorical reef covariates

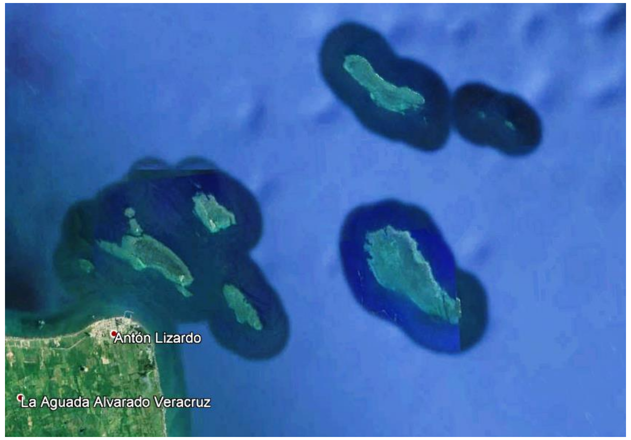
3. Reef type.



Atoll (Belize)

Barrier (The Turks and Caicos Islands)

Fringing (The Turks and Caicos Islands)



Platform (Veracruz)

Ovoid reefs comprising a crest and a central lagoon

Linear, continuous reefs, parallel but not adyacent to the coast

Reefs adyacent to the coast

Big, shallow, rounded reefs sometimes comprising sand keys or islands.

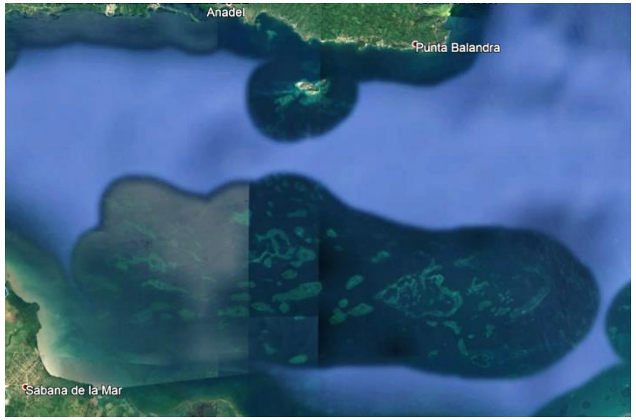
(Lang *et. al.*, 2010)

3. Exploratory data analysis: description of categorical reef covariates

3. Reef type

Bank (The Turks and Caicos Islands)

A system of adyacent, but separate, platform reefs



Shoal (Dominican Republic)

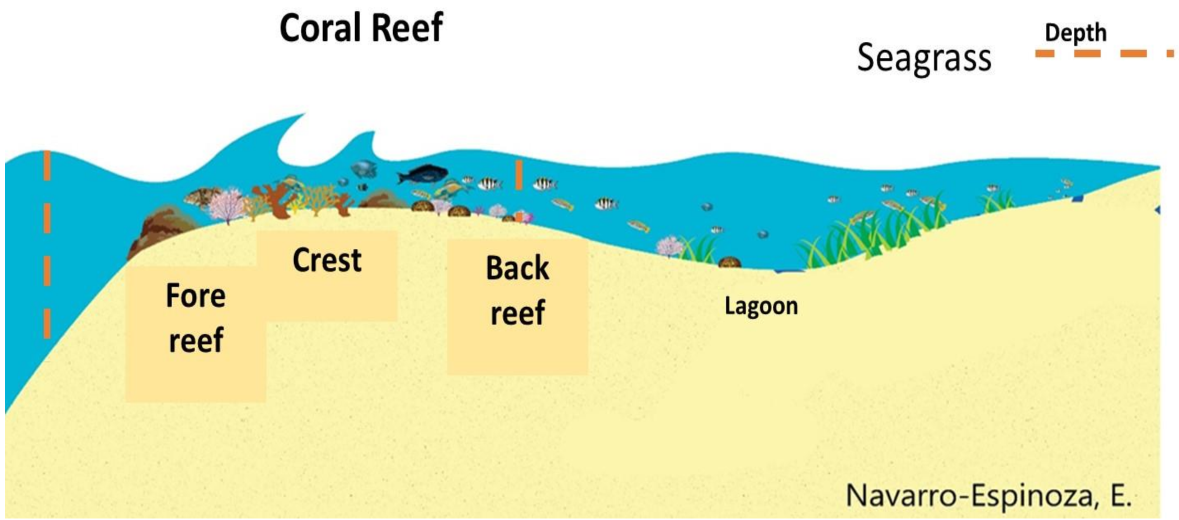
Reefs similar to platform ones, but without emerging to the surface

Patch (Florida))

A system of non-continuous coral reefs that are always underwater

3. Exploratory data analysis: description of categorical reef covariates

4. Reef zone
5. Reef depth (m)

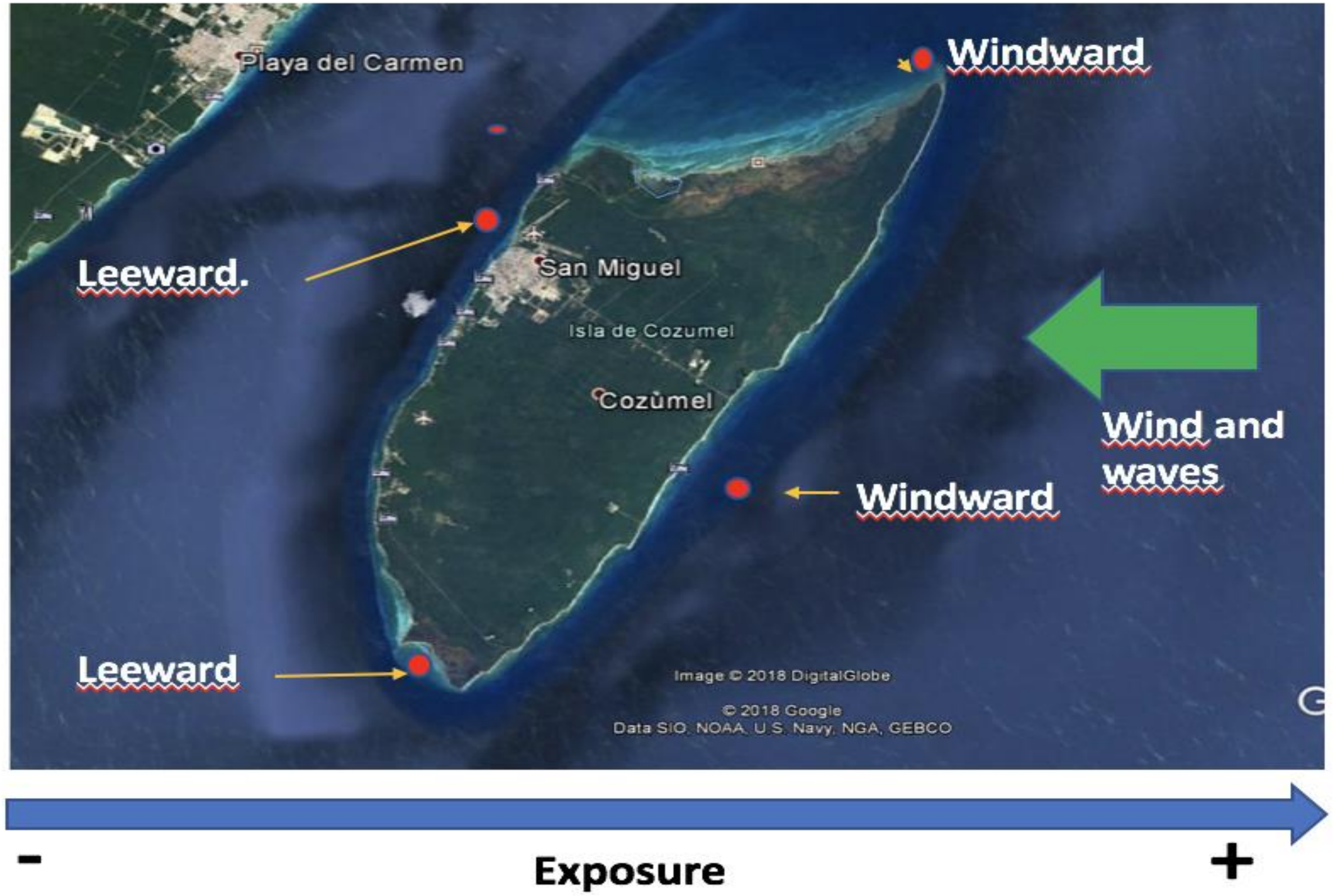


- **Crest**: shallowest part of the reef that is sometimes exposed to the air.
- **Front:** part of the reef that heads towards the sea.
- **Lagoon:** area protected from open sea by another reef structure.
- **Posterior / back:** part of the reef that heads towards the shore

(Lang *et. al.*, 2010)

3. Exploratory data analysis: description of categorical reef covariates

6. Reef location (exposure to wind and waves)



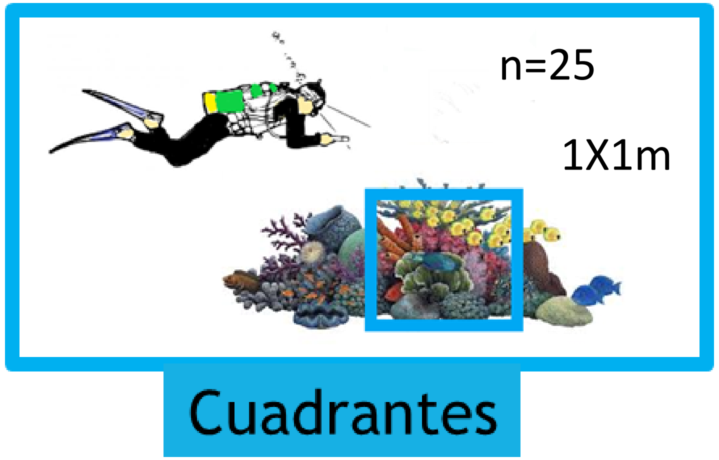
Depending on the reef location (windward / leeward) the reef is more or less protected from wind and waves.

(Lang *et. al.*, 2010):

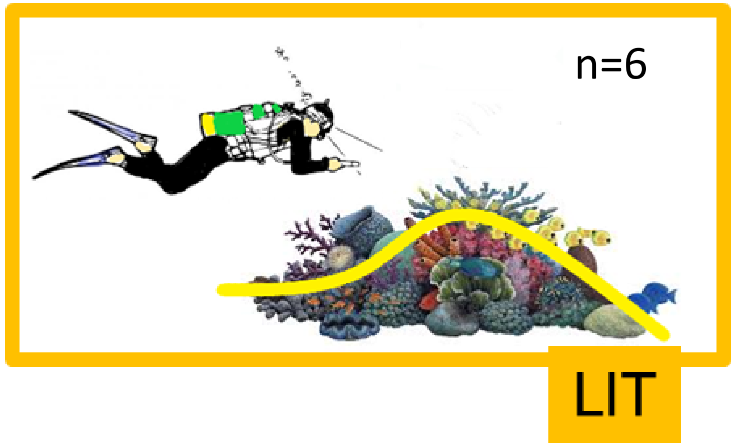
3. Exploratory data analysis: description of categorical reef covariates

7. Reef size.

The size of the sampled area, we used the **average transect/quadrat length** to measure it.



Size=1X1 m
Number of repetitions= 25

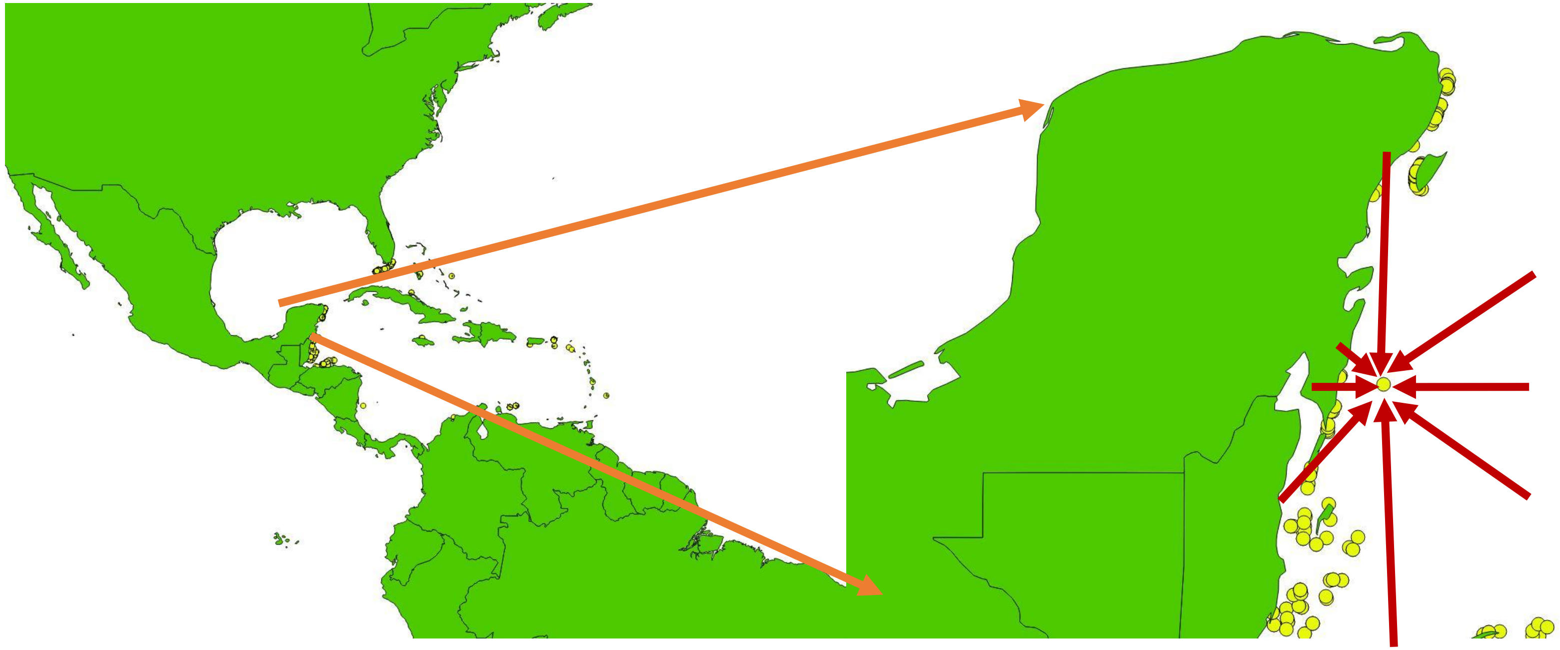


Size =10 m
Number of repetitions= 6

3. Exploratory data analysis: description of categorical reef covariates

8. Fetch

El fetch (m) the open water distance over which wind can blow along a given direction.



We calculated the fetch in the directions: north, northeast, east, southeast, south, southwest, west and northwest with the R package "Waver".

Using the America Shape file and the geografical coordinates of each site.

(InVEST Coastal Vulnerability Model y Rohweder J. et. al., 2008, Porto Tapiquén C. E., 2015)

3. Exploratory data analysis: hurricane covariates

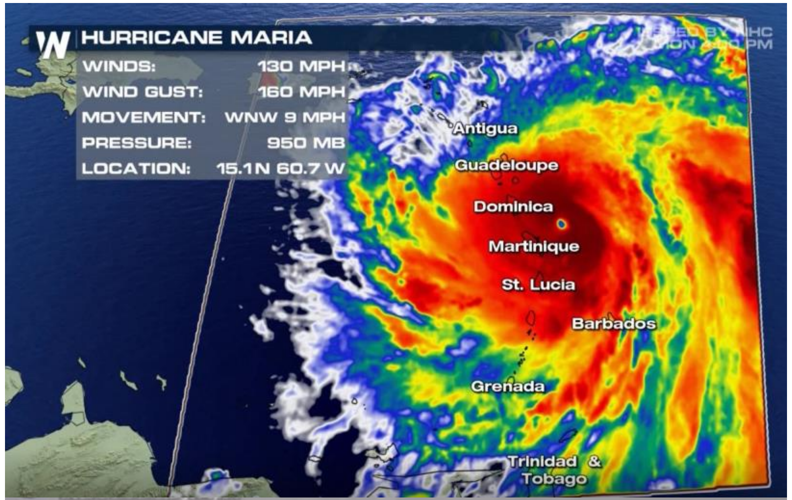
Hurricane covariates considered :

1. Maximum sustained wind (kt)
2. Central pressure (mb)
3. Duration of the exposition to hurricane winds
4. Minimum distance between the hurricane and the study area (m)
5. Intensity of the storm
6. Maximum wind speed at impact (kt)
7. Storm surge (m)

3. Exploratory data analysis: description of hurricane covariates

2. Maximum sustained surface wind (kt)

The maximum 1-min average wind associated with the tropical cyclone at an elevation of 10 m with an unobstructed exposure. Measured in knots (kt).



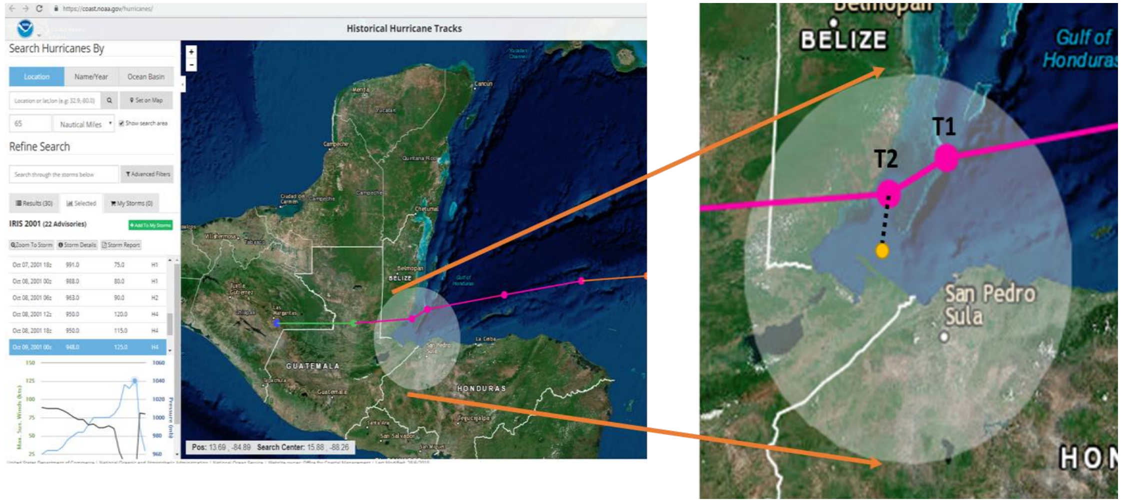
1. Central Pressure (mb)

Pressure at the eye of the hurricane. Measured in millibars (mb).

3. Exploratory data analysis: description of hurricane covariates

3. Duration of the exposition to hurricane winds

We used as a proxy the amount of hurricane ”snapshots” that intersected a 100km radius buffer around each site, between the initial and the final sampling date. Each snapshot is taken every 6 hours.



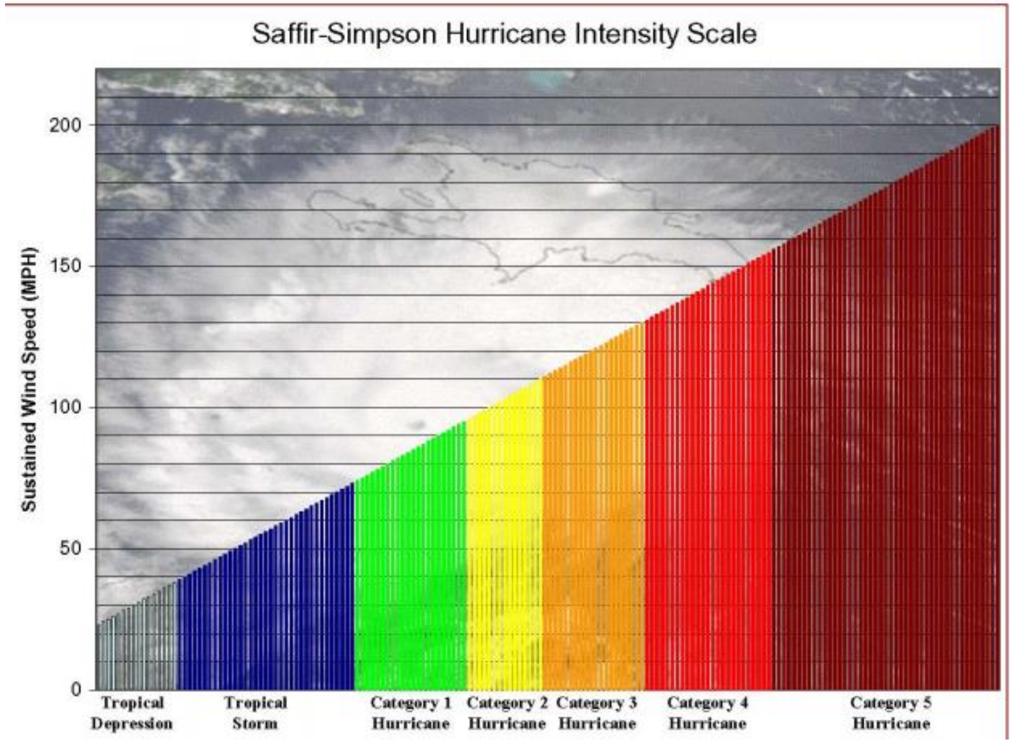
4. Minimum distance between the hurricane and the study area (m)

3. Exploratory data analysis: description of hurricane covariates

5. Intensity of the storm

Hurricanes and storms can be classified into:

Type	Category	Wind (kt)	Pressure (mb)
Tropical depression	TD	>34	---------
Tropical storm	TS	34-63	---------
Hurricane	H1	64-82	> 980
Hurricane	H2	83-95	965-980
Hurricane	H3	96-113	945-965
Hurricane	H4	115-135	920-945
Hurricane	H5	135-249	< 920

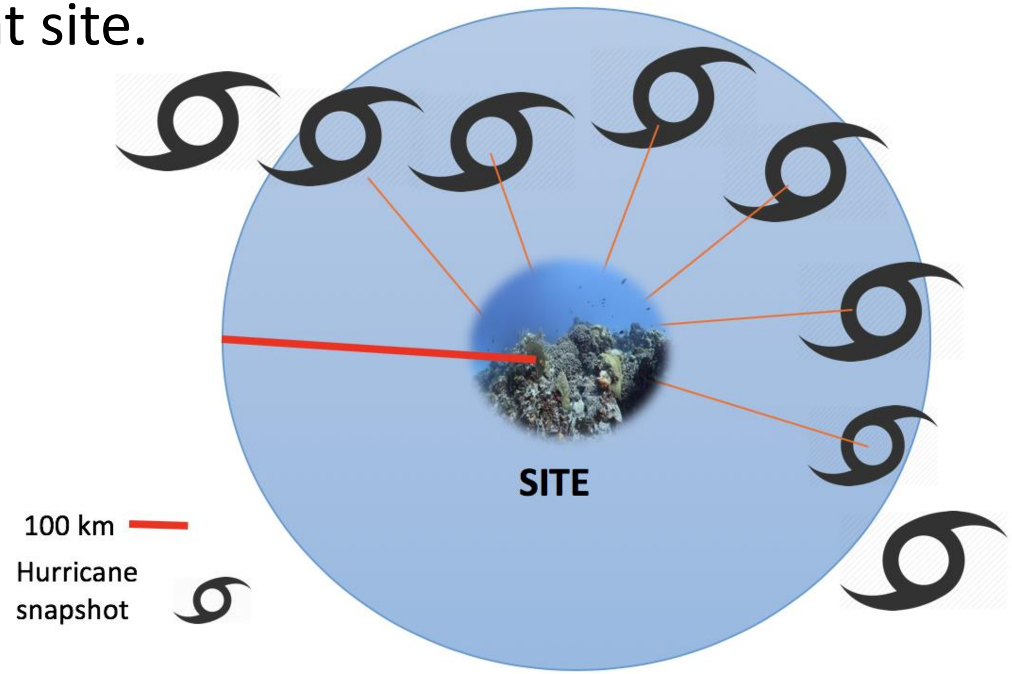


TD TS H1 H2 H3 H4 H5

3. Exploratory data analysis: hurricane covariates

We created a 100km radius buffer around each site, and intersected each of them with the hurricane “snapshots” data contained in the NOAA database, that ocurred between the initial and final sampling dates for that site.

