Combining coral larvae and disease connectivity to optimize mitigation and restoration strategies in the Florida Reef Tract

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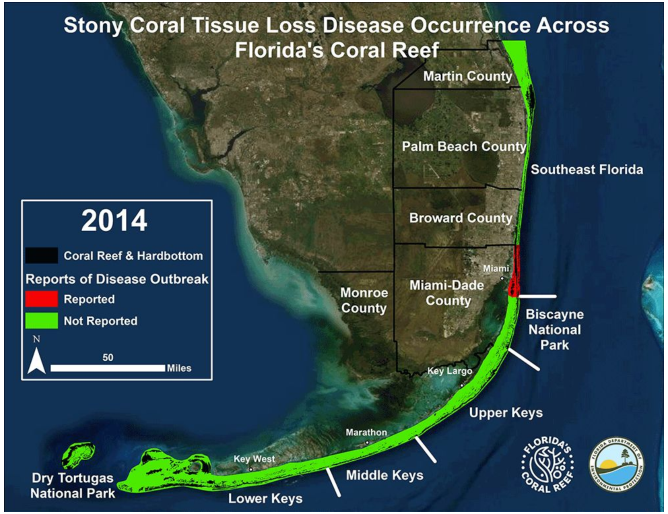
Since 2014, Florida corals are experiencing high mortality due to the Stony Coral Tissue Loss Disease (SCTLD)



At least 22 reef building species affected

Decline in living coral tissue area of ~60% on impacted reefs.

Up to a 95% decrease in density of susceptible species on affected reefs

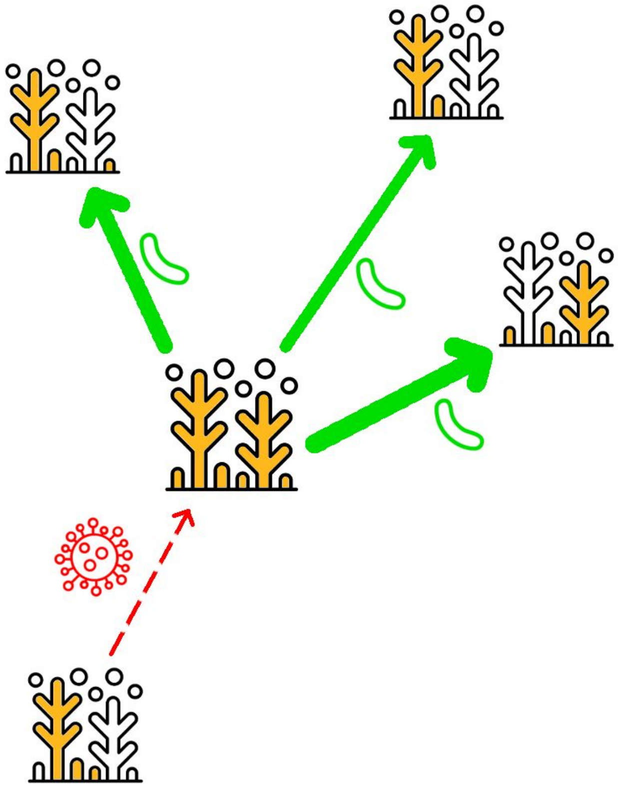
⇒ **Largest coral disease outbreak on record.**

It is thus urgent to restore reefs efficiently while preventing the SCTLD to strike back

Exchanges of larvae between reefs promote the resilience of the network

However, the SCTLD is likely water-borne

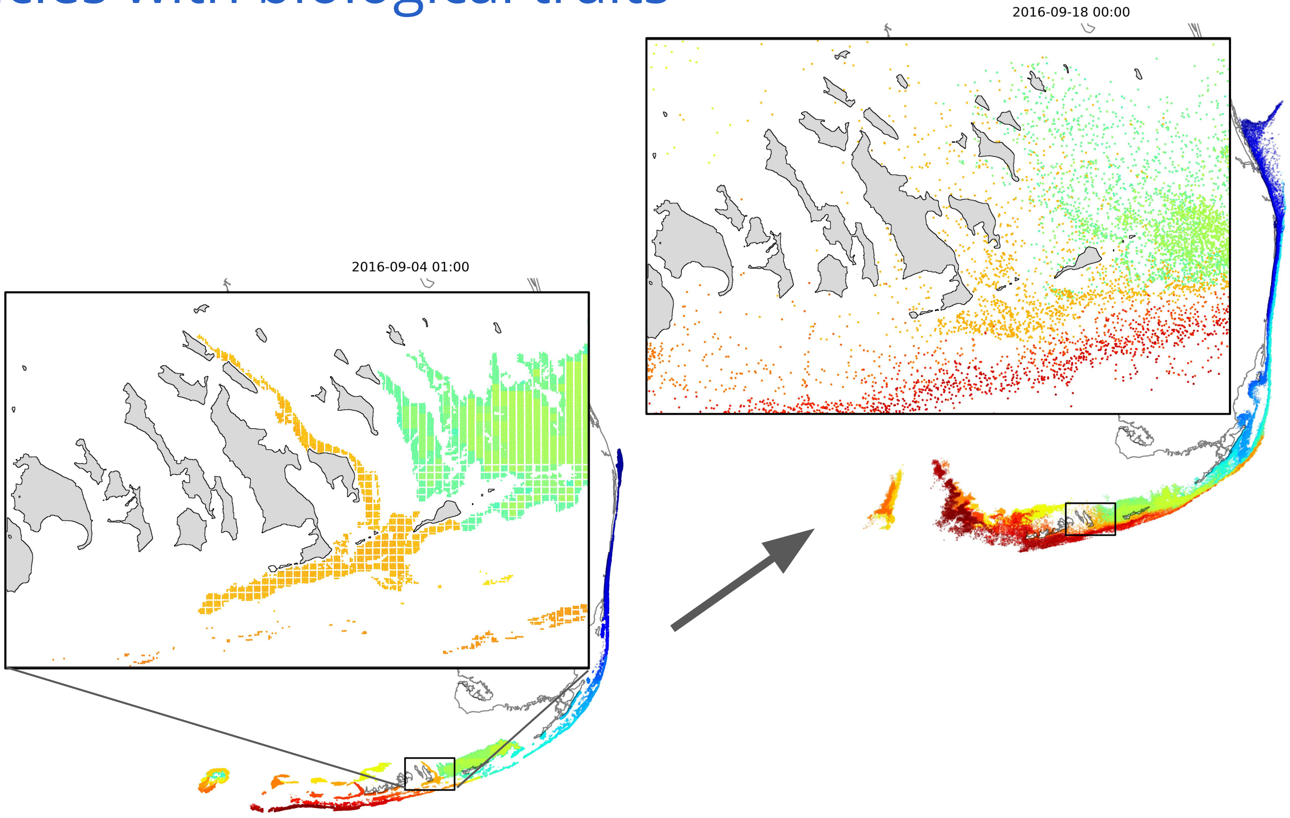
=> Identify reefs that are **good larval sources** for the network while being **weak potential sinks of disease** agent



To do so, exchanges of larvae and disease agents are modeled using virtual particles with biological traits