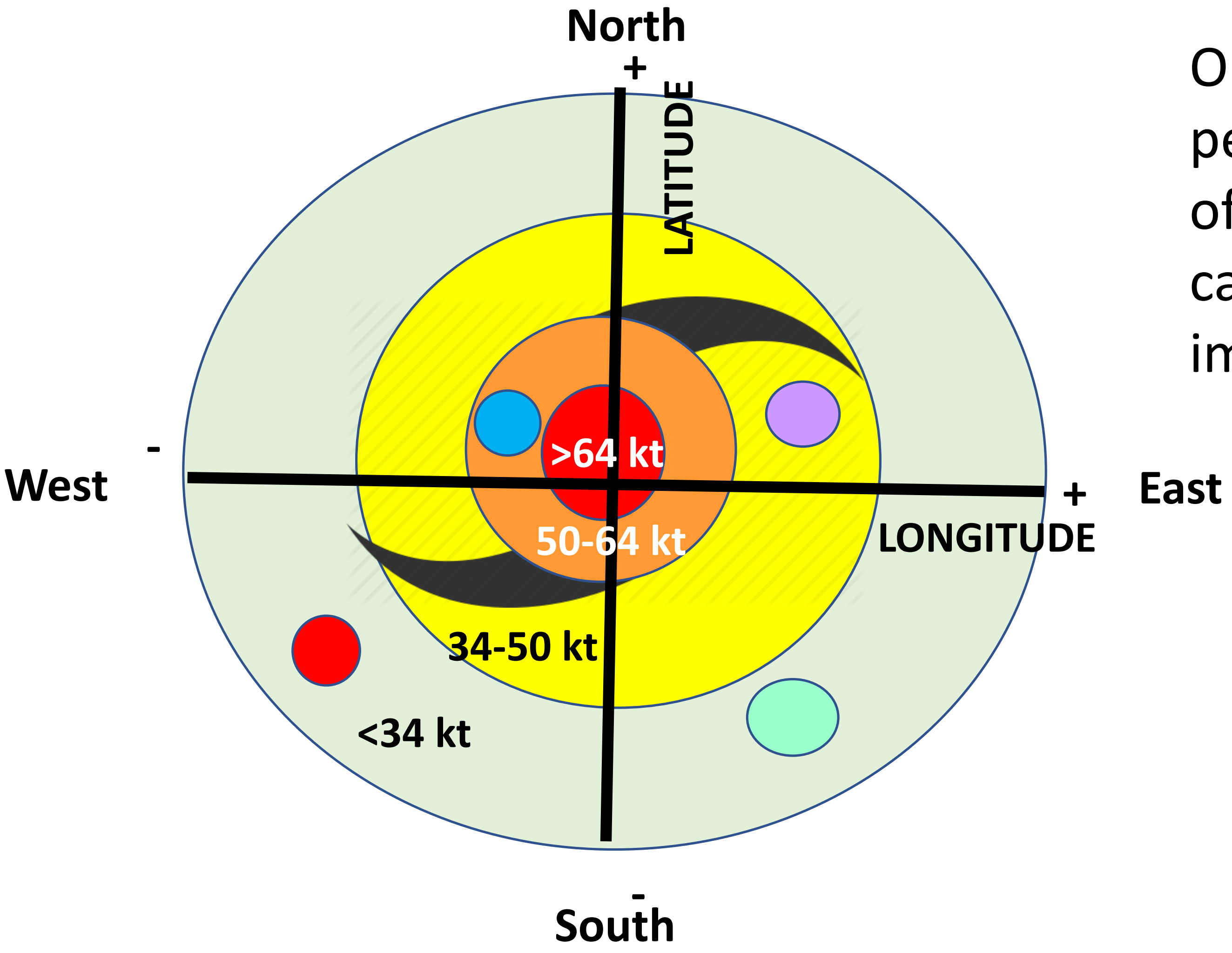
- Maximum sustained wind (kt)*
- Central pressure (mb)*
- Duration of the exposition to hurricane winds (snapshots)
- Minimum distance between the hurricane and the study area (m)
- Intensity of the storm*



* Weighted average by the inverse of the distance of each snapshot to the site.

3. Exploratory data analysis: description of hurricane covariates

6. Maximum wind speed at impact (kt)

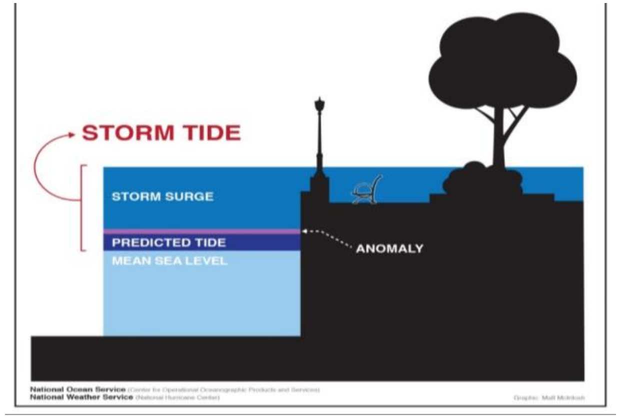


Our data consider radii of wind speed per quadrat (kt), so with the coordinates of each site and hurricane snapshot we can estimate the wind speed that impacted it.

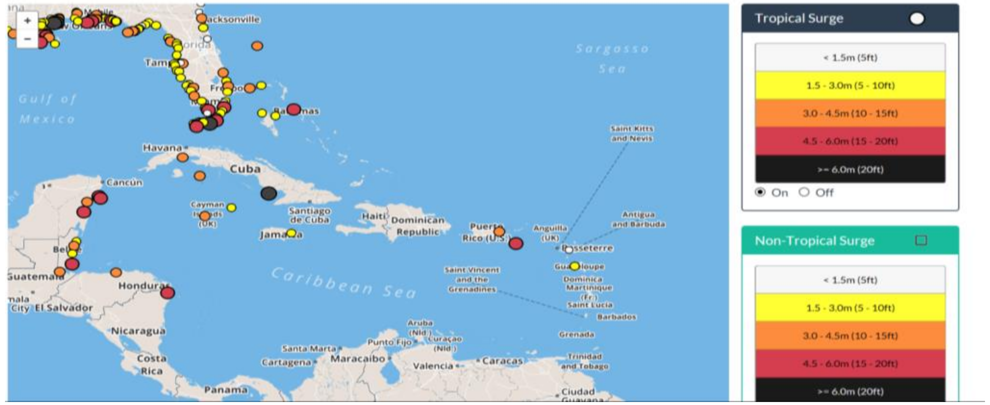
- NE=(Lat site > Lat hurricane) and (Long site > log hurrricane)
- SE= (Lat site < Lat hurricane) and (Long site > log hurricane)
- NW= (Lat site > Lat hurricane) and (Long site < log hurricane)
- SW= (Lat site < Lat hurricane) and (Long site < log hurricane)

3. Exploratory data analysis: description of hurricane covariates

7. Storm surge



Increase on the sea level caused by a storm



Data source: SURGEDAT: The World's Storm Surge Data Center, Louisiana State University

The data were obtained from [SURGEDAT: The World's Storm Surge Data Center](http://surge.srcc.lsu.edu/data.html#GlobalMap), *Louisiana State University*

http://surge.srcc.lsu.edu/data.html#GlobalMap

3. Exploratory data analysis: summary of considered covariates

Reef covariates:

1. Initial coral cover (%)
2. Initial rugosity
3. Reef type
4. Reef zone
5. Reef depth (m)
6. Reef exposure.
7. Reef size
8. Fetch

Hurricane covariates:

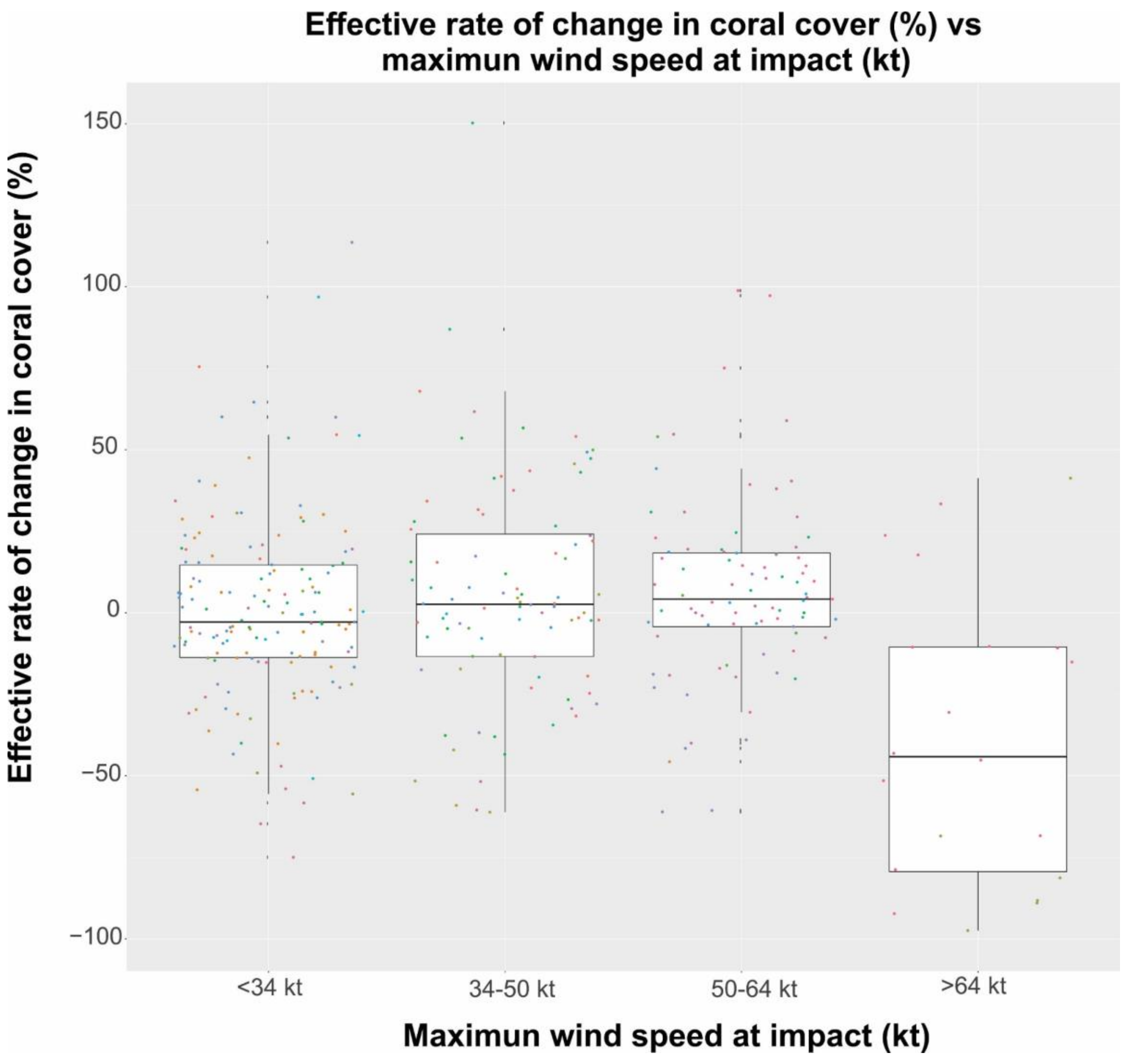
1. Maximum sustained wind (kt)
2. Central pressure (mb)
3. Duration of the exposition to hurricane winds
4. Minimum distance between the hurricane and the study area (m)
5. Intensity of the storm
6. Maximum wind speed at impact (kt)
7. Storm surge (m)

Variate		Apparent relationshio with the coral cover change rate	Apparent relationship with the rugosity change rate
Reef	**1. Initial coral cover**	**Correlated**	
	2. Initial rugosity		**Correlated.**
	3. Reef type.	No correlated	No correlated
	4. Reef zone	No correlated	No correlated
	5. Reef depth	No correlated	No correlated
	6. Reef exposure	**Correlated**	**Correlated.**
	7. Reef size	No correlated	No correlated
	8. Fetch	No correlated	No correlated
Hurricane	**1. Maximum sustained wind**	**Correlated**	No correlated.
	2. Central pressure	**Correlated**	No correlated
	3. Duration of the exposition to hurricane winds	**Correlated**	No correlated
	4. Minimum distance between the hurricane and the study area	No correlated	No correlated
	5. Intensity of the storm	**Correlated**	No correlated
	6. Maximum wind speed at impact	**Correlated**	No data
	7. Storm surge	**Correlated**	No correlated

Coral cover

Maximum wind speed at impact

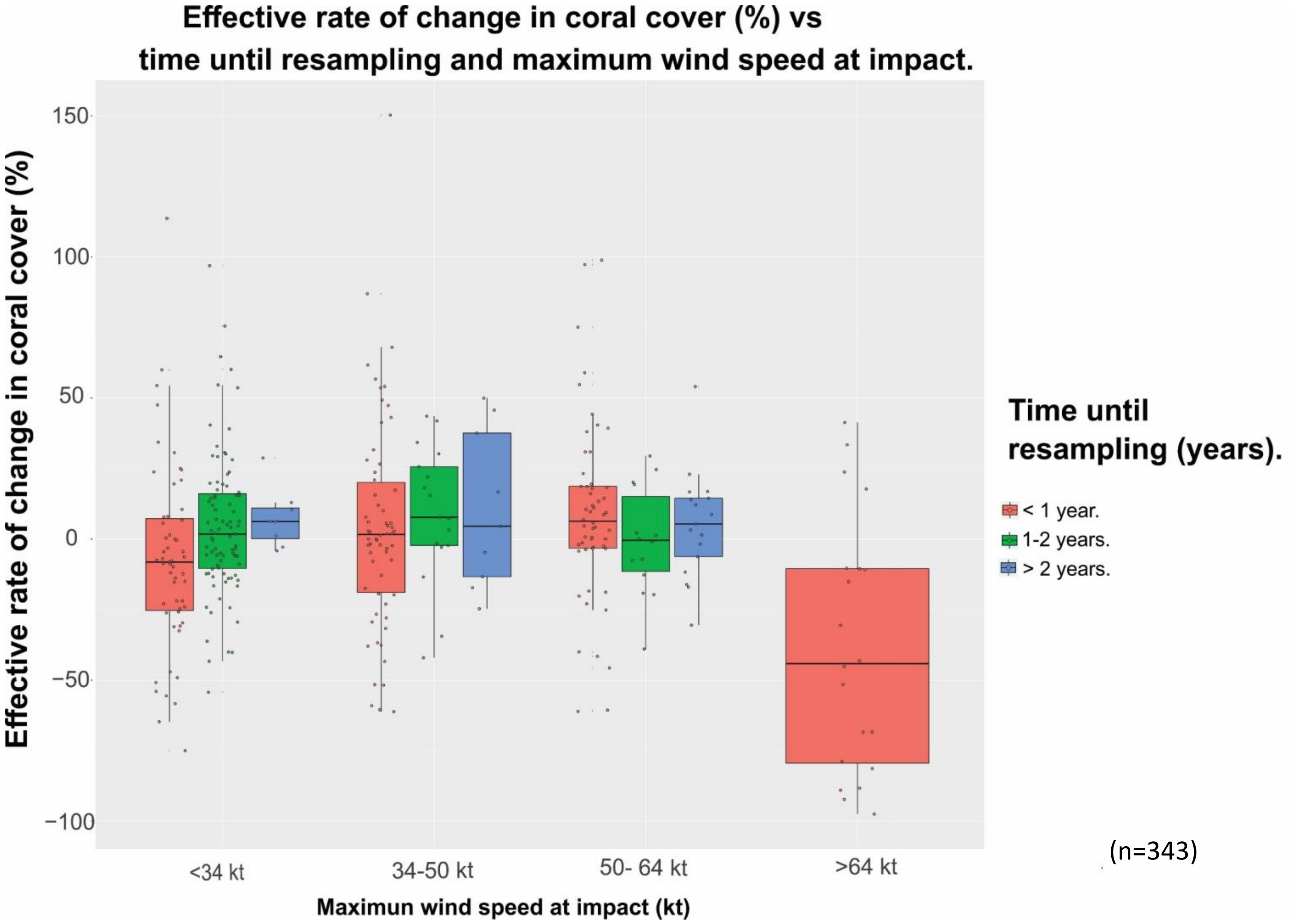
Maximum wind speed at impact appears to be a better predictor of coral reef damage



(n=343)

Maximum wind speed at impact

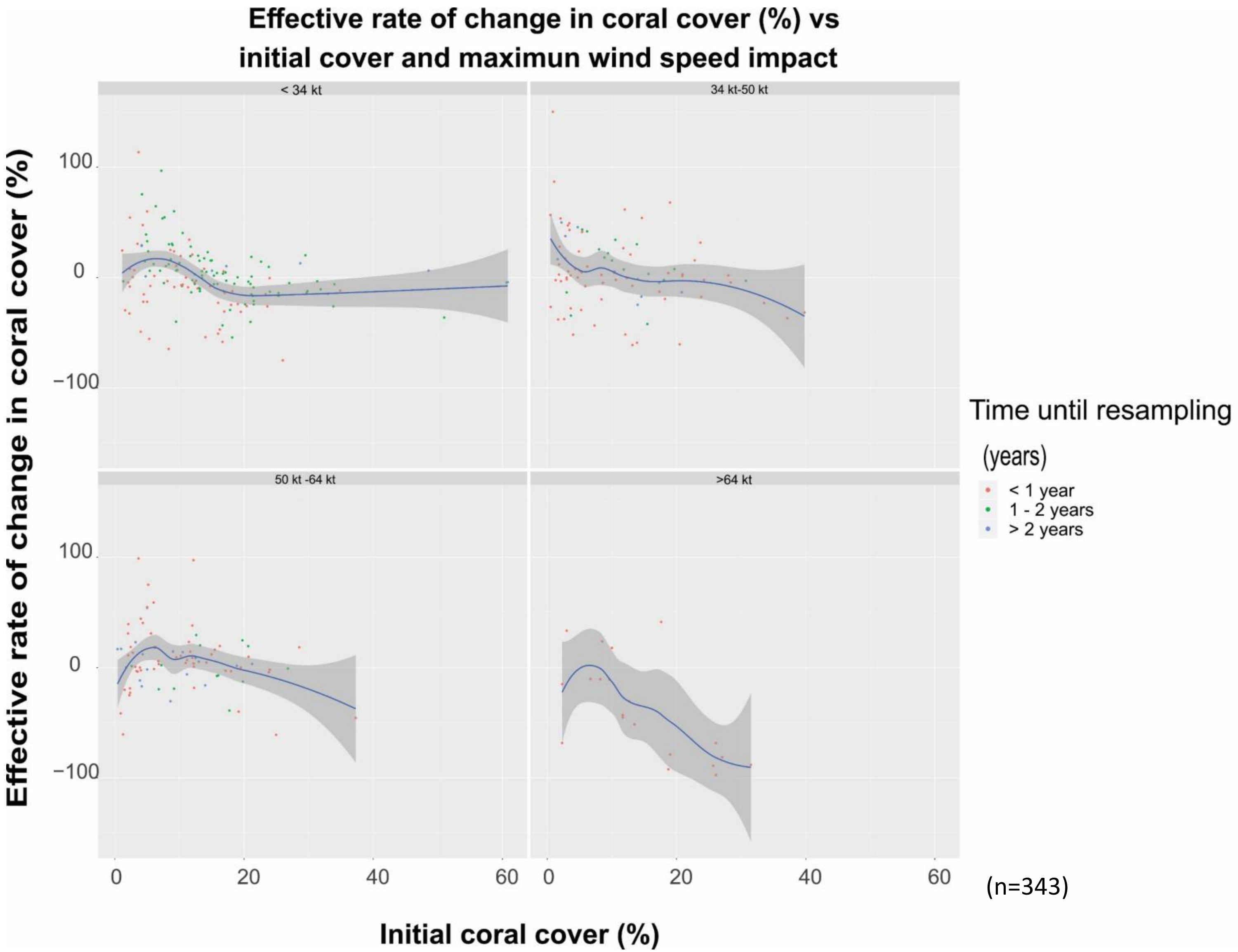
We can see that sites impacted by hurricanes with wind speeds greater than 64kt show greater coral cover loss. We only have data for resamples made after less than one year.



(n=343)

Initial coral cover.