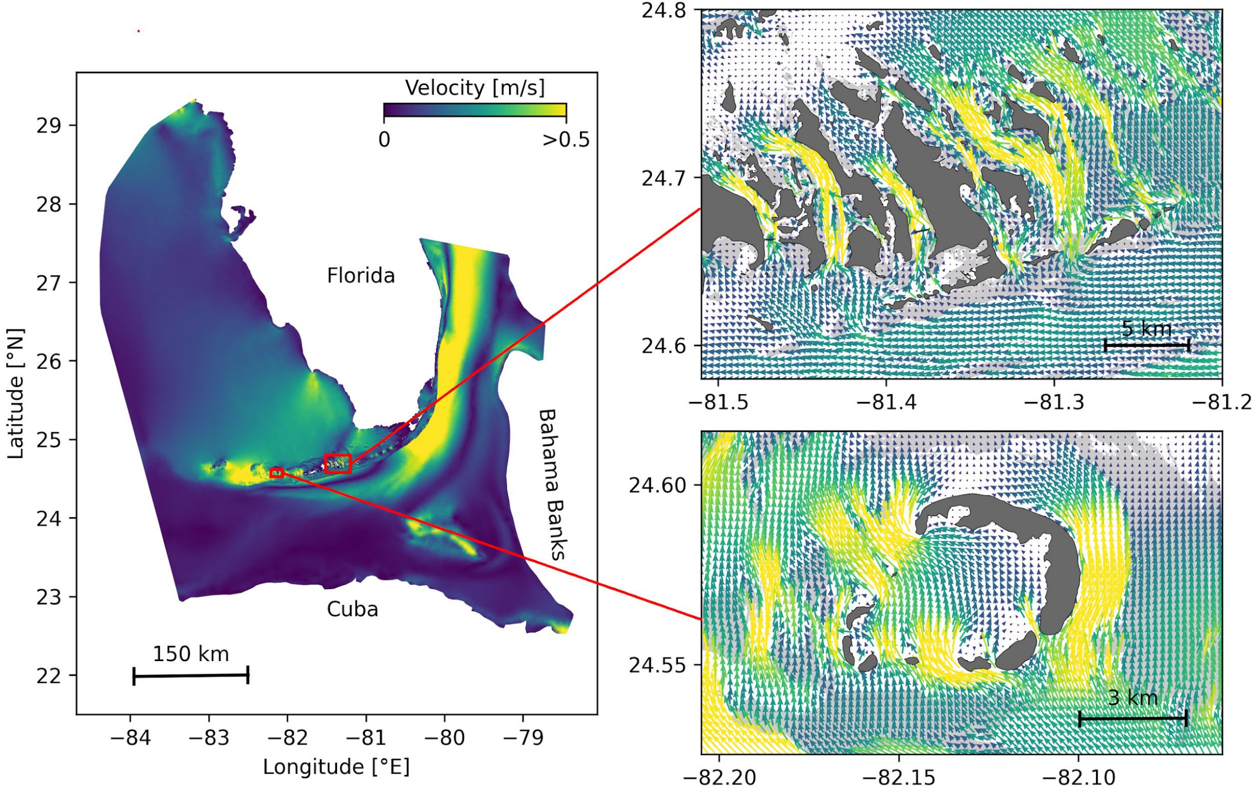
Monthly connectivity matrices for SCTLD between May 2018 and December 2020

Connectivity matrices for the spawnings of *Acropora cervicornis*, *Dendrogyra cylindrus* and *Orbicella faveolata* in 2018, 2019 and 2020



Circulation through the reefs is modeled using the high-resolution coastal ocean model SLIM

SLIM simulates the circulation around reefs and islands with a resolution of 100m (~10x more than existing models)



We then developed a restoration index based on the weighted in- and out-degrees for SCTLD and larvae for each reef

Weighted disease in-degree

$$\left.\begin{aligned} D_i^{in} &= k_i^{in,dis} \times \left(\frac{s_i^{in,dis}}{k_i^{in,dis}}\right)^{\alpha^{dis}} \\ C_i^{out} &= k_i^{out} \times \left(\frac{s_i^{out}}{k_i^{out}}\right)^{\alpha} \end{aligned}\right\} \longrightarrow R_i = \frac{C_i^{out} - \beta D_i^{in}}{C_{\max}^{out}}$$

Weighted coral out-degree

Restoration index

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Weighted disease in-degree

Restoration index

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Weighted larval out-degree

number of connections (= degree)

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Weighted larval out-degree

number of connections (= degree)

sum of connection weights

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Restoration index

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Weighted larval out-degree

number of connections (= degree)

sum of connection weights

relative importance of degree versus connection weight

We then developed a restoration index based on the weighted in- and out-degrees for SCTLD and larvae for each reef

Weighted disease in-degree

Restoration index

Relative importance of disease risk

$$\left.\begin{array}{l} D_i^{in} = \boxed{k_i^{in,dis}} \times \left(\dfrac{\boxed{s_i^{in,dis}}}{k_i^{in,dis}}\right)^{\boxed{\alpha^{dis}}} \\[2em] C_i^{out} = \boxed{k_i^{out}} \times \left(\dfrac{\boxed{s_i^{out}}}{k_i^{out}}\right)^{\boxed{\alpha}} \end{array}\right\} \longrightarrow R_i = \frac{C_i^{out} - \boxed{\beta} D_i^{in}}{C_{\max}^{out}}$$

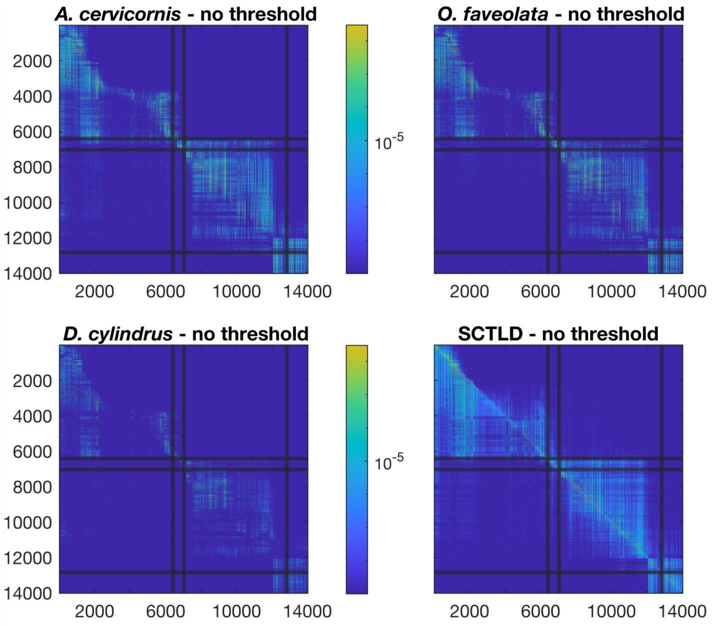
Weighted larval out-degree

number of connections (= degree)

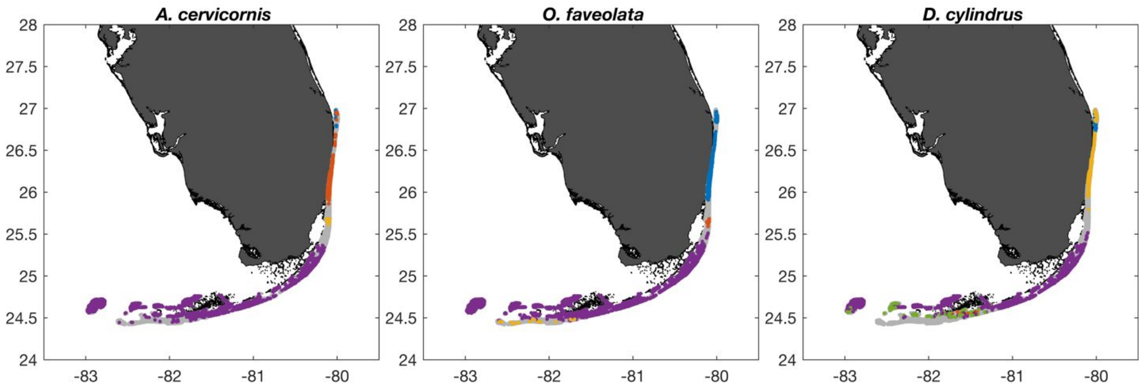
sum of connection weights

relative importance of degree versus connection weight

Connectivity analysis suggests that all reefs are reachable by the disease pathogen and reveals more fragmented network for D. cylindrus