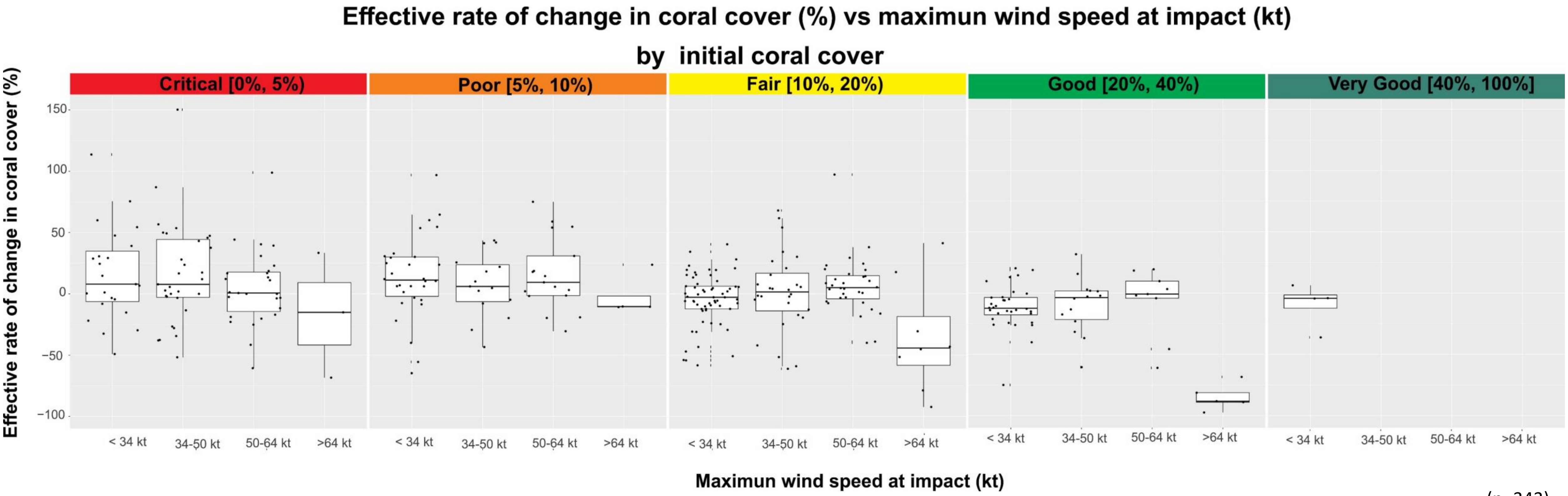
We can observe greater coral cover loss with increasing wind speeds and initial coral cover.



(n=343)

Initial coral cover.

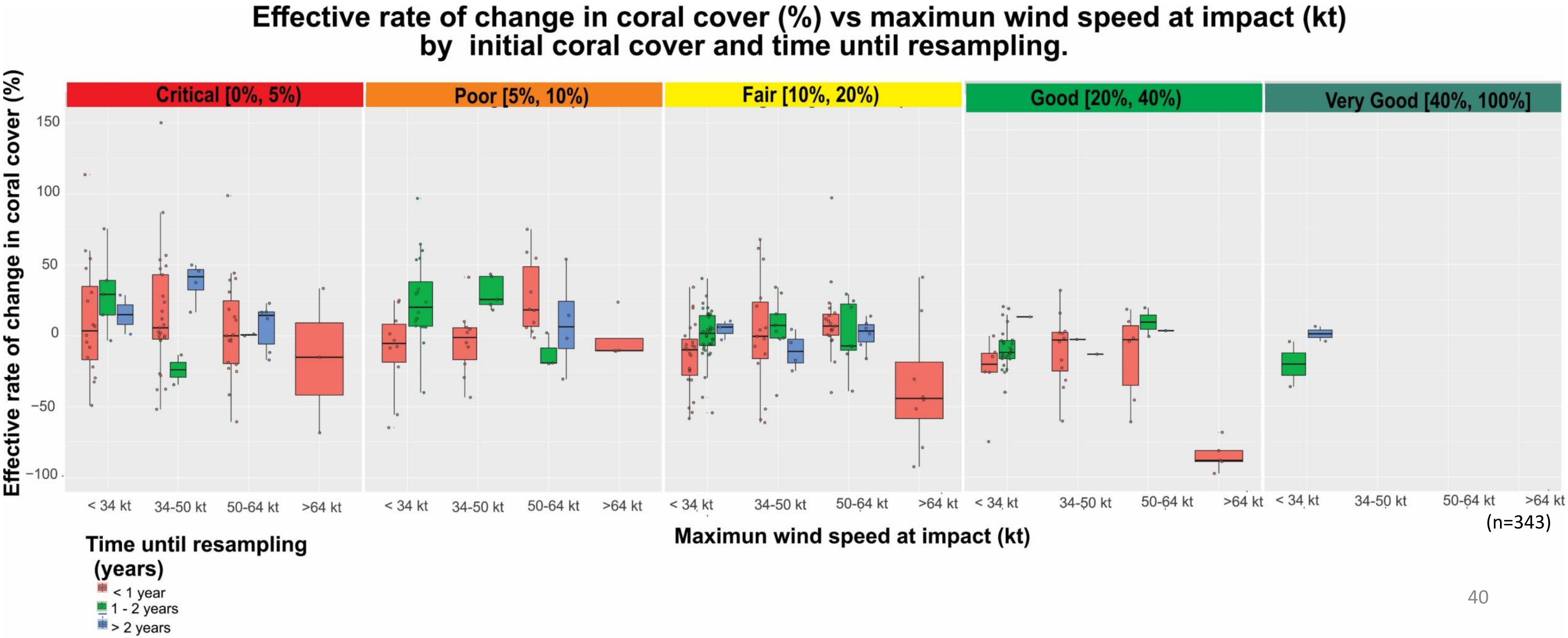
All sites tend to show a greater coral cover loss after being impacted by windspeeds of more than 64kt. However, the efect is more evident in coral reefs with higher initial coral cover (20%-40%) .



(n=343)

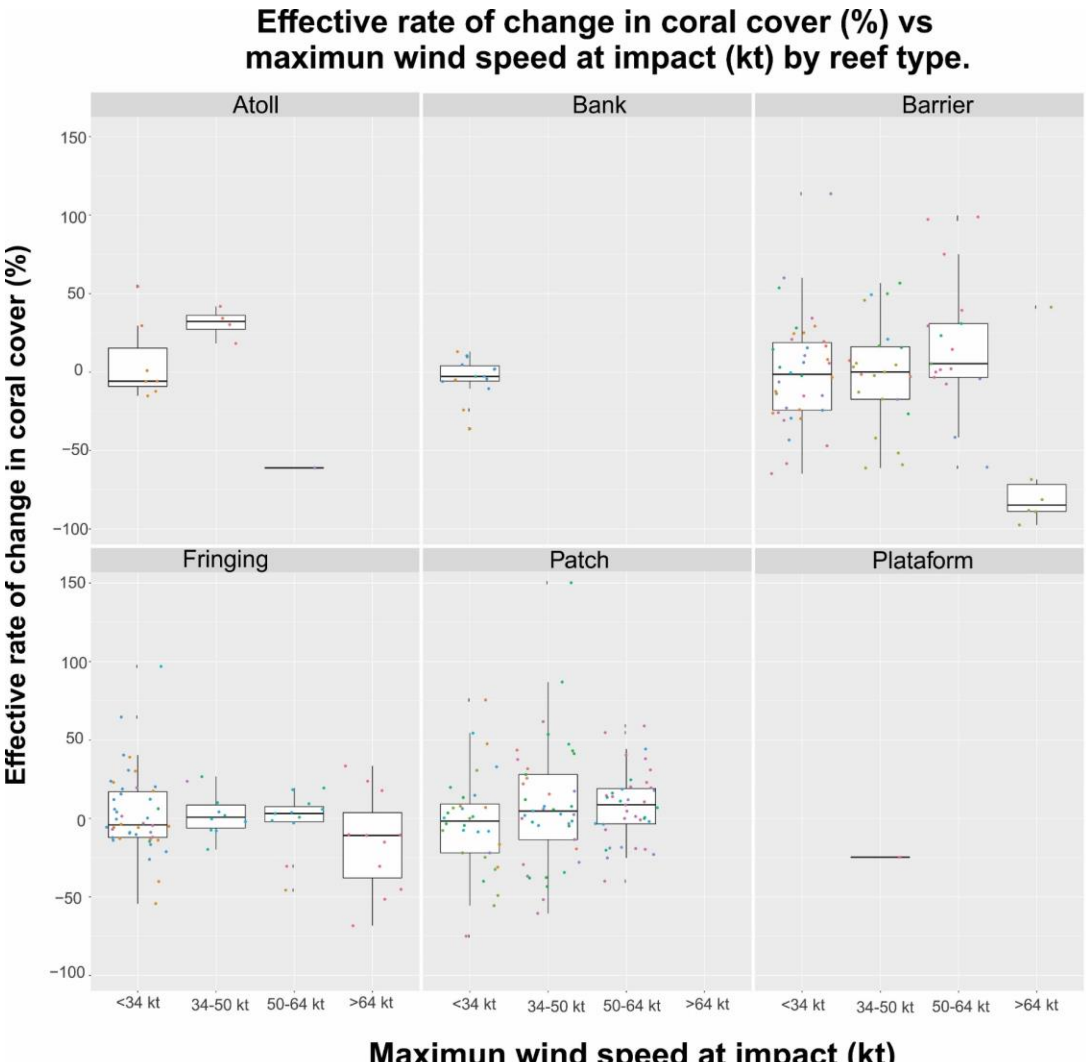
Initial coral cover.

If we check by time until resampling, we can see that the trend continues to hold for sites resampled after less than 1 year, for coral reefs with greater coral cover (10%-40%).



Reef type

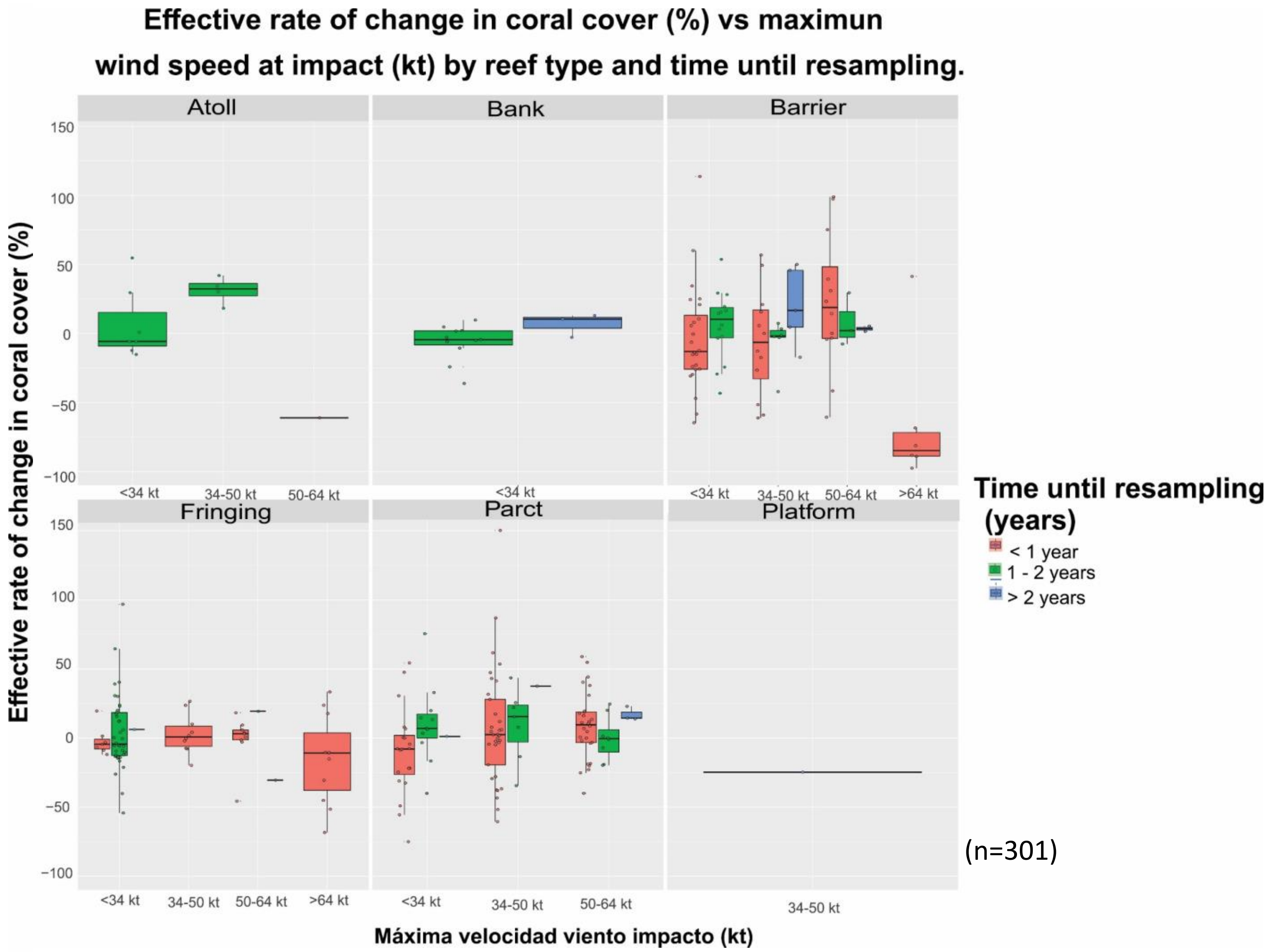
Reef type is apparently not correlated with coral reef loss: the 5 sites in frontal zone were impacted by the same hurricane.



(n=301)

Reef type

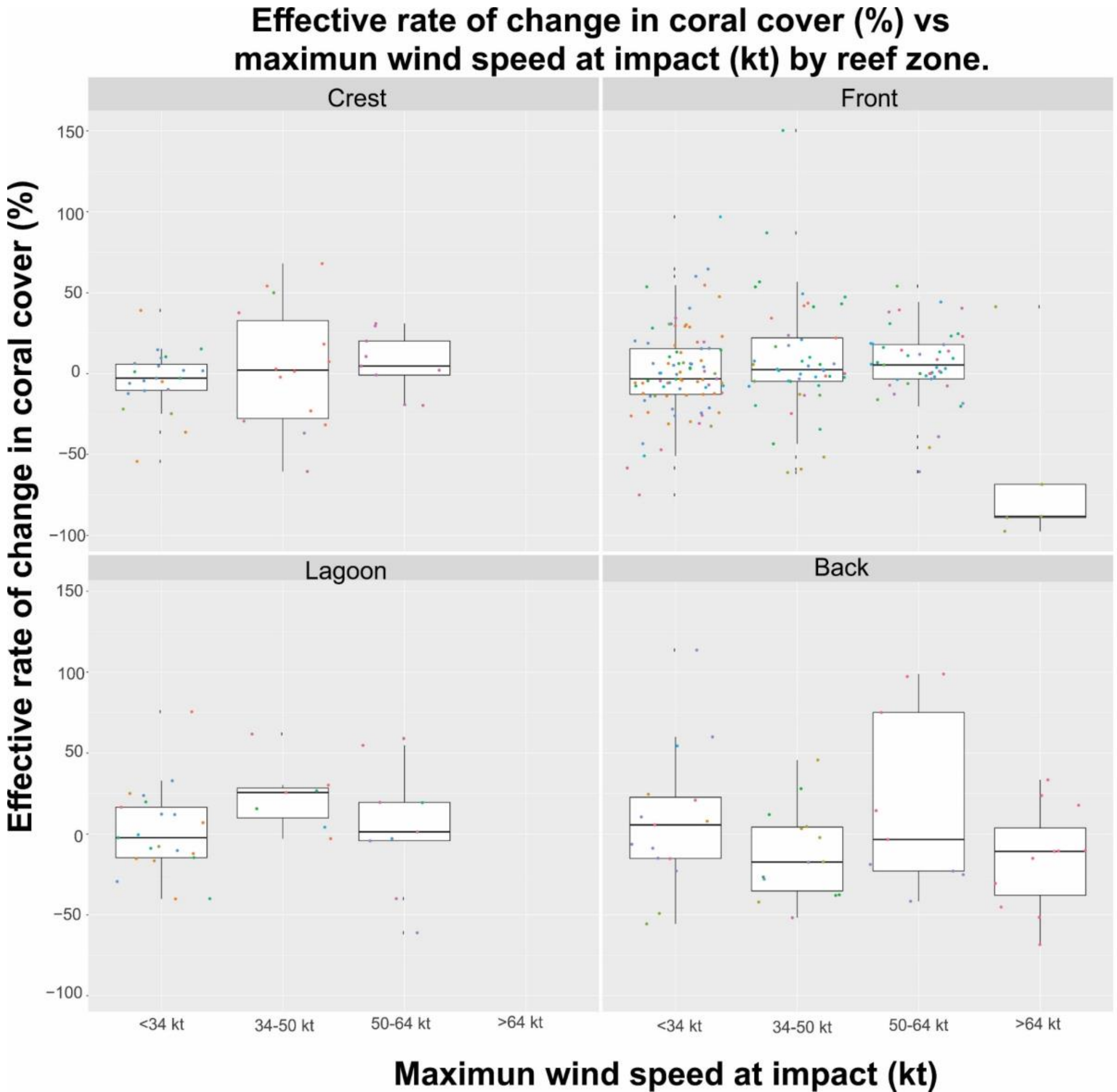
Barrier reefs are apparently more sensible to winds greater tha 64kt, however, when using a quantile classification for time until resampling, it was evident the difference in times (the barrier reefs had less time to recover).



(n=301)

Reef zone

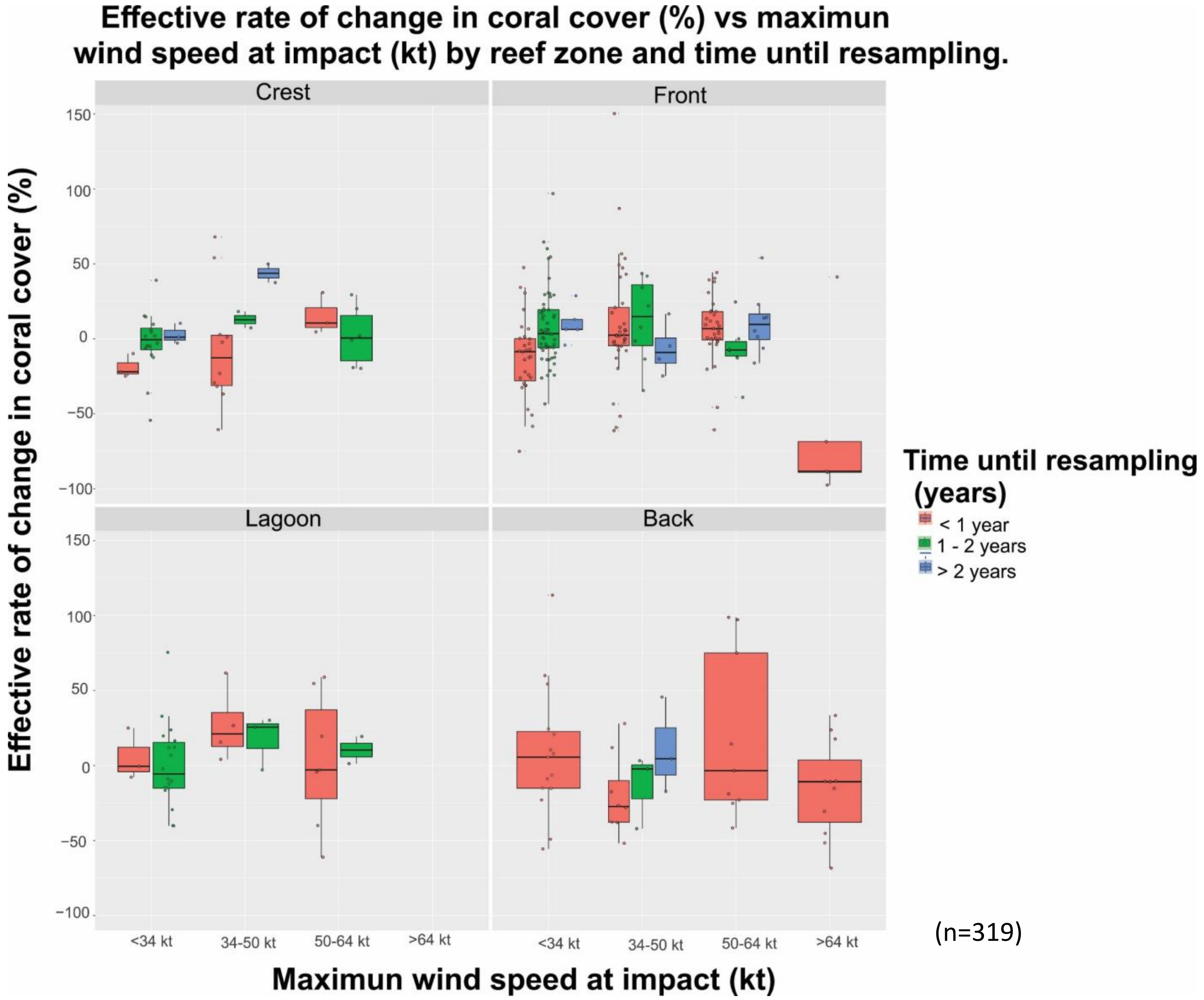
Reef zone is apparently not correlated with coral reef loss: the 5 sites in frontal zone were impacted by the same hurricane.