Mean connectivity matrices: SCTLD has stronger connections while D. cylindricus exhibits weak connections compared to the other two species



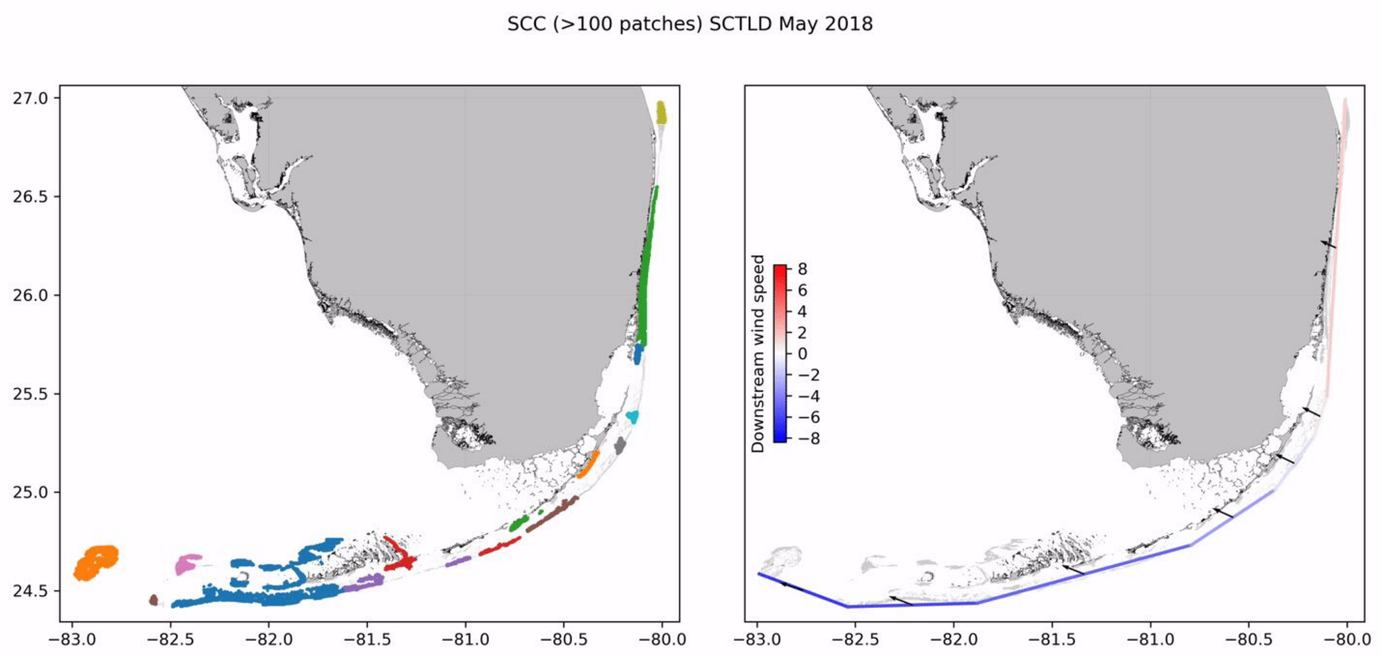
Strongly connected communities (SCC):

Consistent separation between the North of the Florida Reef Tract and the Florida Keys