(n=319)

Reef zone

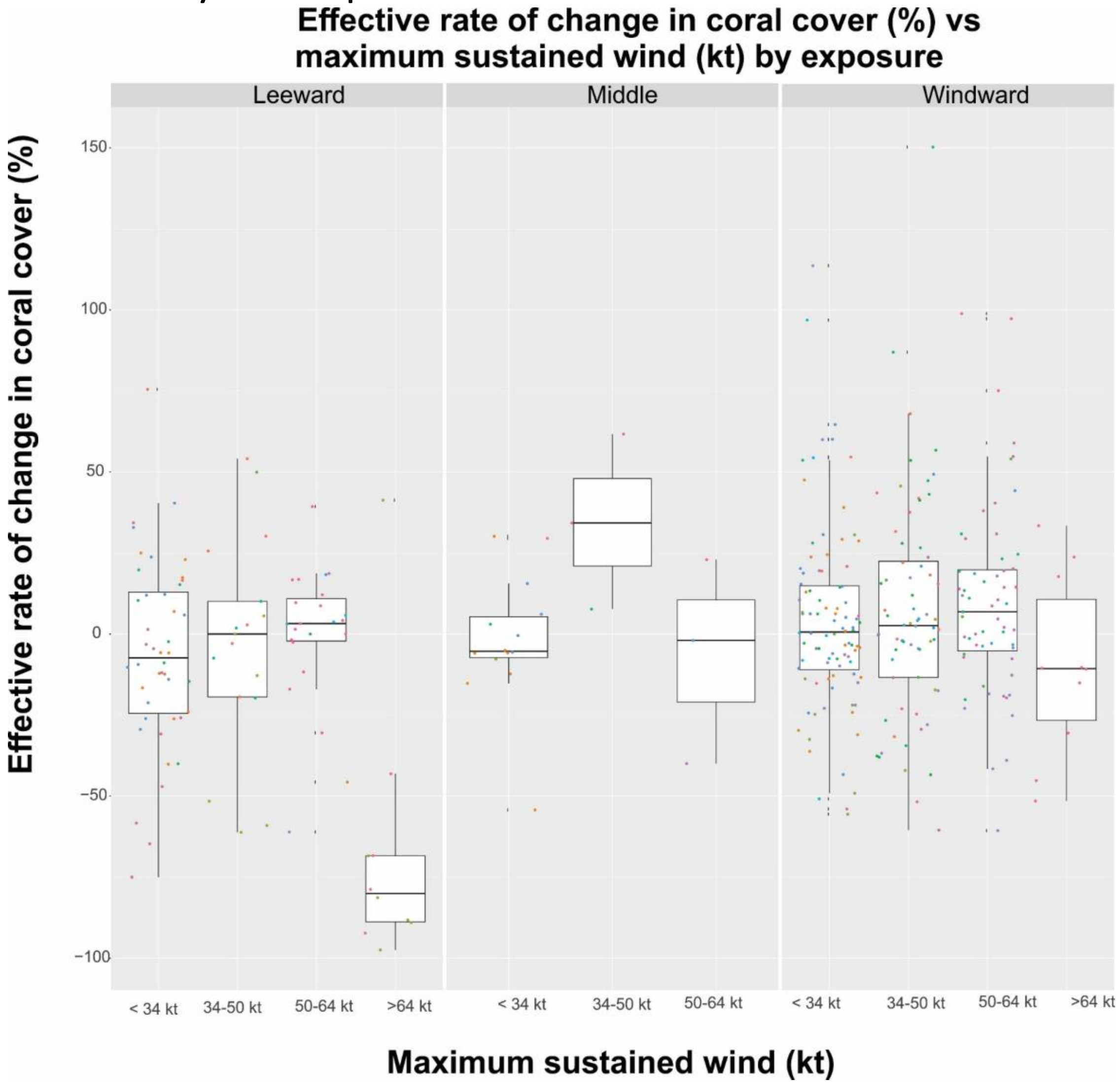
By taking into account time until resampling, we can see the relationship does not change.



(n=319)

Reef exposure

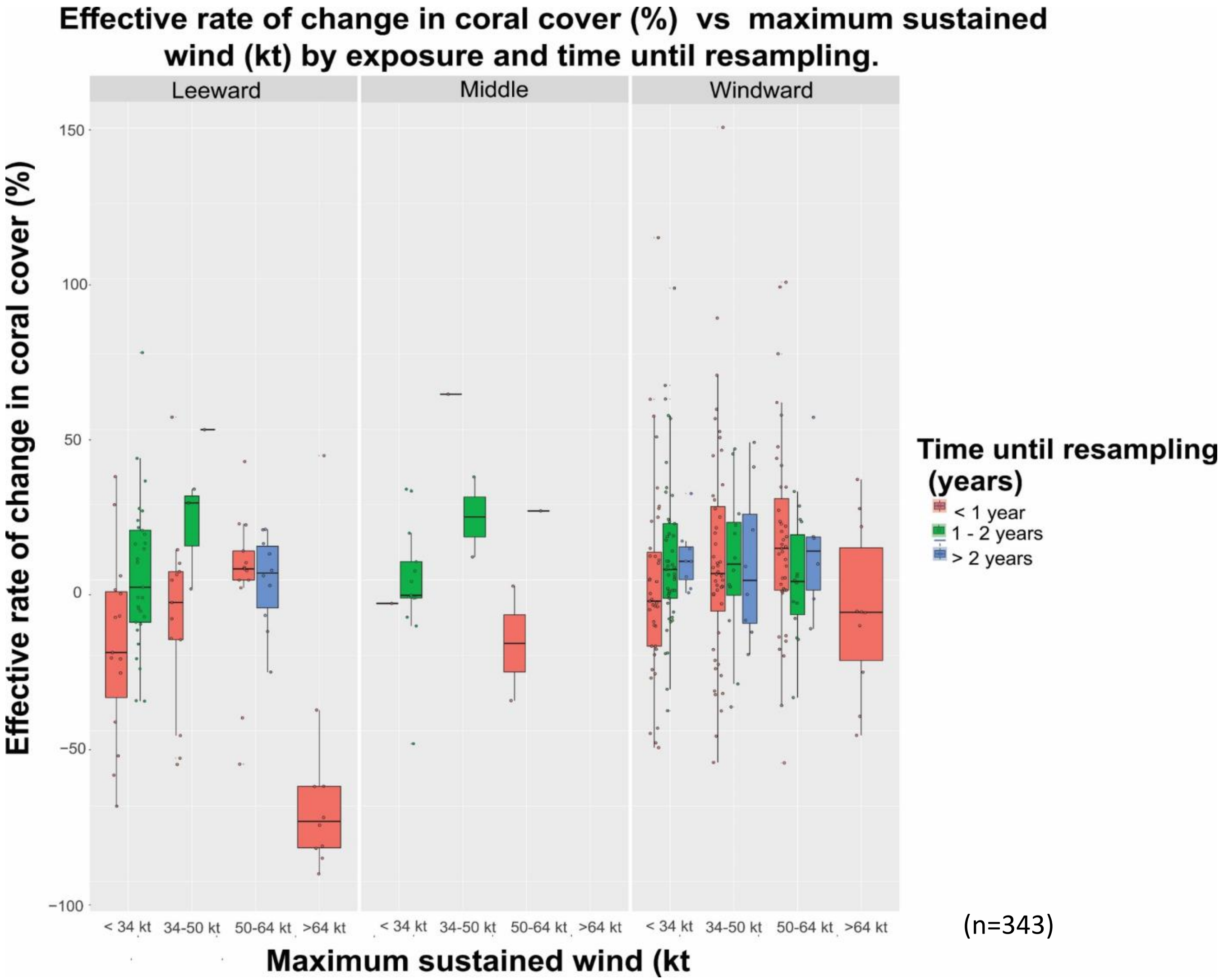
Coral reefs with less exposure (leeward) reflect more coral reef damage with strong winds (>64 kt) than coral reefs with more exposure (windward): A possible explanation could involve differences in coral community composition.



(n=343)

Reef exposure

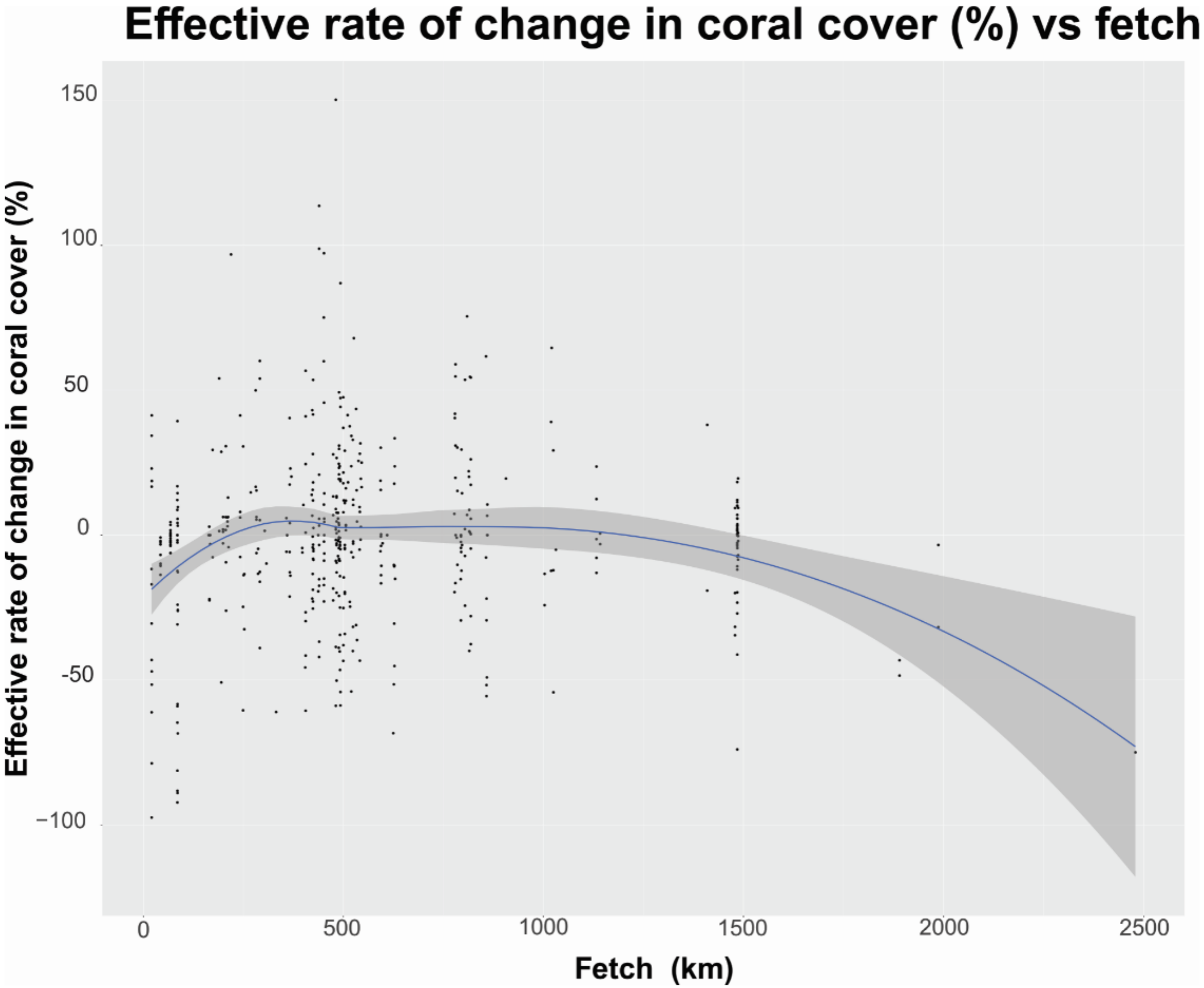
By taking into account time until resampling, we can see the relationship does not change.



(n=343)

FETCH

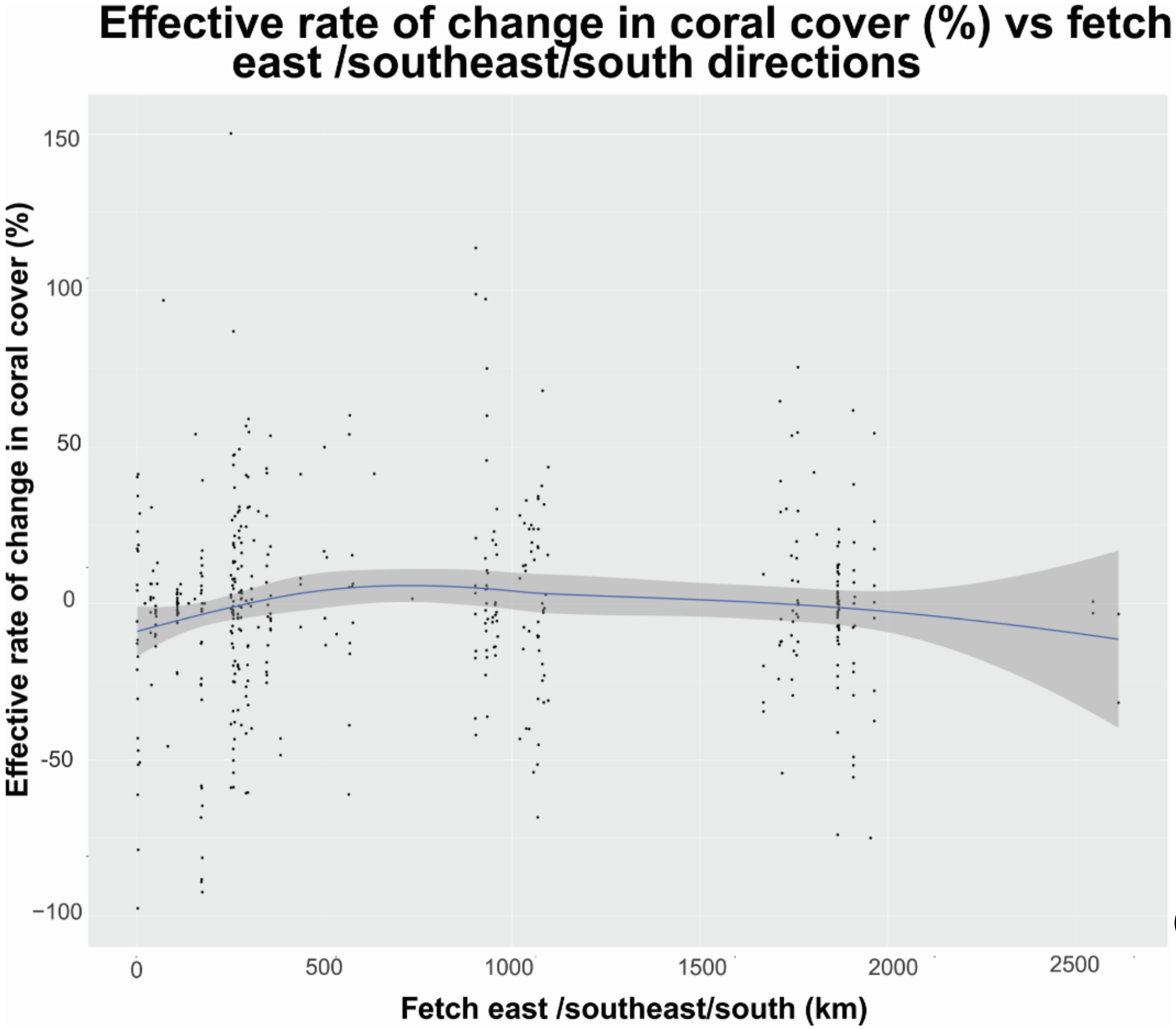
Sites with an average fetch greater than 1500km tended to show more affectation when using the average fetch across the eight directions.



(n=470)

FETCH

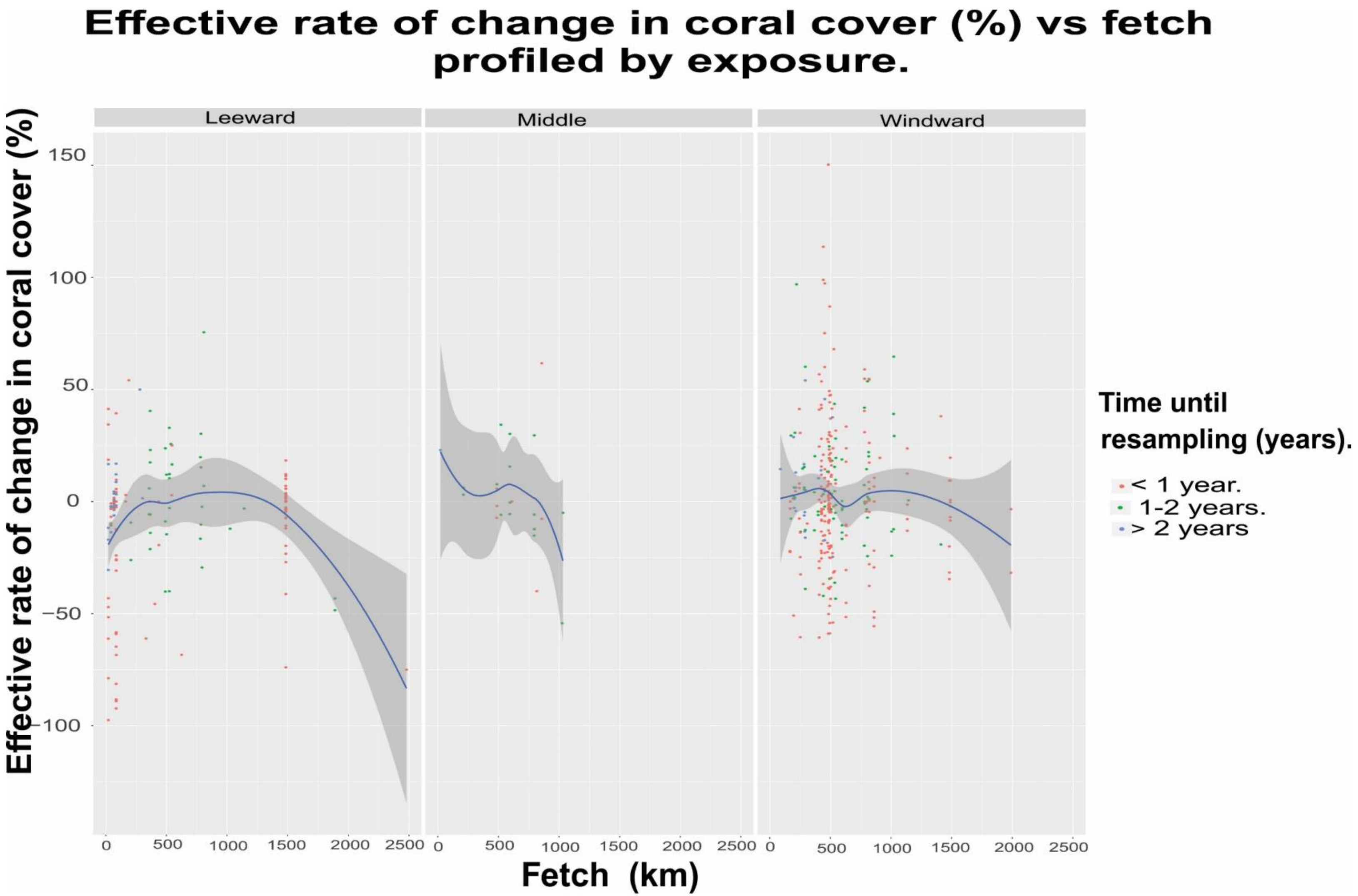
However, when averaging only the east /southeast/south directions, we lose all signs of correlation



(n=470)

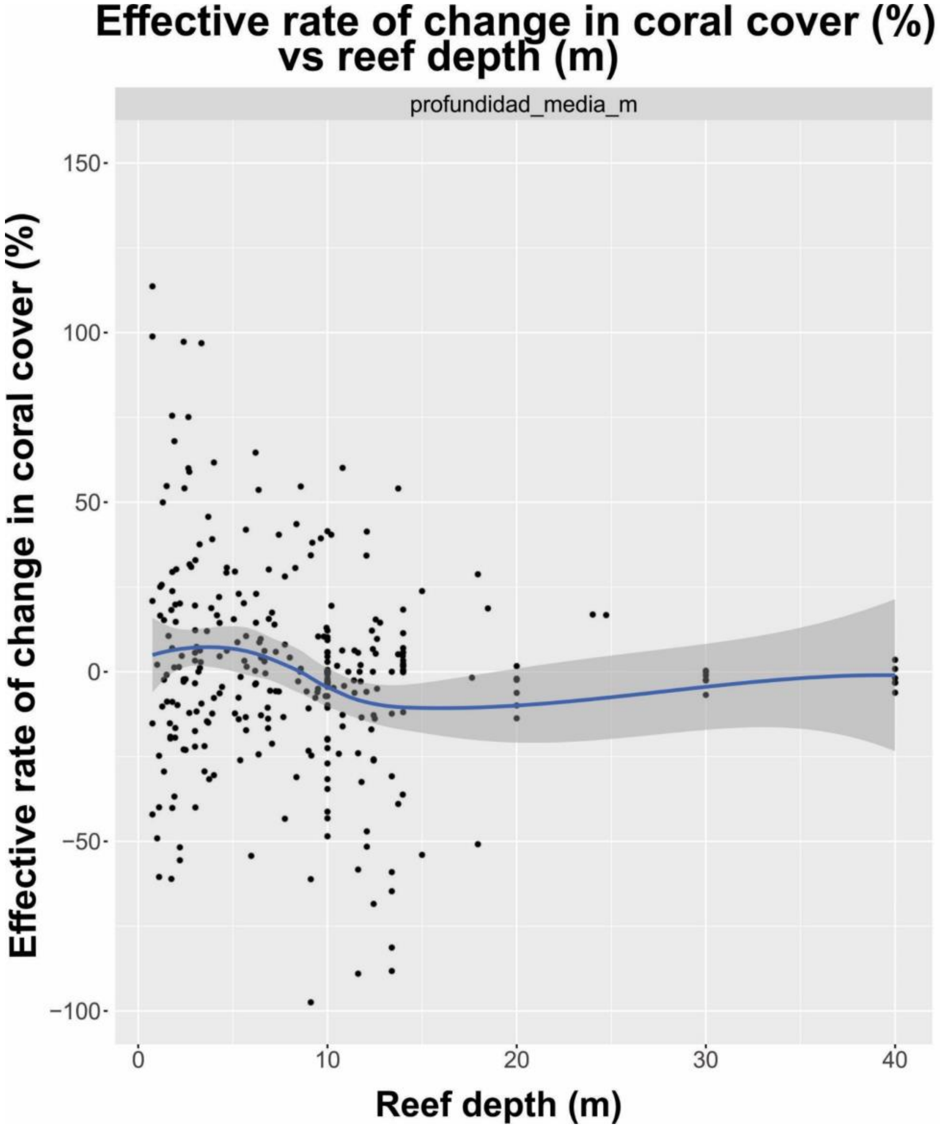
FETCH

Leeward sites appear to correlate with more coral cover damage than windward sites. Again, a possible explanation could involve differences in coral community composition.



Reef depth.