Notably smaller SCC in the Keys for D. cylindrus

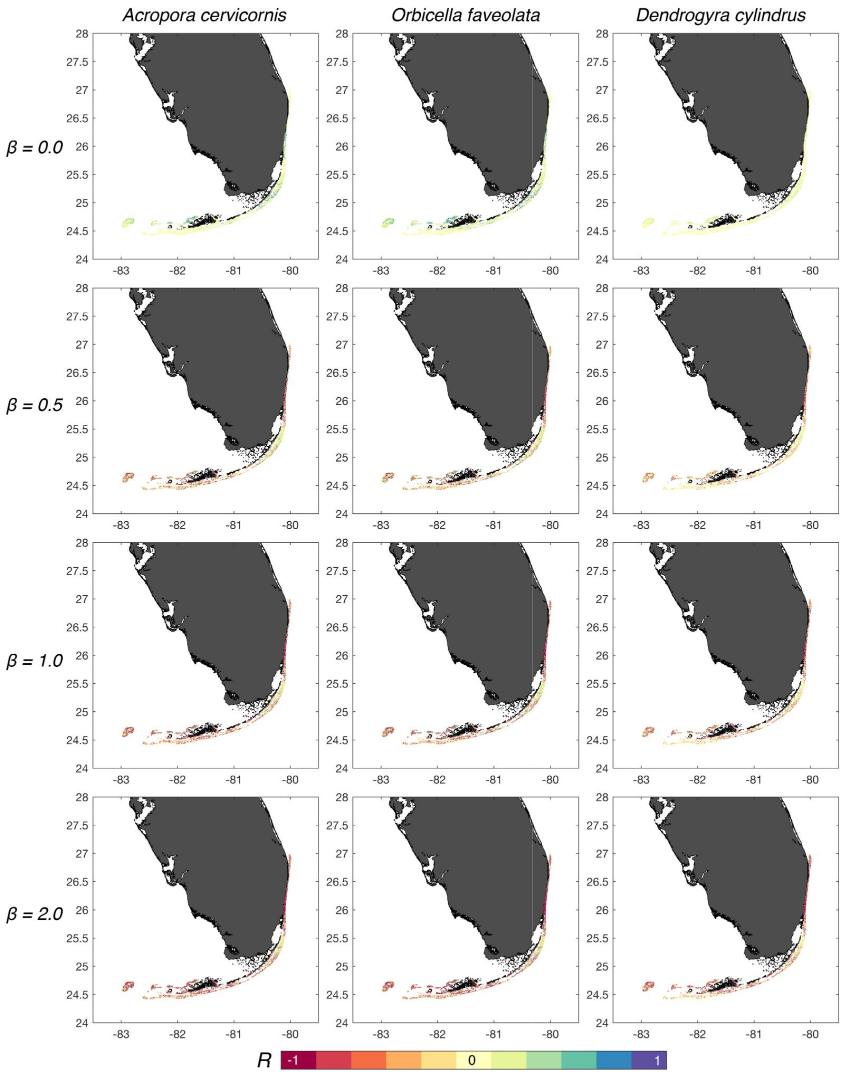
Averaged SCTLD network has a single SCC covering the whole FRT ⇒ can potentially reach any reef

The disease networks (and SCCs) have a clear seasonality



Temporal variability of the size and number of the disease SCCs

Possible link to seasonal wind regime shifts but no clear correlation identified so far...



Some reefs have consistent restoration index values across species for different values of β