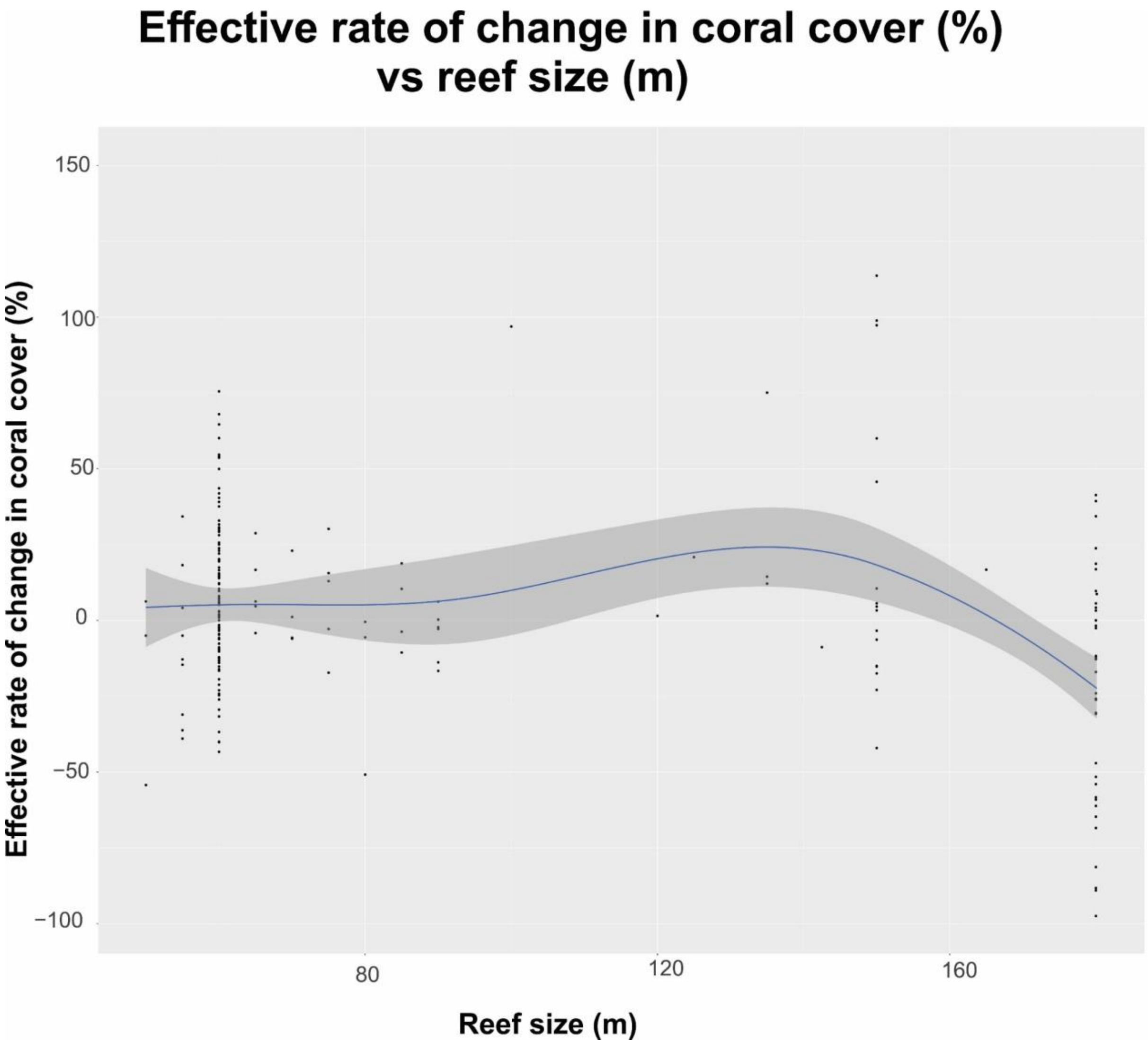
Apparently there exists no correlation between average depth (m) and coral cover change rate.



n=304

Reef size

Apparently there exists no correlation between reef size (m) and coral cover change rate.

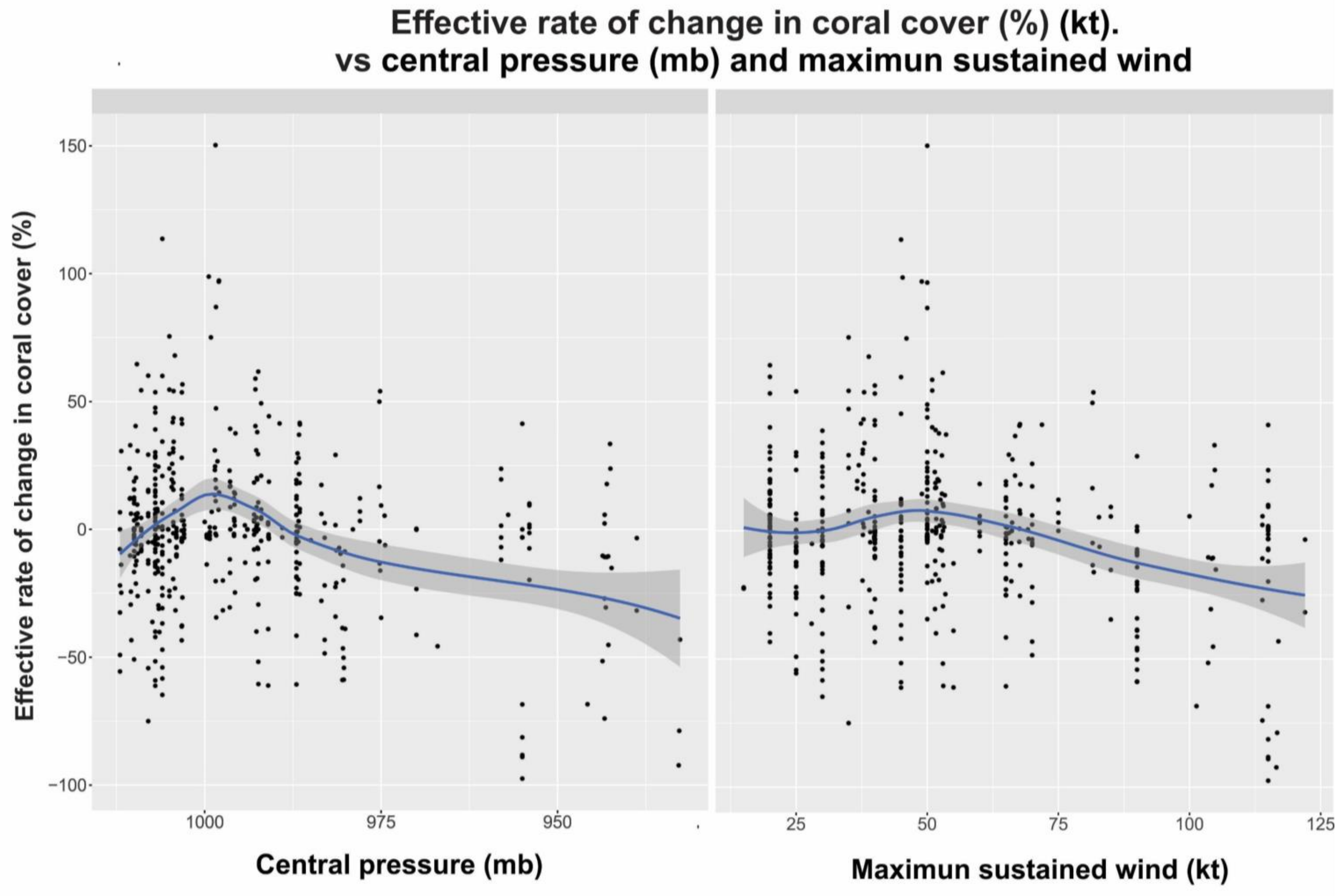


(n=304)

Maximum sustained wind y central pressure.

In general, a higher maximum sustained wind (kt) / lower central pressure (mb) appear to correlate with higher coral reef loss. It is important to say that maximum sustained swind and central pressure are higly correlated (p = -0.92)

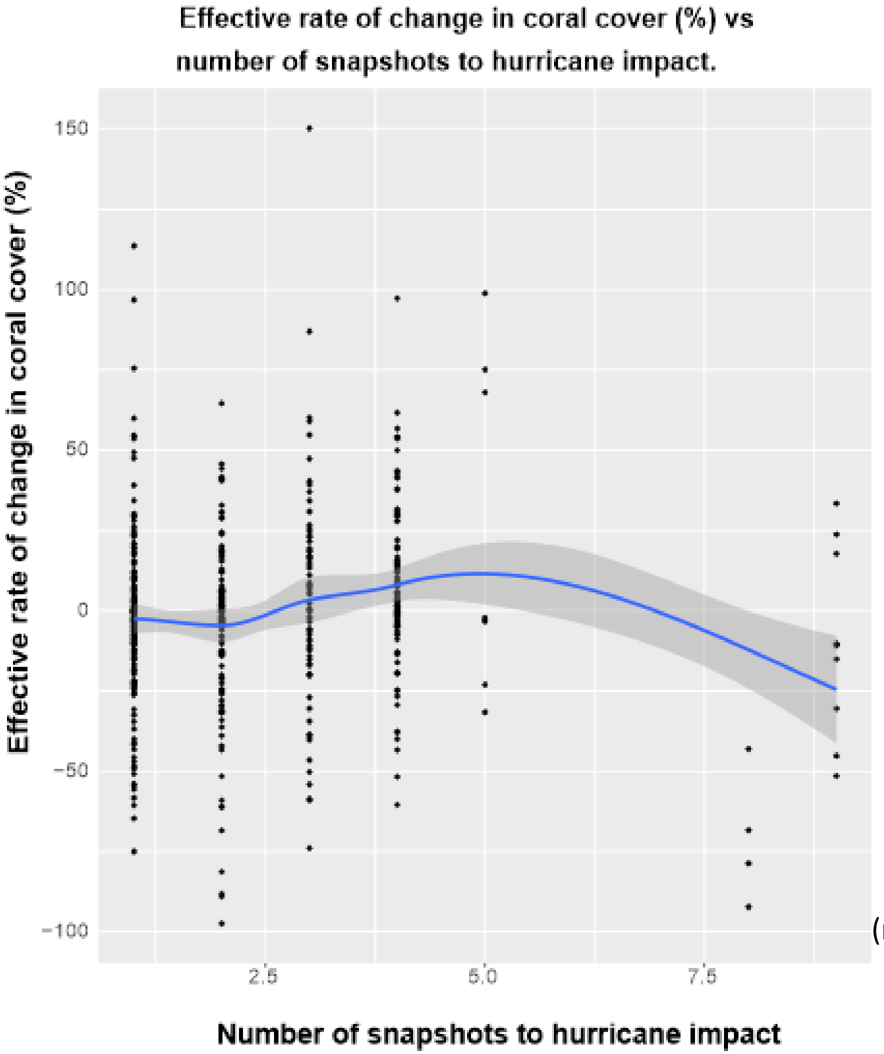
(n=468)



(n=470)

Duration of the exposition to hurricane winds.

Sites exposed more time to hurricane winds appear to show more coral cover loss.

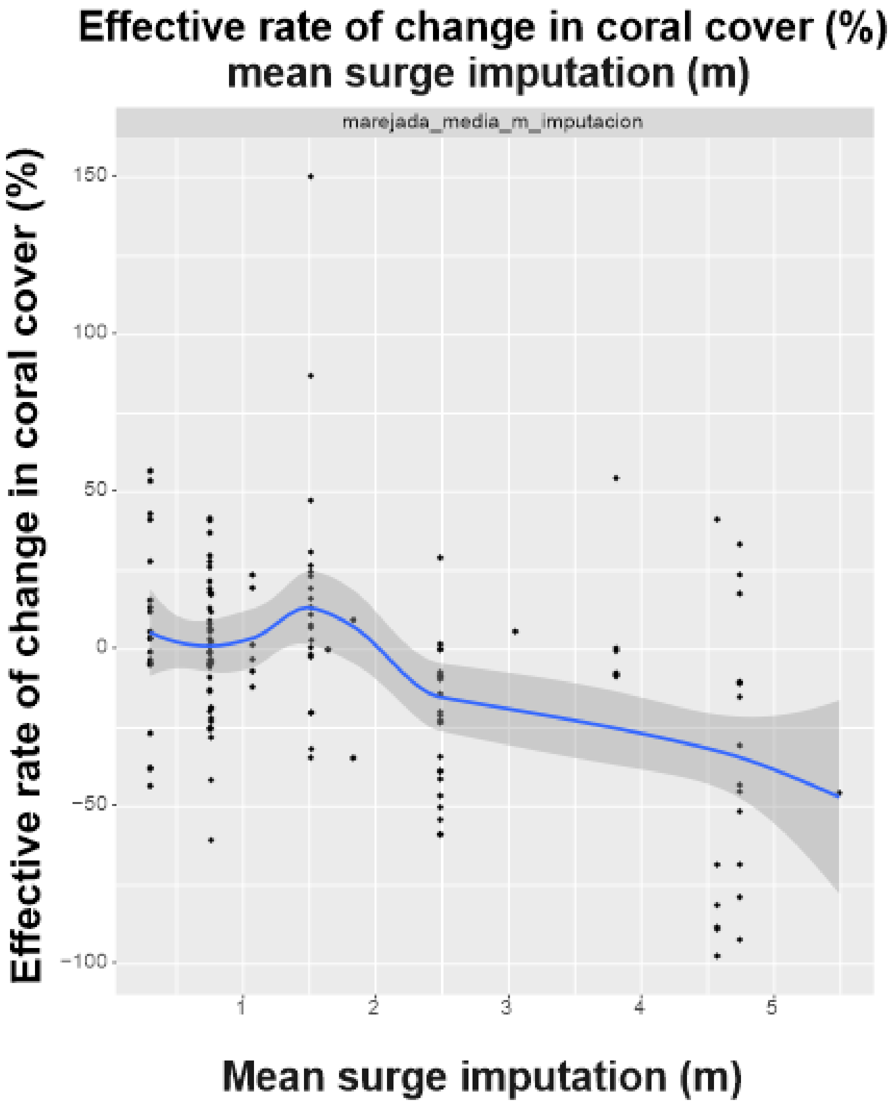


(n=470).

1 snapshots= 6 hour

Storm surge

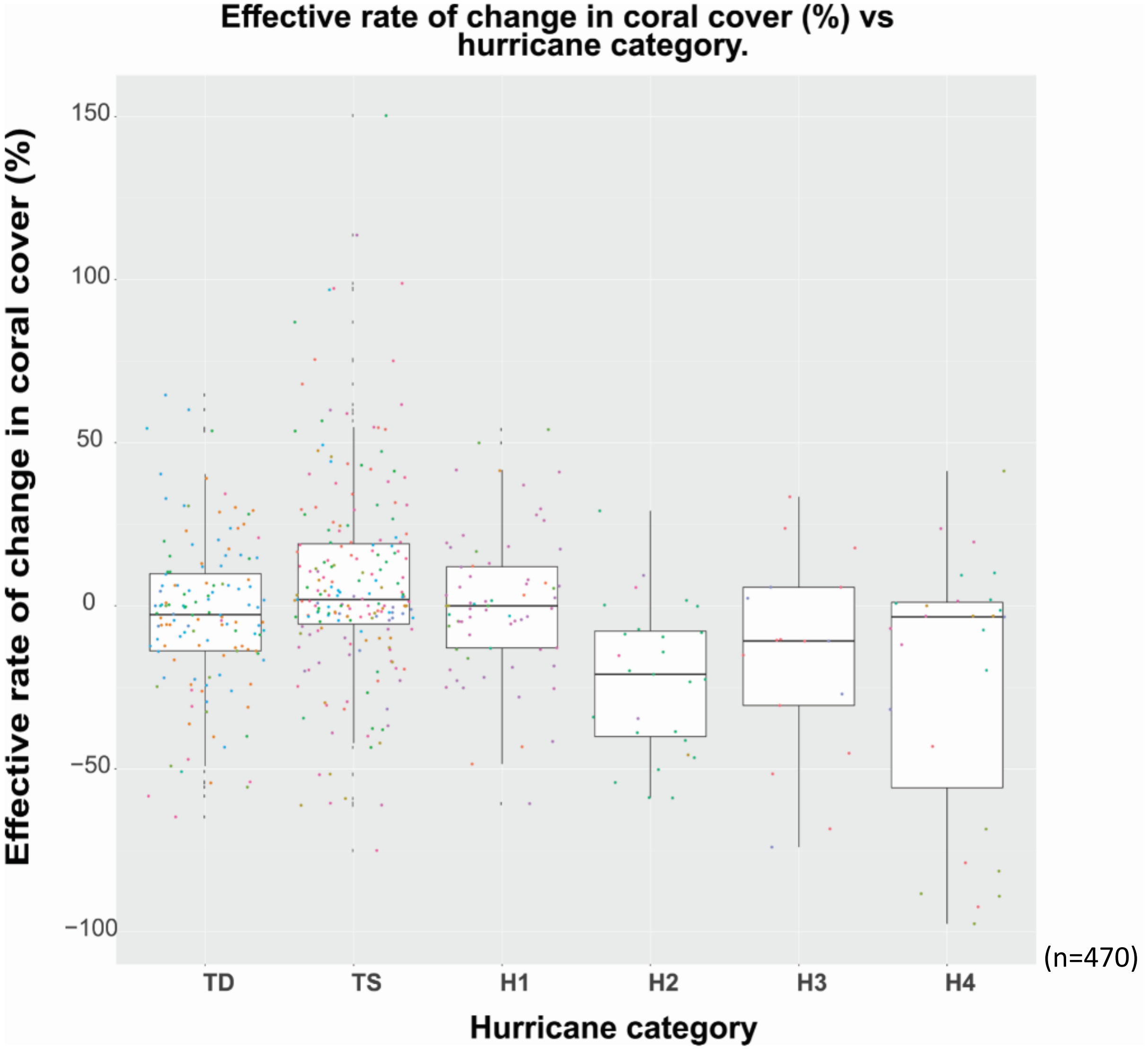
A higher surge value (m) appears to correlate with higher coral cover loss.



(n=146)

Intensity of the storm.

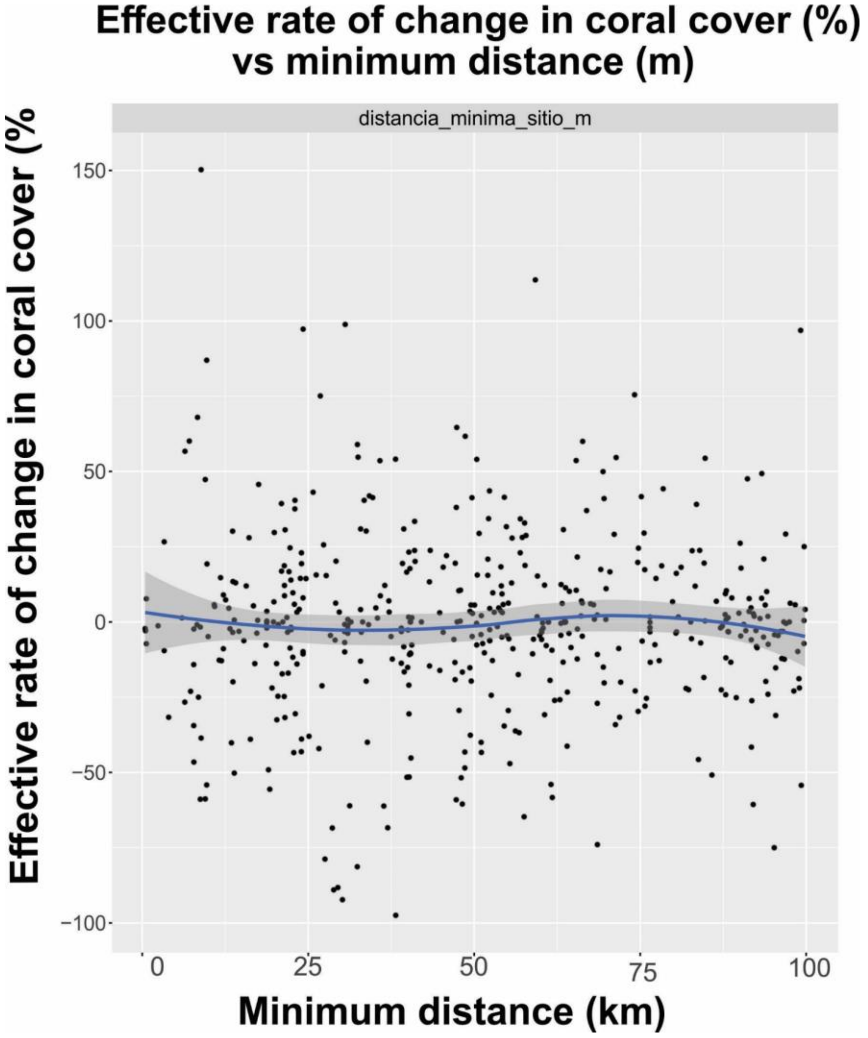
We used wind speed at impact as it showd a greater correlation with coral cover change rate than intensity of the storm



(n=470)

Minimum distance between the hurricane and the study area

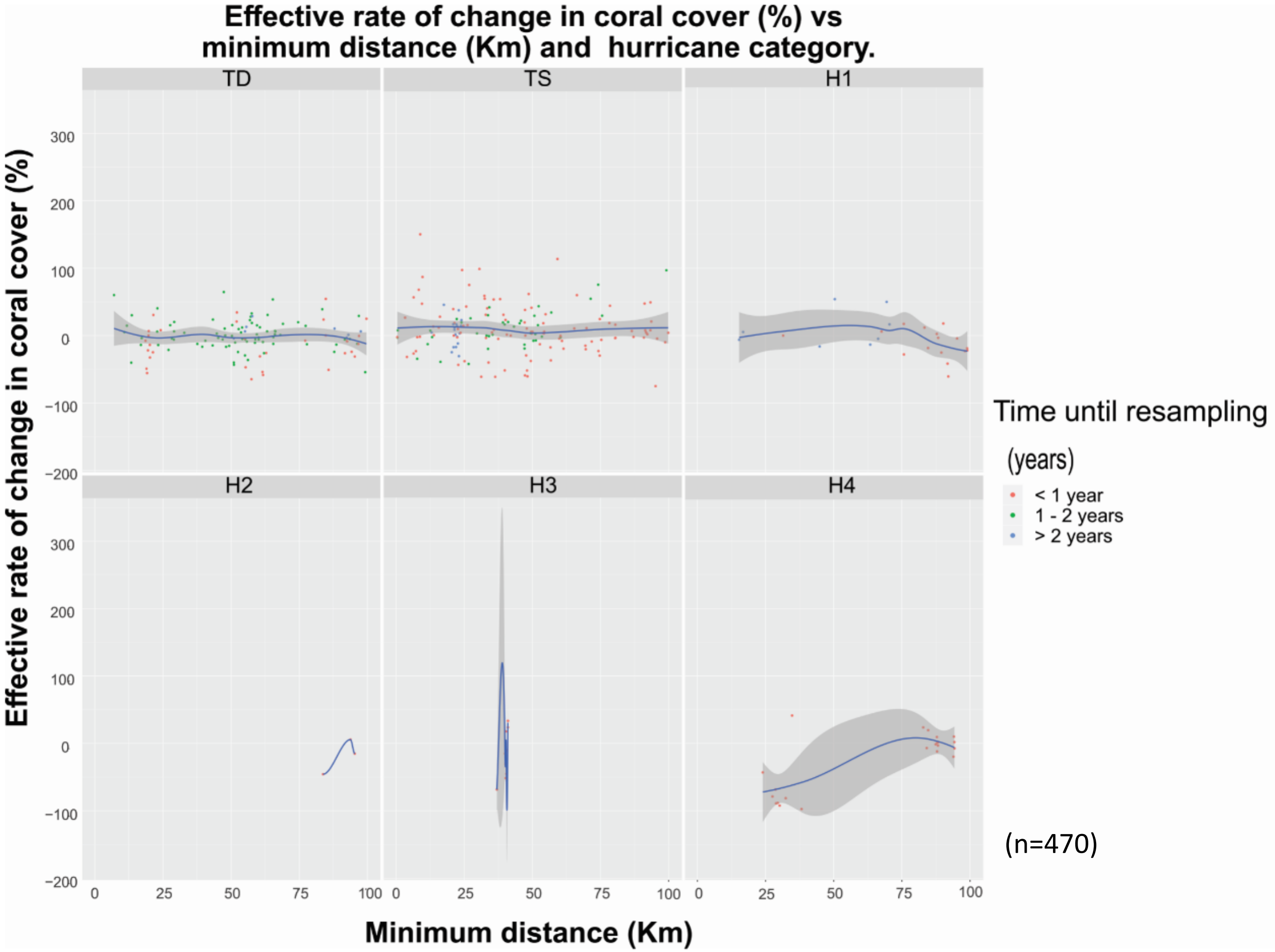
La distancia media del ojo del huracán al sitio No tiene correlación con el daño arrecifal, ya que no hay cambio en la cobertura de coral.



(n=470)

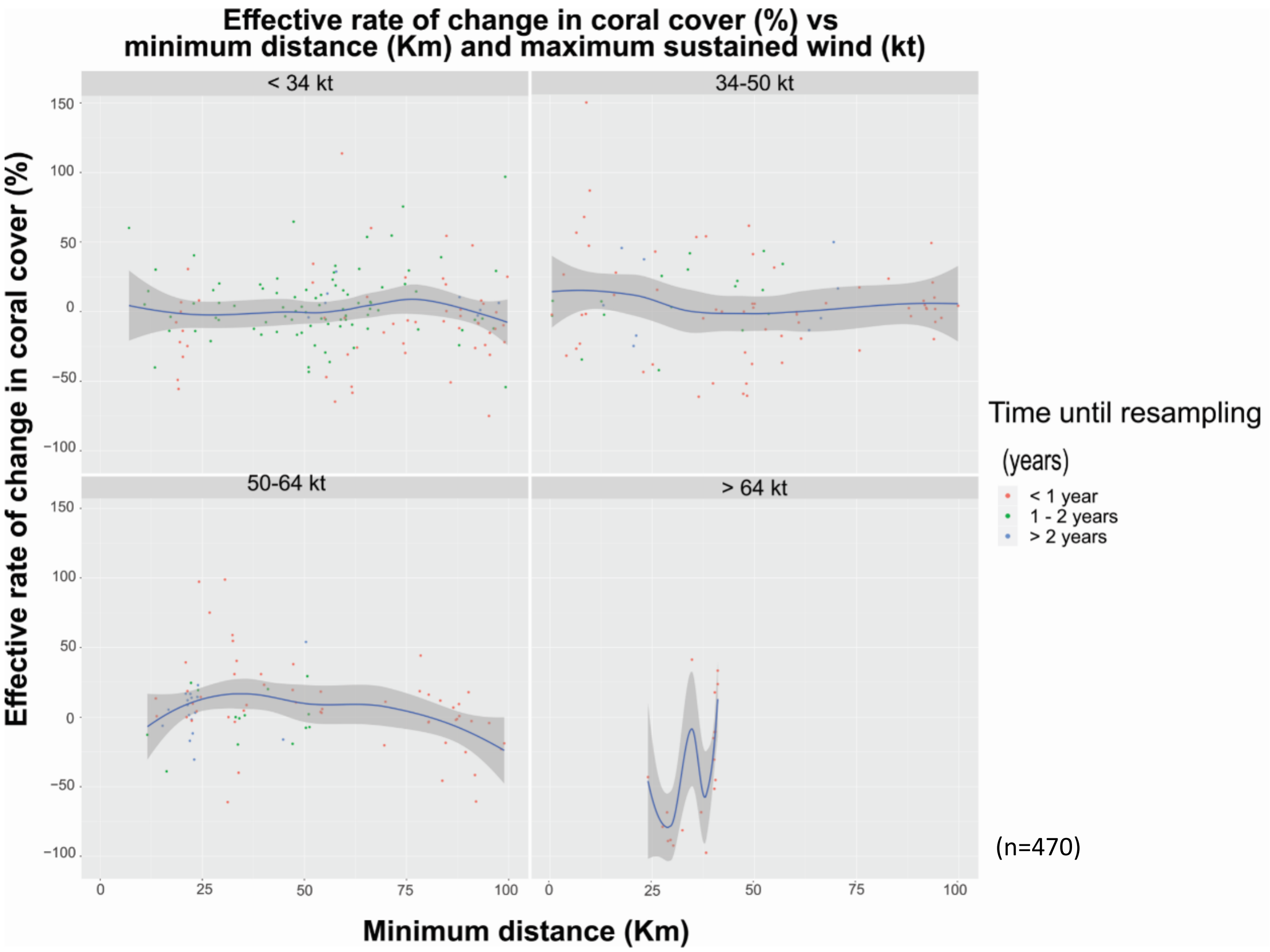
Minimum distance between the hurricane and the study area

Profiling the coral cover change rate vs minimum distance to site (km) by hurricane category we did not see any apparent correlation.



Minimum distance between the hurricane and the study area

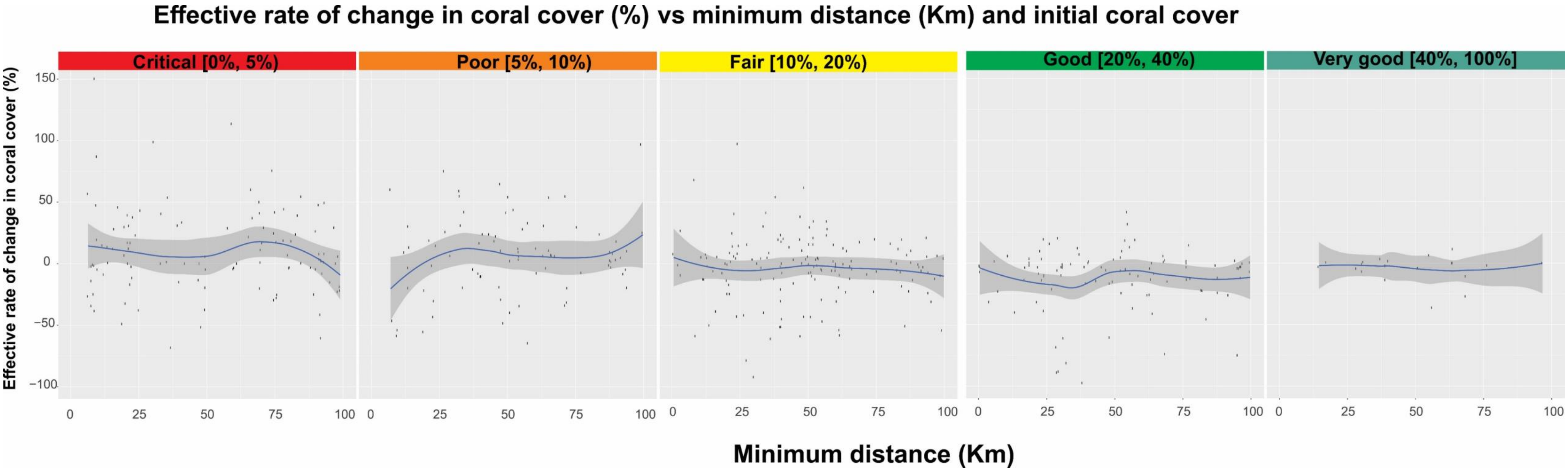
Also, profiling the coral cover change rate vs minimum distance to site (km) by wind speed at impact (kt), we did not find any contunding relationships.



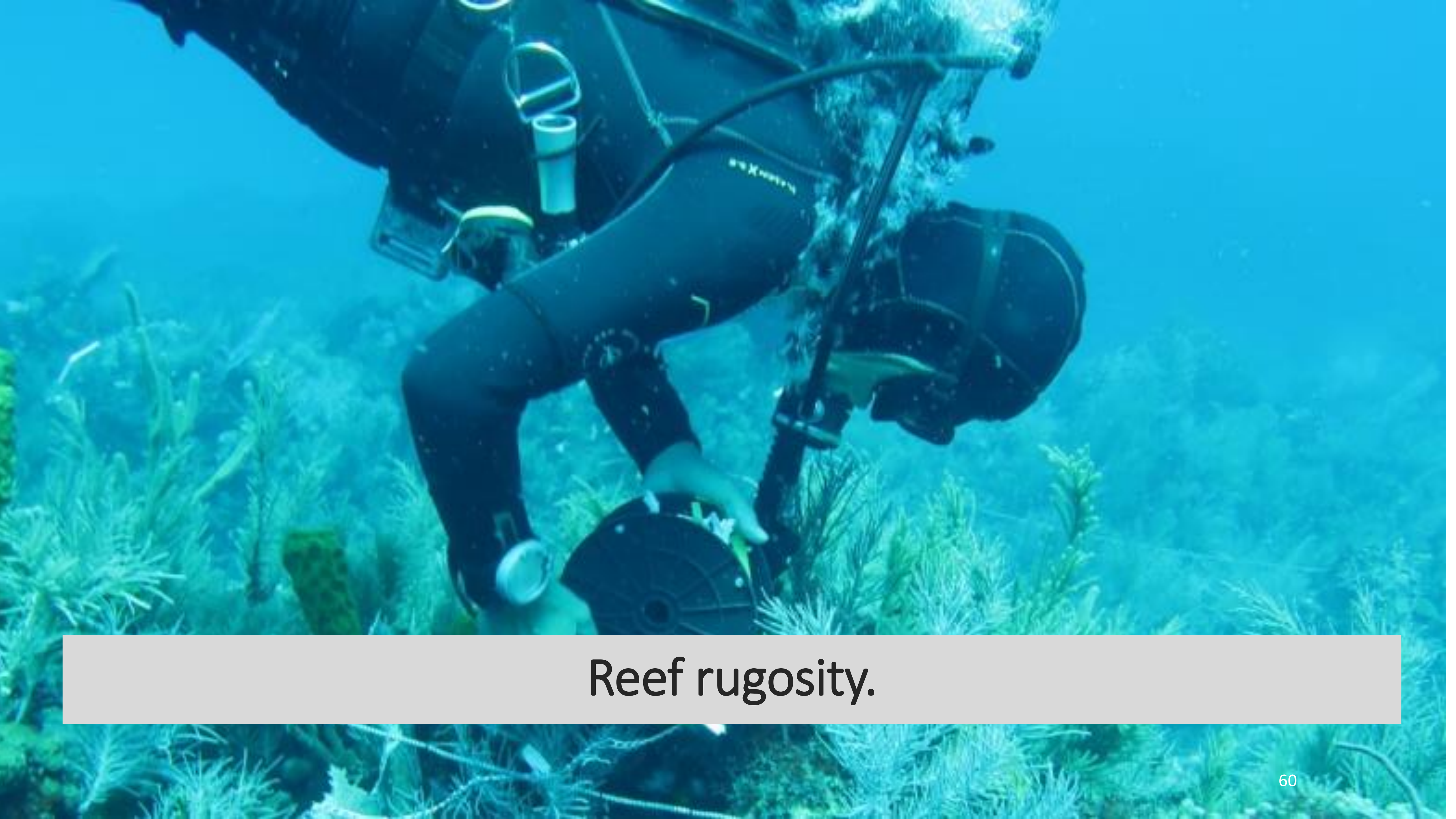
(n=470)

Minimum distance between the hurricane and the study area

Profiling the coral cover change rate vs minimum distance to site (km) by initial coral cover, we did not find any contunding relationships.



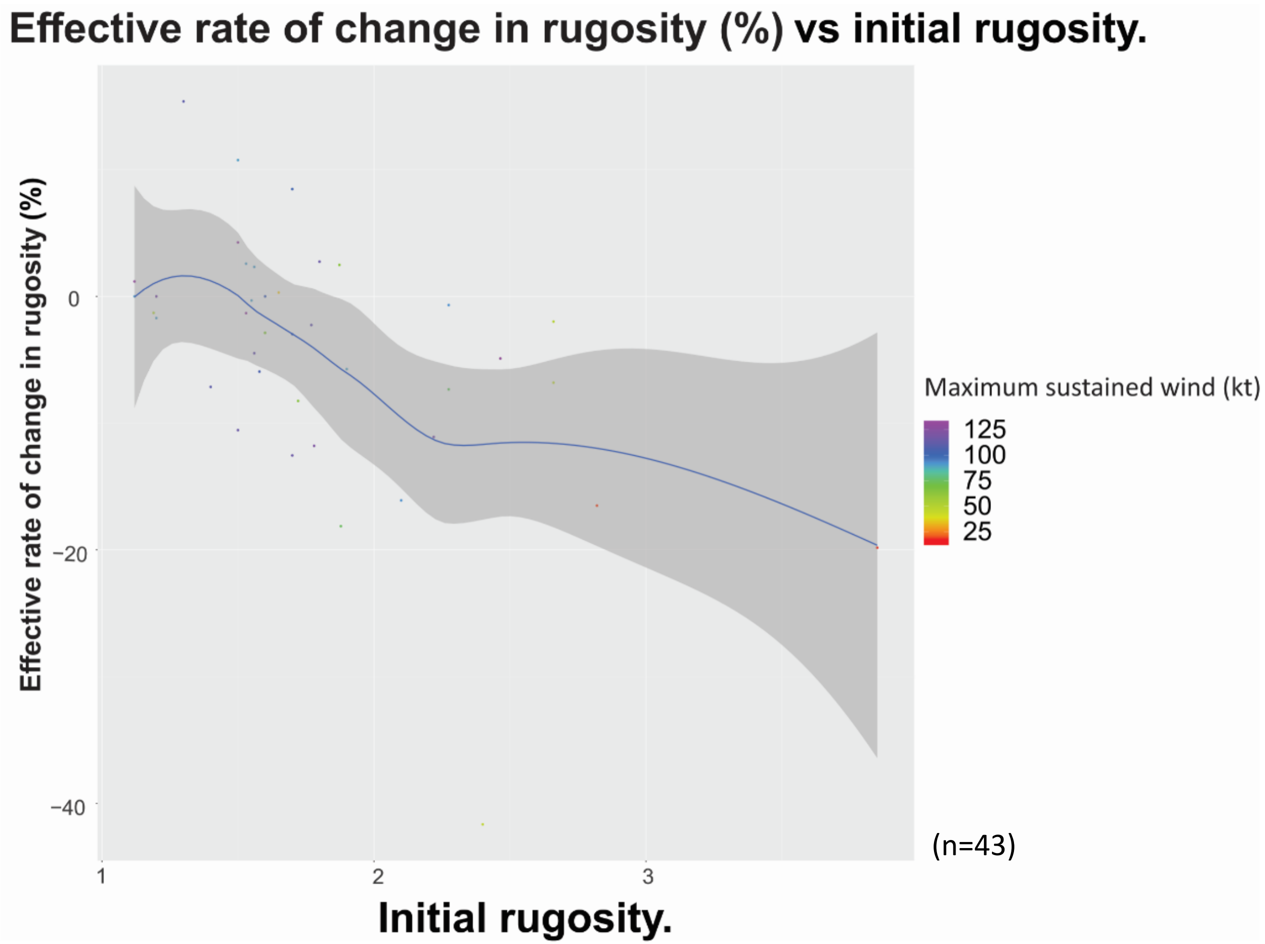
(n=470)



Reef rugosity.

Initial rugosity.

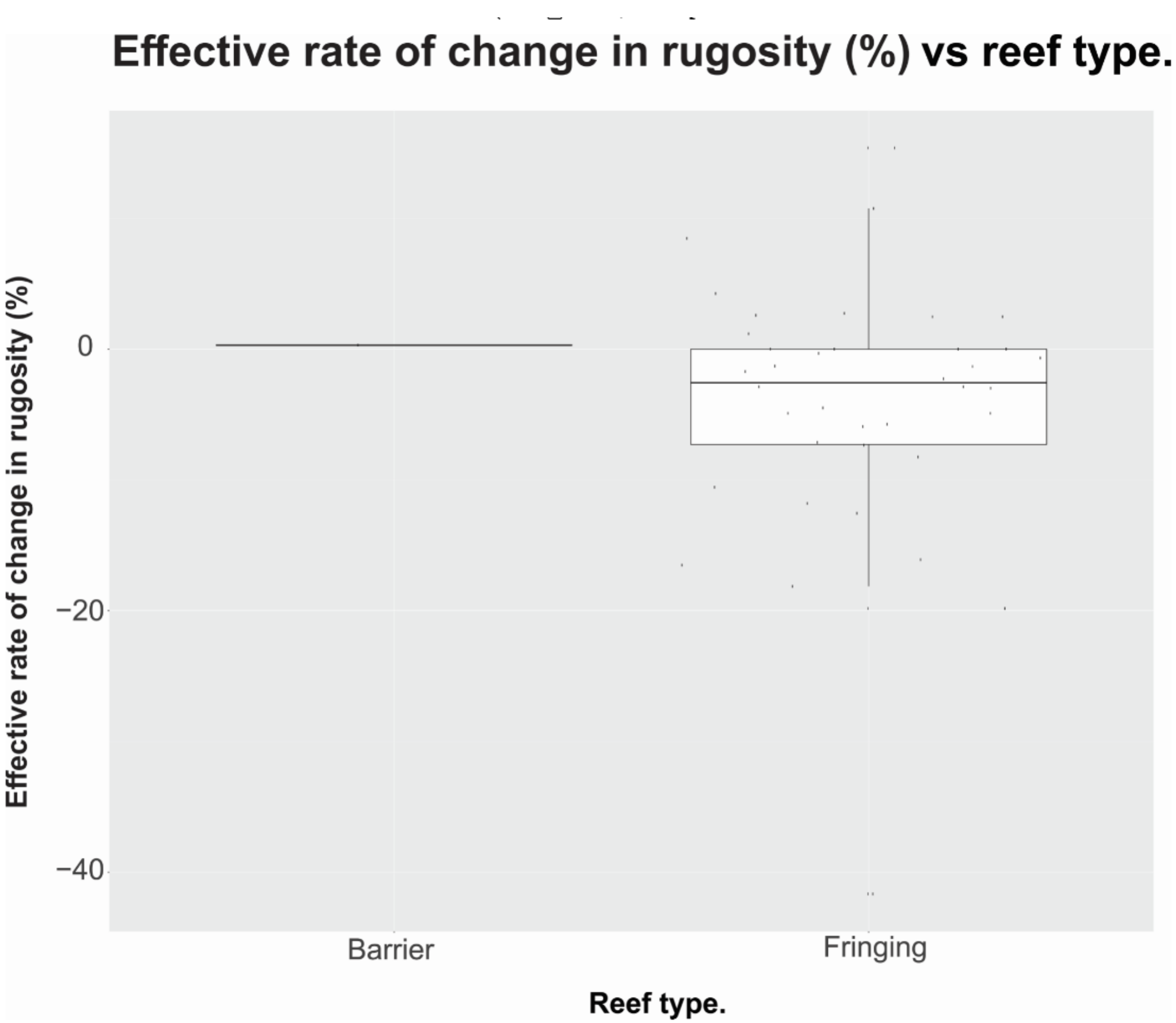
Reefs with high rugosities showed more coral cover loss after hurricane impact.



(n=43)

Reef type.

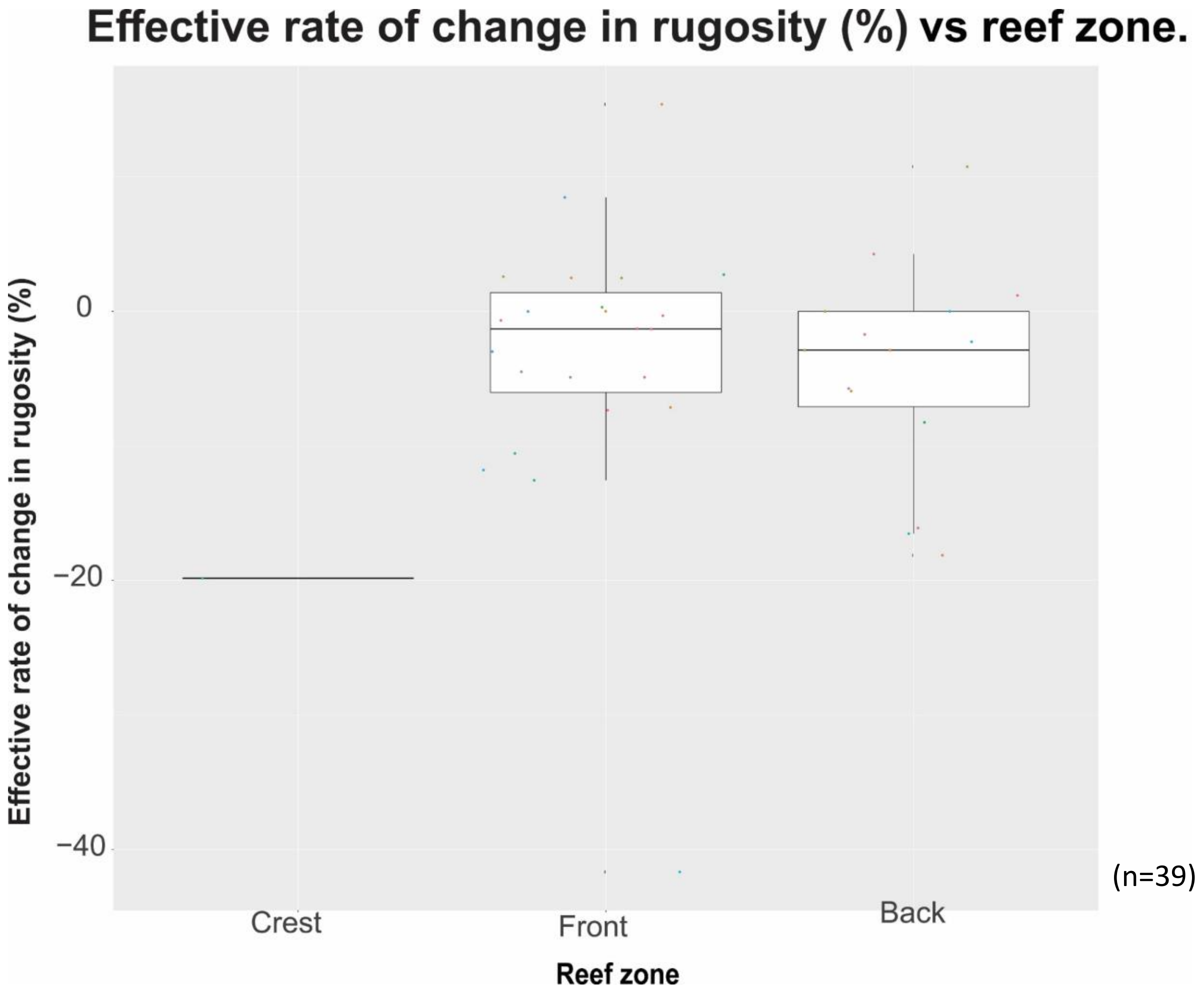
Change in rugosity did not show any signs of correlation with reef type.