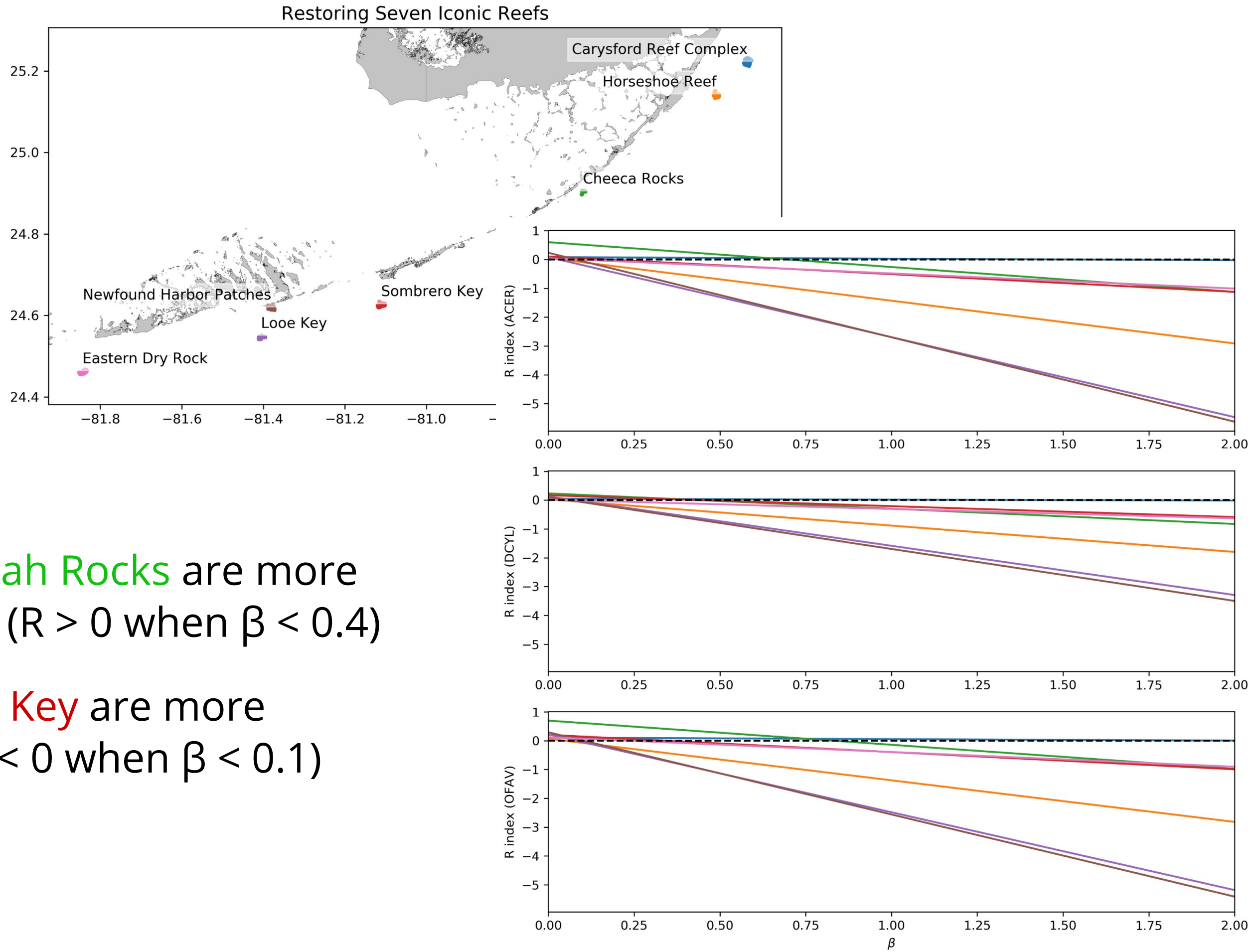
Reefs in the Upper Keys generally have low restoration index value

Some reefs exhibit high restoration index values even with high β for all species ⇒ attractive for ecosystem-based restoration

Similar spatial patterns between O. faveolata and A. cervicornis ⇒ possible coupled restoration

R can be used to assess the susceptibility of restored reefs to disease

Seven reefs selected for restoration in the Florida Keys based on their ecological services, connectivity and genetic complexity



Our results suggest that:

Carysford Reef and Cheecah Rocks are more protected against disease (R > 0 when β < 0.4)

Horseshoe Reef and Looe Key are more susceptible to disease (R < 0 when β < 0.1)

In brief

High resolution bio-physical models allow to build restoration metrics taking larval connectivity and disease risk into account.

D. cylindrus is especially at risk due to its susceptibility to the SCTLD and fragmented larval connectivity.

Reefs with high R value for all species are good potential candidates for restoration although complementary studies taking coral species distribution and density into account are required.