(n=39)

Reef zone.

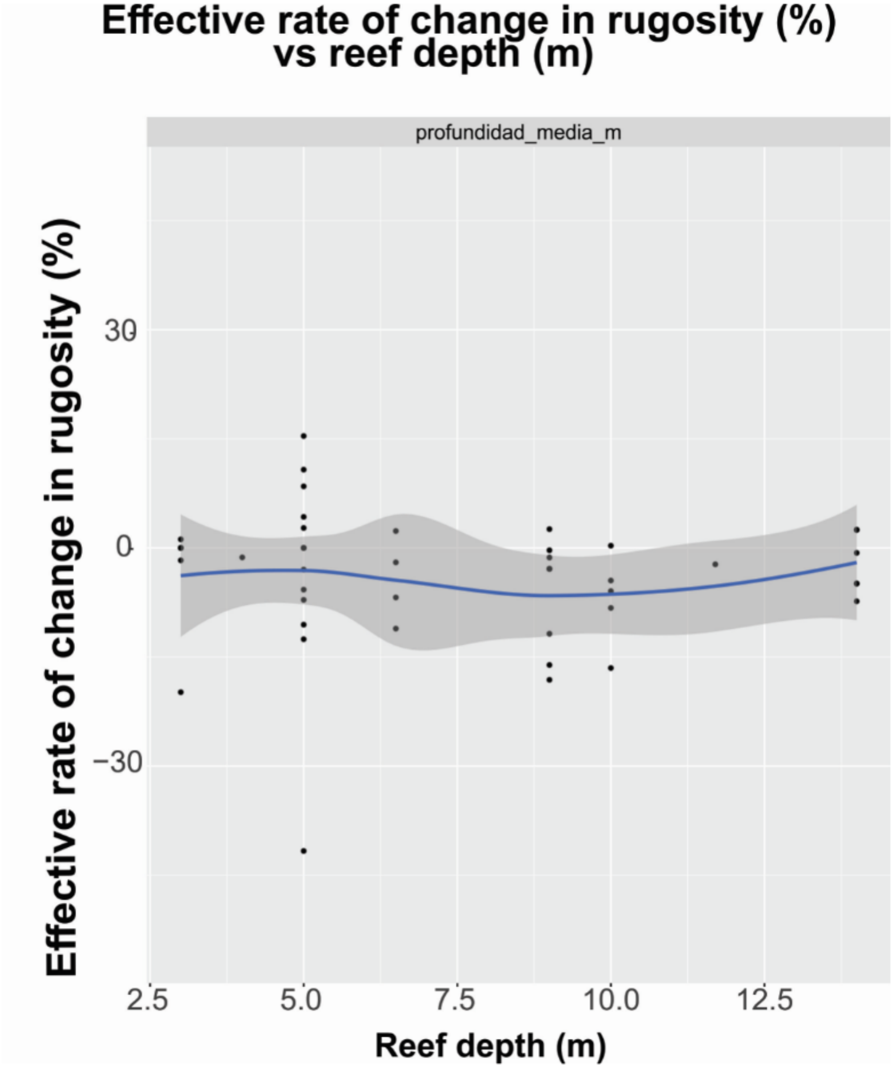
Reef zone apparently did not show any correlation with rugosity, however, the fact that the outlier in “crest” is much lowe than any other, made us inquire about including this variable.



(n=39)

Reef depth.

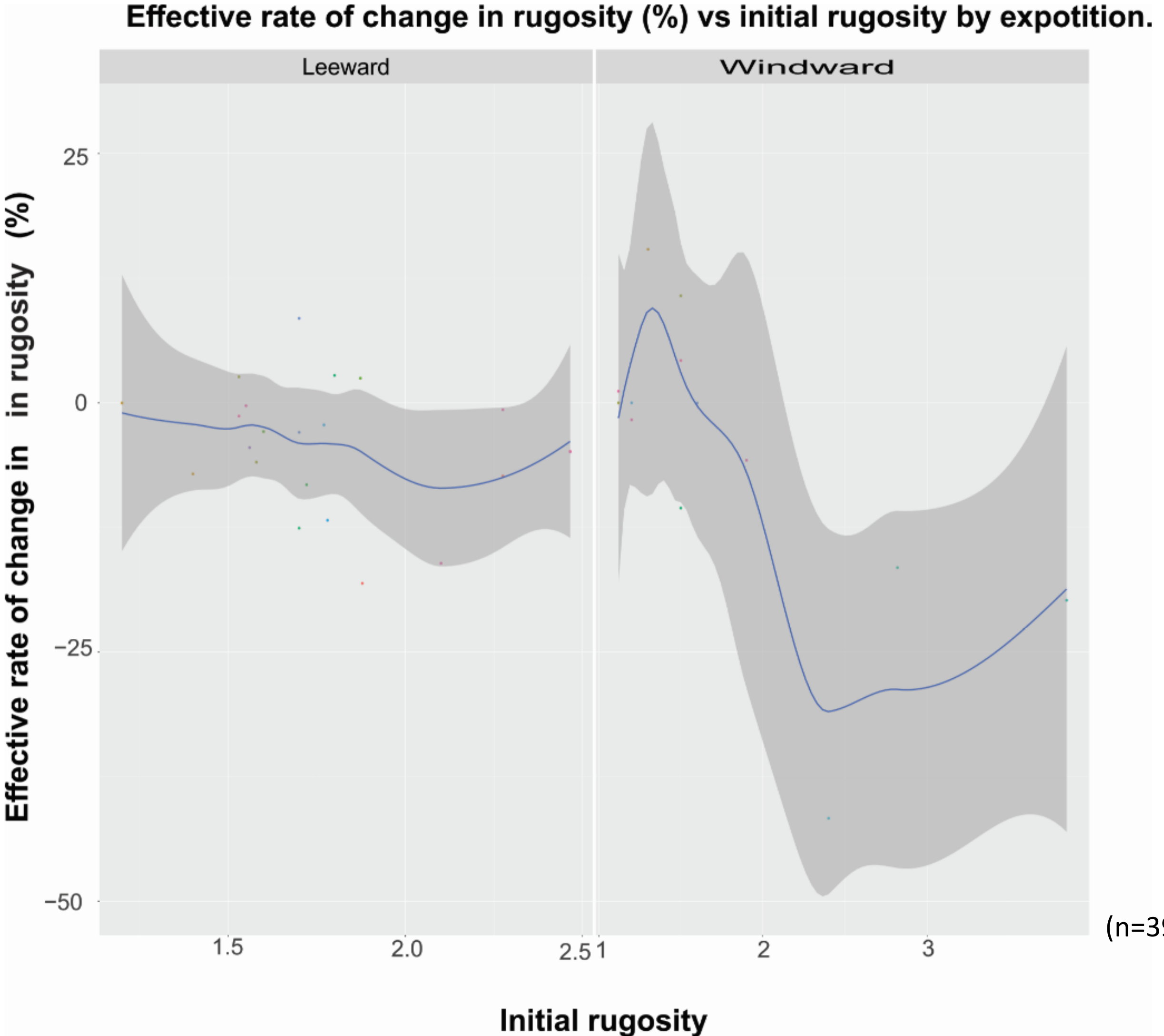
Reef depth (m) showed not correlation with the rugosity rate of change



(n=43)

Reef exposure.

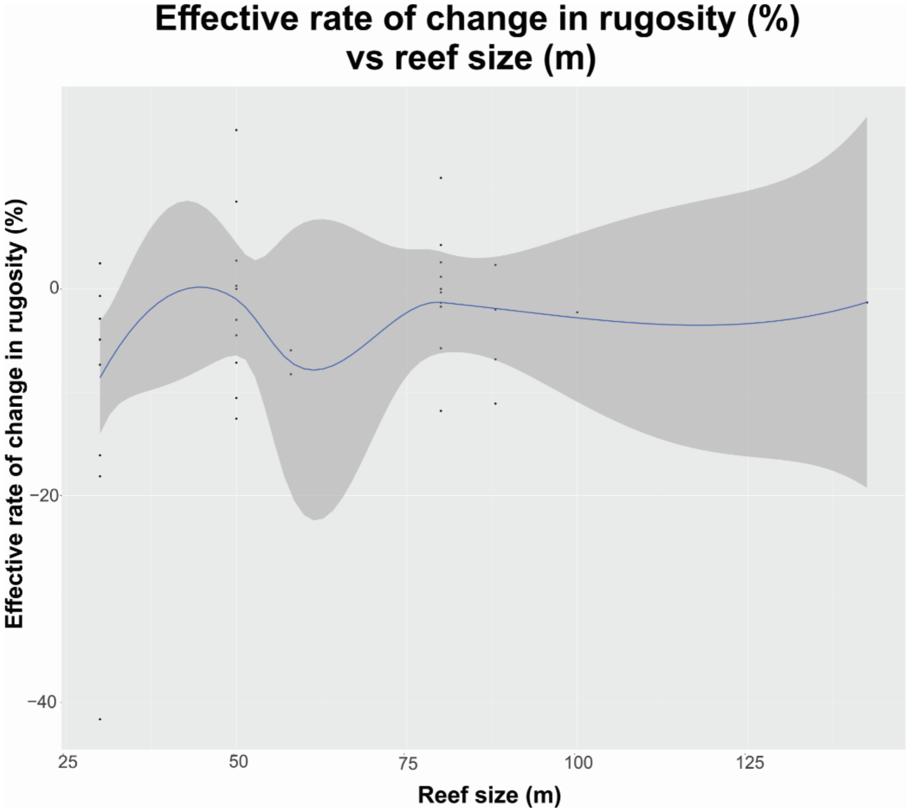
Windward sites display a higher correlation between initial rugosity and rugosity rate of change than leeward sites



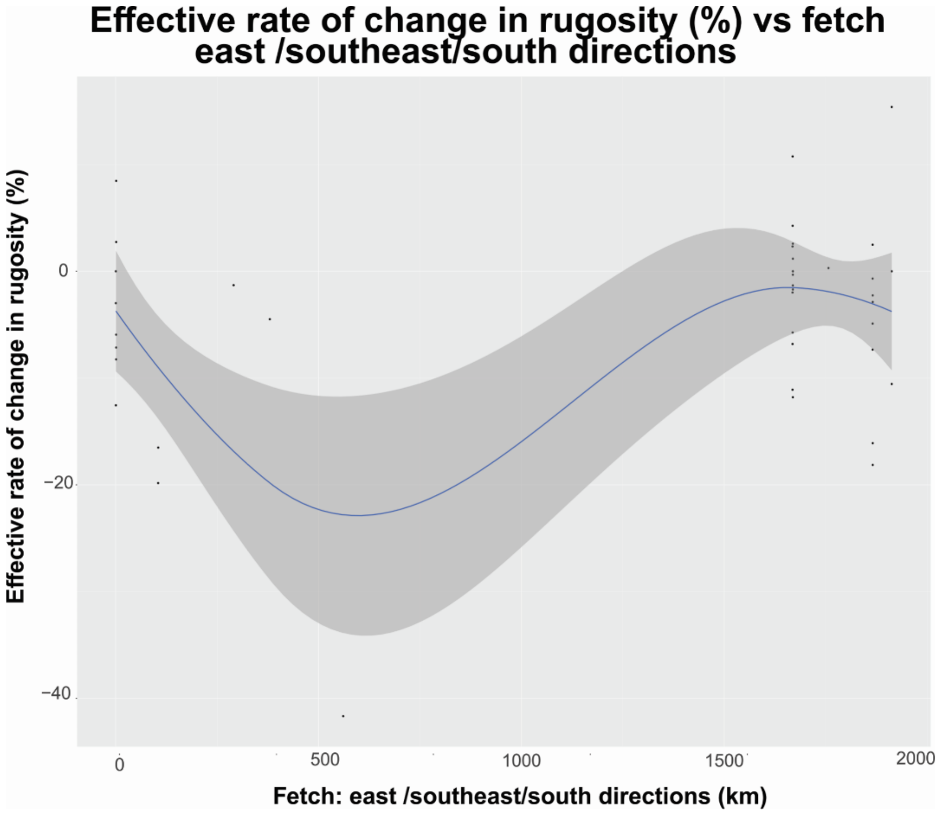
(n=39)

Reef size y fetch.

Reef size (m) and fetch (km) appear uncorrelated to rugosity rate of change.



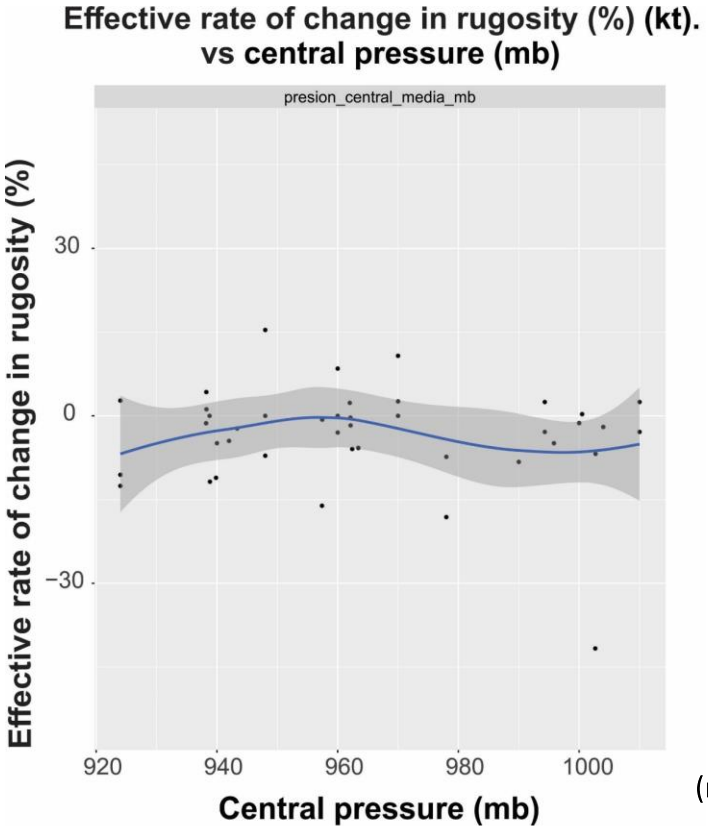
(n=41)



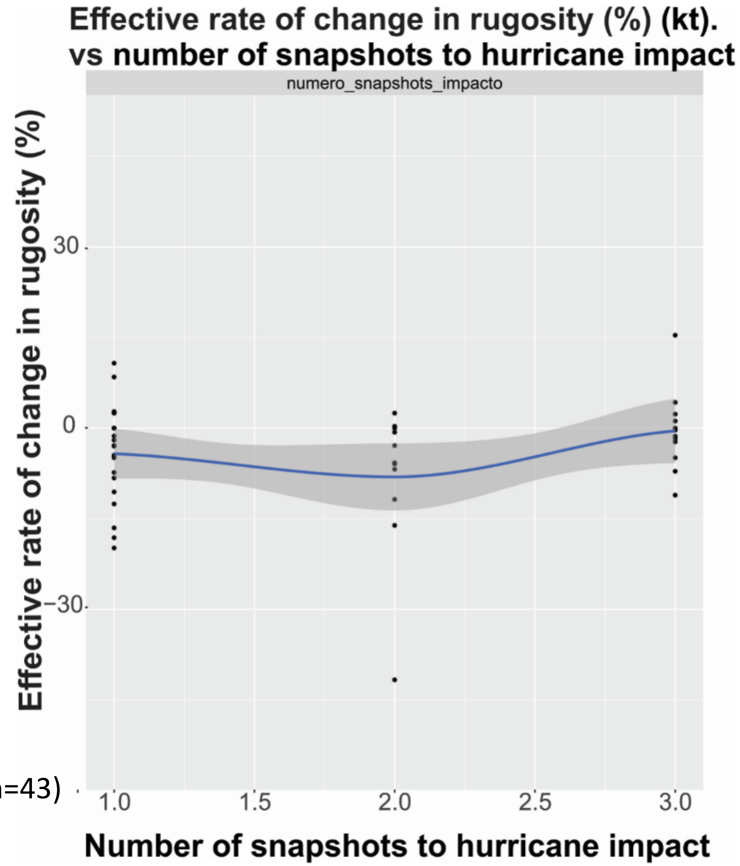
(n=43)

Central pressure, duration of the exposition to hurricane winds and minimum distance between the hurricane and the study area.

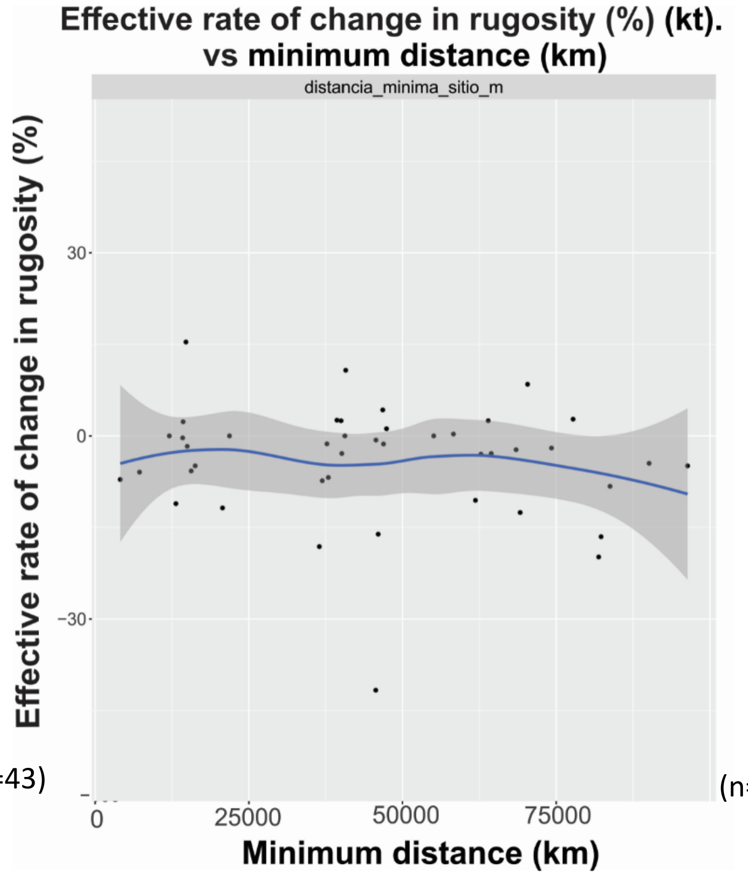
Central pressure, time of exposition to hurricane winds and minimum distance to site (m) appear uncorrelated to the rate of change in rugosity



(n=43)



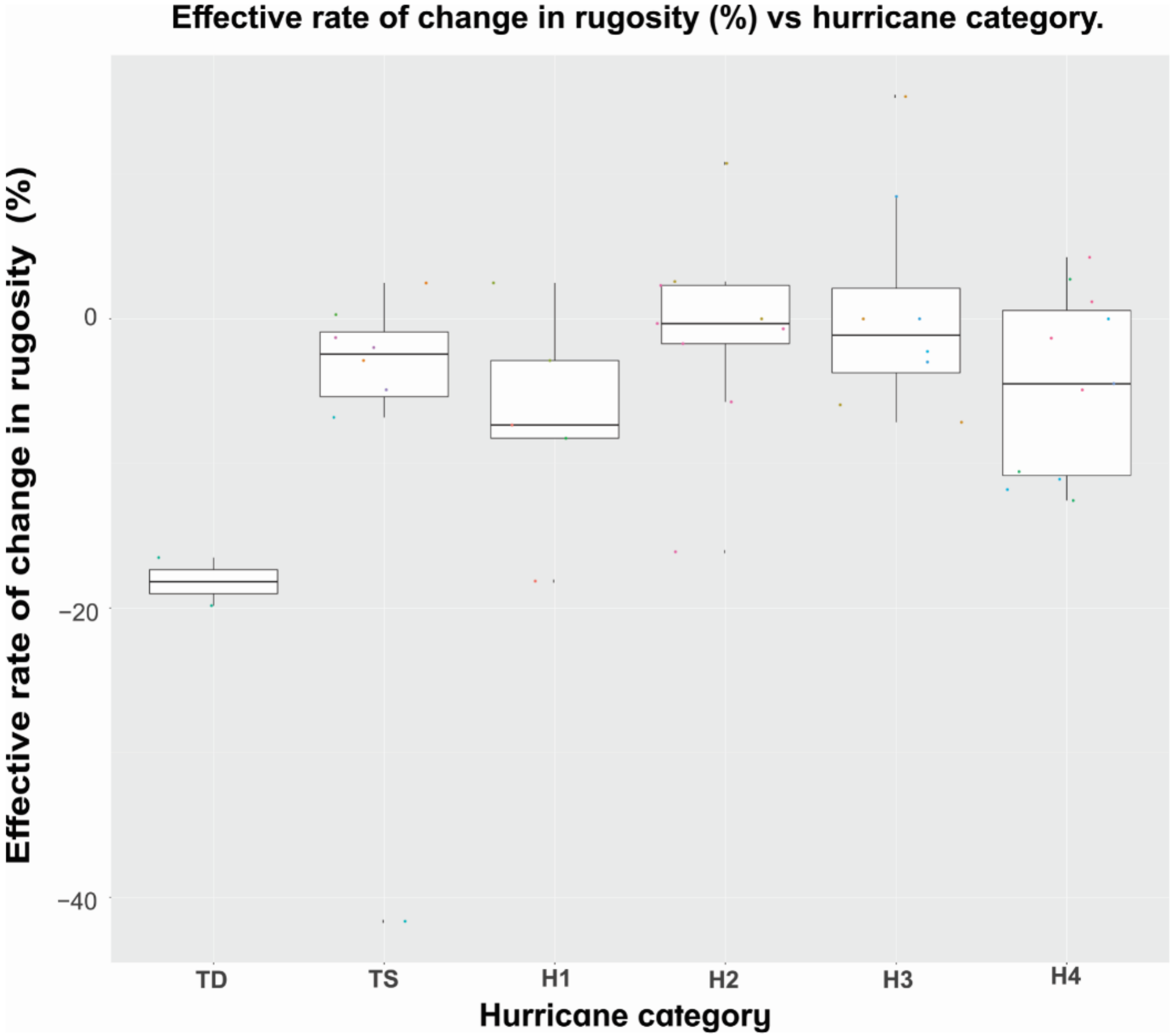
(n=43)



(n=43)

Intensity of the storm.

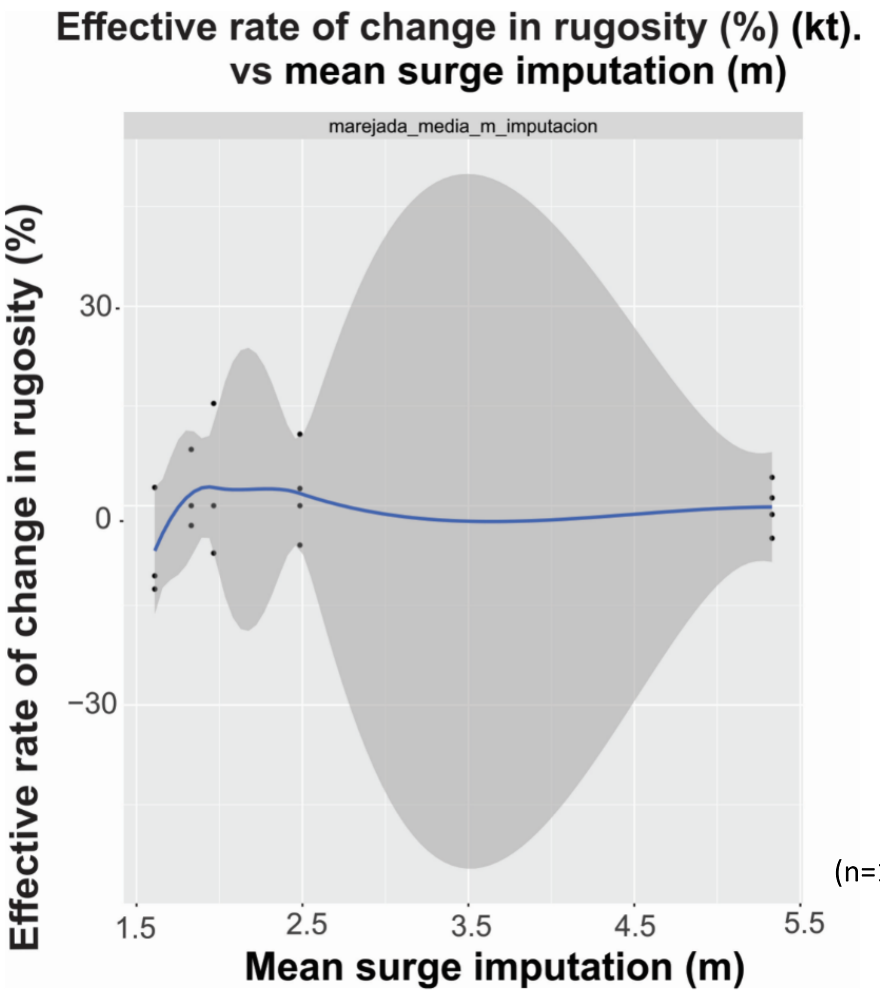
Hurricane category appears to be uncorrelated to rate of change in rugosity



(n=43)

Storm surge.

Storm surge appears to be uncorrelated to rate of change in rugosity.



(n=17)

4. Inferencial model: linear mixed model.

Using a linear mixed model, we assessed the significance of the principal variables that appeared to be correlated in our exploratory analysis. We did not use all variables in the model because the amount of missing data reduced a lot our sample size.

	Value	Std.Error	DF	t-value	p-value
(Intercept)	3.73	8.94	298.00	0.42	0.677
Difference sample final exit hurricane dayskt cat.L	-0.26	0.26	298.00	-0.98	0.3261
Maximum wind speed at impact kt cat.Q	-0.11	0.18	298.00	-0.62	0.5372
Maximum wind speed at impact kt cat.C	-0.05	0.10	298.00	-0.51	0.6071
Initial coral cover %	-0.02	0.01	298.00	-3.90	**0.0001**
Number of snapshot to the impact	0.03	0.02	298.00	1.23	0.2213
Central pressure mb	0.00	0.01	298.00	-0.43	0.6643
Maximum sustained wind kt	0.00	0.01	298.00	-0.40	0.6865
Exposure middle	0.21	0.15	298.00	1.43	0.1528
Exposure Windward	0.17	0.07	298.00	2.59	**0.0101**
Fetch medium km	0.00	0.00	298.00	0.98	0.3257
Difference sample final exit hurricane days	0.00	0.00	298.00	-0.08	0.9343
Difference sample final exit hurricane days kt cat.L:Initial coral cover %	-0.02	0.01	298.00	-1.60	0.1116
Difference sample final exit hurricane days kt cat.Q:Initial coral cover %	-0.02	0.01	298.00	-1.86	0.0642
Maximum wind speed at impact kt cat.C:initial coral cover %	-0.02	0.01	298.00	-2.67	**0.008**
Exposure middle:fetch medio km	0.00	0.00	298.00	-1.15	0.2526
Exposure Windward:Fetch medium km	0.00	0.00	298.00	-1.02	0.3078

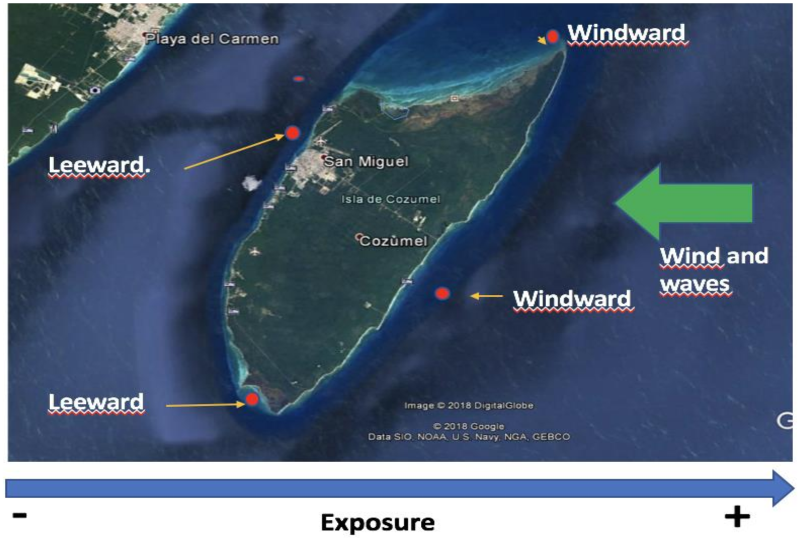
Itntercep, value: β, Std. Error: Standard error, DF: degrees of freedom, t-value, p-value.

4. Inferencial model.

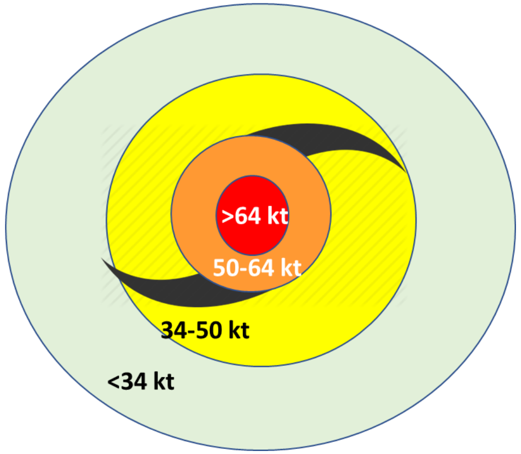
The following variables significantly ($p < 0.05$) explain coral cover loss:

1. Initial coral cover %
2. Reef exposure Windward
3. Maximum wind speed at impact kt

Coral cover



Reef exposure

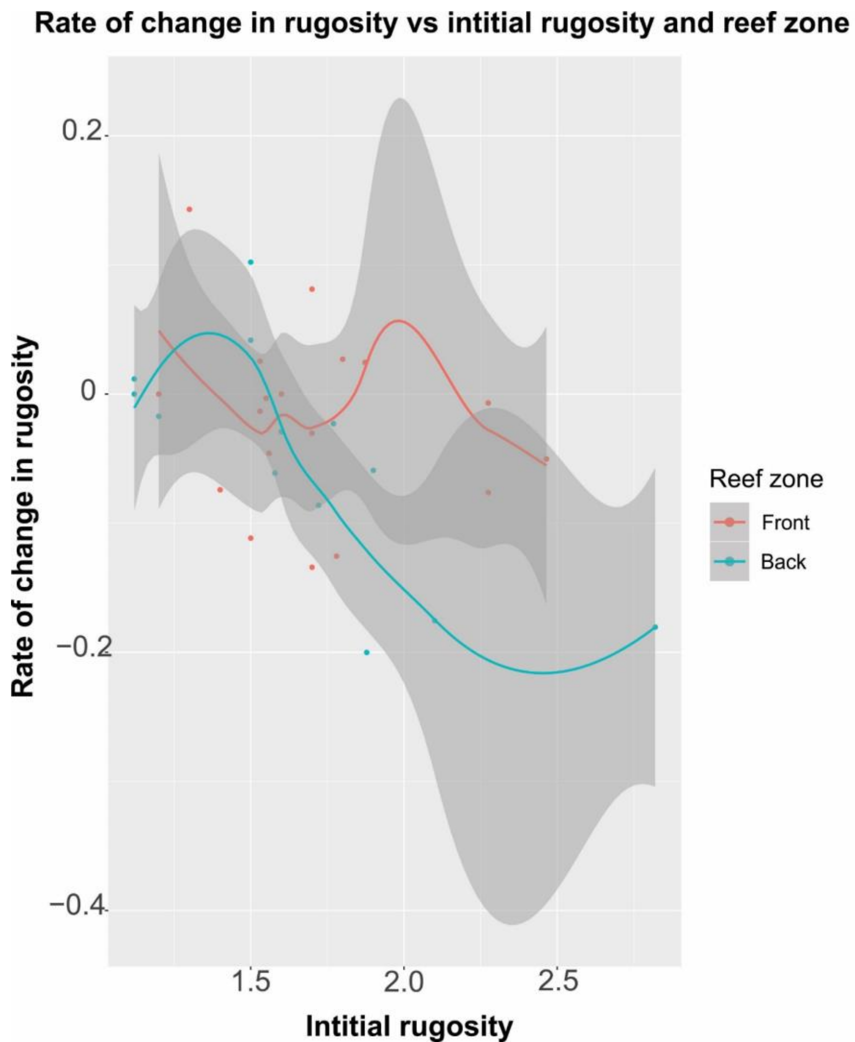


Maximum wind speed at impact

4. Inferencial model: multiple linear regression.

For rugosity, the only variable that significantly ($p < 0.05$) explains the rate of change in rugosity is initial rugosity, however, we recommend assessing as well reef zone back, as it is very close to significance.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.144	0.053	2.715	0.011
Initial rugosity	**-0.094**	**0.029**	**-3.216**	**0.003**
Reef zone back	-0.038	0.023	-1.648	0.109



4. Helper model: equation derived by linear regression.

We realized a multiple linear regression considering only the variables that were significant in the inferential model for rate of change in coral cover, as a helper model to assess coral cover damage across different scenarios.

	Estimate
(Intercept)	0.067329
Initial coral cover %	-0.008203
Exposure Windward	0.094204
Initial coral cover % maximum wind speed at impact (kt) 34-50 kt	-0.001374
Initial coral cover % maximum wind speed at impact (kt) 50-64 kt	0.001929
Initial coral cover % maximum wind speed at impact (kt) > 64 kt	-0.024567

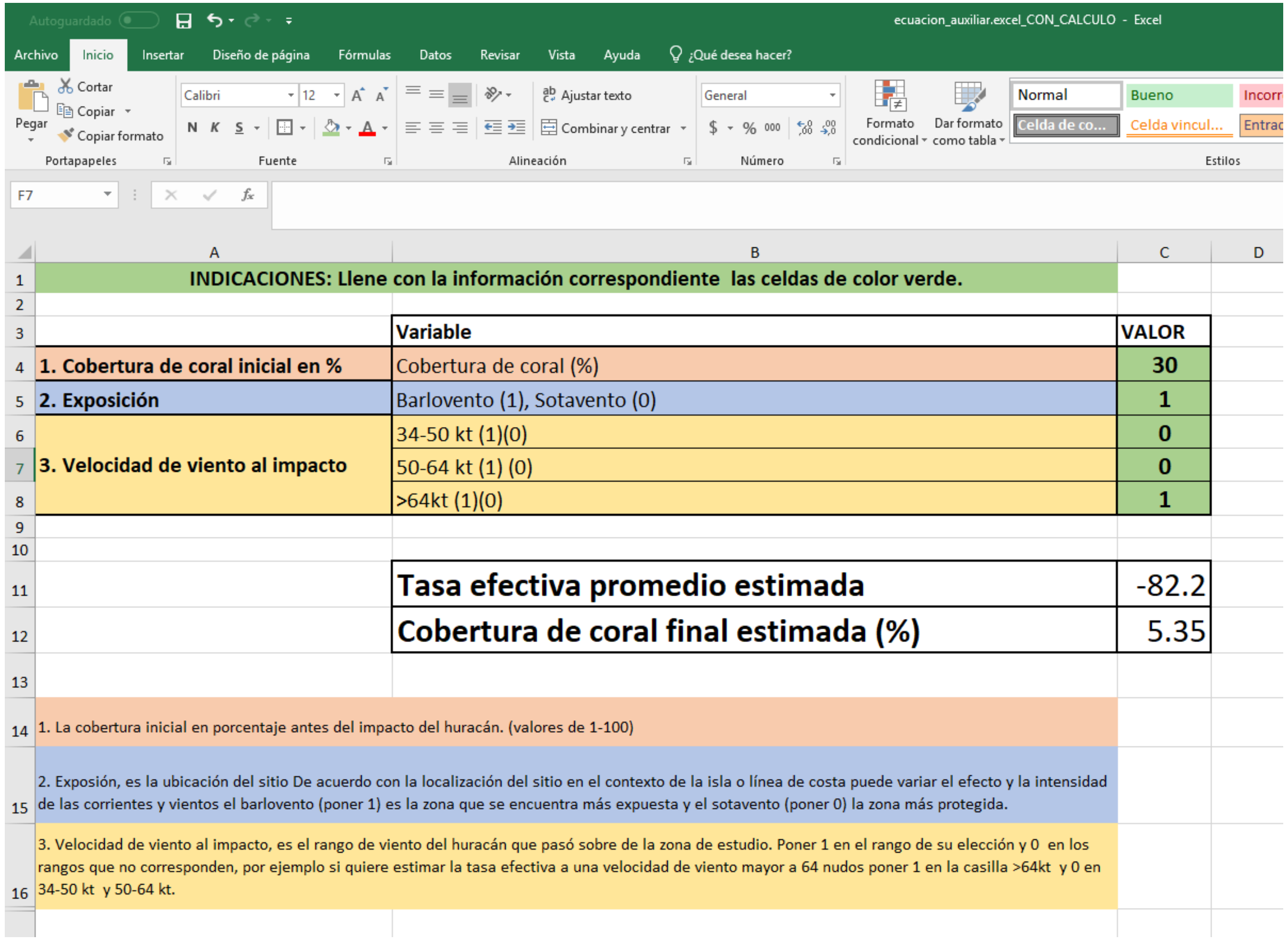
Equation:
Estimated effective rate of change

Estimated effective rate of change = (0.067329 – (0.008203*%ICC)+(0.094204* 0(W) ó 1 (L))-(0.001374*(1 if MWSi is 34-50 kt or 0)+ (0.001929 * (1 if MWSi is 50-64 kt or 0) – (0.024567*(1 if MWSi is >64 kt or 0)**)***100

%ICC=Initial coral cover %
W= windward.
L=Leeward
MWSi= maximum wind speed at impact
Kt=nudos

4. Inferential analyses: equation with linear regression.

That equation was included into an Excel file, in order to easily assess different scenarios.



Conclusions

After performing the exploratory data analysis, the reef variables that apparently correlated with the rate of change in coral cover are the following

1. **Coral cover**, we observed greater coral cover loss with increasing wind speeds and initial coral cover.
2. **Initial rugosity**, greater initial rugosity appears correlated with greater coral cover loss.
3. **Reef exposure**, Apparently greater coral loss is observed for leeward sites with winds greater than 64 kt. The trend continues to hold if we only include sites with less than 1 year before resampling.
4. **Fetch** using all angles, the effect appears greater in leeward sites.

Conclusions

After performing the exploratory data analysis, the reef variables that apparently correlated with the rate of change in coral cover are the following

1. **Wind speed at impact**, at sites impacted by wind speeds greater than 64kt the rate of change in coral cover is clearly lower.
2. **Maximum sustained wind and central pressure,** appear to be correlated with greater coral cover loss.
3. **Duration of the affectation,** appears to be correlated with greater coral cover loss
4. **Storm surge,** appears to be correlated with greater coral cover loss

The variables that do not show any apparent correlation are: reef depth, reef size, reef type, reef zone, and minimum distance to site.

Conclusions

- The variables that significantly ($p < 0.05$)correlated with change in coral cover after hurricane impact are the following:
  - ✓ **Initial coral cover**
  - ✓ **Reef exposure**
  - ✓ **Maximum wind speed at impact**
- The only variable that significantly ($p < 0.05$) correlated with change in rugosity after hurricane impact:
  - ✓ **Initial rugosity.**

That's why we recommend to take into account those variables for implementing the parametric insurance.

Recommendations

- We recommend a second phase that includes
  - Dr Simon Young's data (Willis Towers Watson/Global Ecosystem Resilience Facility) concerning a finer categorization of wind speeds at impact and storm surge.
  - Taking into account the coral reef species to incorporate taxonomic information into the assessment
  - Training a predictive model and validating it properly, in order to make more reliable predictions about the coral cover loss in specific scenarios. That predictive model should be accessed via a Web interface for ease of use.

THANK YOU

Supplementary material.

Artículo 13

Alcolado, P. M., Hernández-Muñoz, D., Aragón, H. C., Busutil, L., Valderrama, S. P., & Hidalgo, G. (2009). Efectos de un inusual período de alta frecuencia de huracanes sobre el bentos de arrecifes coralinos. Revista Ciencias Marinas y Costeras, 1(1), 73-93.

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Beltrán-Torres, A. U., Muñoz-Sánchez, L., & Carricart-Ganivet, J. P. (2003). Effects of hurricane Keith at a patch reef on Banco Chinchorro, Mexican Caribbean. Bulletin of marine science, 73(1), 187-196.

Bythell, J. C., Bythell, M., & Gladfelter, E. H. (1993). Initial results of a long-term coral reef monitoring program: impact of Hurricane Hugo at Buck Island Reef National Monument, St. Croix US Virgin Islands. Journal of Experimental Marine Biology and Ecology, 172(1-2), 171-183.

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Woodley, J. D., Chornesky, E. A., Clifford, P. A., Jackson, J. B. C., Kaufman, L. S., Knowlton, N., ... & Rylaarsdam, K. W. (1981). Hurricane Allen's impact on Jamaican coral reefs. Science, 214(4522), 749-755.

Base de datos 8

Álvarez Filip, L y Nava Martínez, G. (2006). Reporte del efecto de los Huracanes Emily y Wilma sobre arrecifes de la costa Oeste del Parque Nacional Arrecifes de Cozumel (Reporte técnico). Parque Nacional Arrecifes de Cozumel-Comisión Nacional de Áreas Naturales Protegidas.

BASE DE DATOS BARCO LAB

Guest, J.R., Edmunds, P.J., Gates, R.D., Kuffner, I.B., Brown, E.K., Rodgers, K.S., Jokiel, P.L., Ruzicka, R.R., Colella, M.A., Miller, J., Atkinson, A., Feeley, M.W., Rogers, C.S., 2018, Time-series coral-cover data from Hawaii, Florida, Mo'orea, and the Virgin Islands: U.S. Geological Survey data release, https://doi.org/10.5066/F78W3C7W. Accessibility FOIA Privacy Policies and

Linton, Dulcie; Bermuda Institute of Ocean Sciences (2010). A unified, long-term, Caribbean-wide initiative to identity the factors responsible for sustaining mangrove wetland, seagrass meadow, and coral reef productivity, February 1993 - October 1998 (NODC Accession 0000501). Version 1.2. National Oceanographic Data Center, NOAA. Dataset.

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Nava-Martínez, G. G., Alvarez-Filip, L., y Hernandez-Landa, R. (2006) Reporte del Programa de Monitoreo Arrecifal Parque Nacional Arrecifes de Cozumel 2004-2005 (Reporte técnico). Parque Nacional Arrecifes de Cozumel-Comisión Nacional de Áreas Naturales Protegidas.

(en blanco)

Informe 1

PNAPM-CONANP. Evaluación de la condición de las comunidades coralinas que se desarrollan en sitios de visita, destinados al uso turístico semi-intensivo, dentro de las Unidades Arrecífales del Parque Nacional Arrecife de Puerto Morelos. (WILMA). Sin fecha de publicación.

Tesis Licenciatura 1

Rodríguez-Martínez, R. E. (1993). Efectos de un ciclón en la estructura comunitaria de corales escleractinios. Tesis de Licenciatura. ENEP Iztacala. Universidad Nacional Autónoma México, México. TESIUNAM

Tabla b. Lista de los huracanes que se usaron en el estudio. Clave del huracán y nombre.

1.	AL012008	ARTHUR	19.	AL062006	ERNESTO	37.	AL111989	HUGO
2.	AL021996	BERTHA	20.	AL062007	FELIX	38.	AL111996	KYLE
3.	AL022007	BARRY	21.	AL062008	FAY	39.	AL121994	GORDON
4.	AL022013	BARRY	22.	AL071998	GEORGES	40.	AL121996	LILI
5.	AL031993	BRET	23.	AL072000	DEBBY	41.	AL122005	KATRINA
6.	AL031996	CESAR	24.	AL072010	EARL	42.	AL122013	KAREN
7.	AL032010	BONNIE	25.	AL072012	HELENE	43.	AL131990	KLAUS
8.	AL041980	ALLEN	26.	AL081994	UNNAMED	44.	AL131999	IRENE
9.	AL042007	DEAN	27.	AL081996	HORTENSE	45.	AL132010	KARL
10.	AL042008	DOLLY	28.	AL082011	HARVEY	46.	AL152008	OMAR
11.	AL051995	ERIN	29.	AL092004	IVAN	47.	AL162007	NOEL
12.	AL052001	DEAN	30.	AL092011	IRENE	48.	AL172007	OLGA
13.	AL052005	EMILY	31.	AL092012	ISAAC	49.	AL182010	PAULA
14.	AL052011	EMILY	32.	AL092014	HANNA	50.	AL182011	RINA
15.	AL052012	ERNESTO	33.	AL101981	DENNIS	51.	AL191995	ROXANNE
16.	AL052016	EARL	34.	AL101994	UNNAMED	52.	AL252005	WILMA
17.	AL061978	CORA	35.	AL102002	ISIDORE			
18.	AL061994	DEBBY	36.	AL111988	JOAN			