Florida Keys Coral Reef Analysis

Introduction

In this report, I present my comprehensive analysis of coral reef ecosystems in the Florida Keys. My research addresses the following key objectives:

- Determining long-term trends in stony coral cover and species richness.
- Evaluating Sanctuary-wide reef community changes.
- Distinguishing localized variations from broad-scale shifts.
- Examining correlations affecting coral health.
- Modelling future scenarios to anticipate potential declines.

The report follows a structured approach, beginning with Exploratory Data Analysis (EDA) that visualizes critical metrics through time-series charts of colony counts, density, and morphological characteristics. In the Correlation and Relationships section, I investigate connections between health indicators like disease prevalence, tissue isolation, and environmental factors.

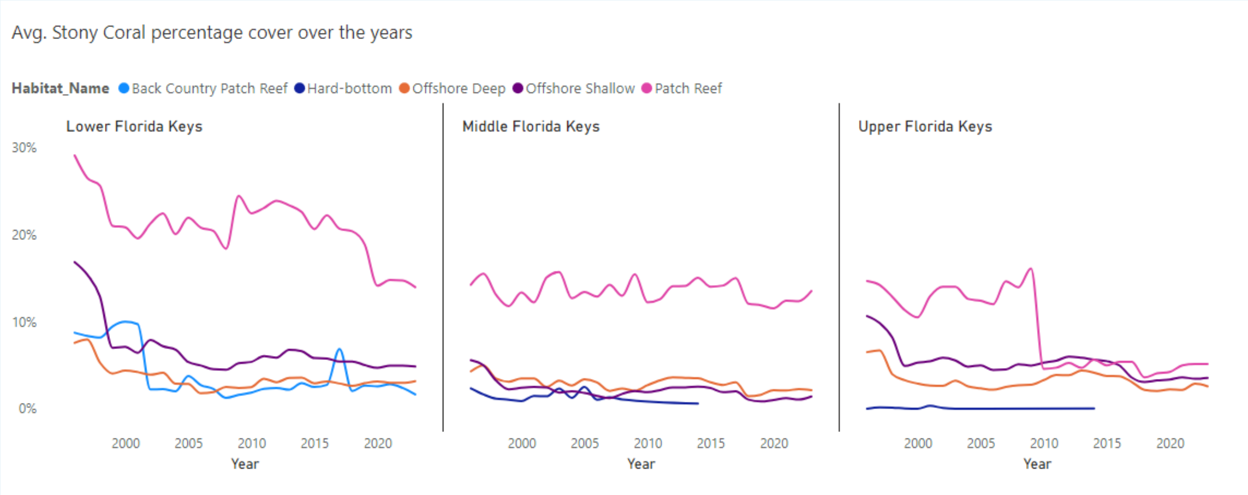
The Regional Comparison identifies geographic variations in reef health through comparative visualizations, while the Future Outlook combines ML-based and traditional statistical methods to forecast reef trajectories under various scenarios. Throughout, I've translated complex data into actionable insights, with each visual accompanied by clear implications and targeted recommendations.

My findings reveal both challenges and opportunities: while our reefs face significant threats, the early warning indicators I've identified can help detect declines before they become severe, providing valuable lead time for implementing the targeted interventions detailed in this analysis.

[Note: Follow this link to Power BI report, for some of the analyses presented in the report.]

Exploratory Data Analysis

Evolution of Stony Coral Percentage Cover



What the Chart Shows

Stony coral cover trends over time (1996–2023), with Patch Reef habitats performing relatively well initially but declining post-2010, while other habitats show modest decreases.

Key Takeaways

Across all subregions, **Patch Reef habitats** experience the sharpest post-2010 declines, while **Offshore Shallow habitats** show stability followed by modest decreases.

Avg. Stony Coral percentage cover across stations

StationID	Habitat_Name	Subregion	%age cover	Year-wise trend
252	Patch Reef	LK	31.207%	
254	Patch Reef	LK	29.211%	
363	Patch Reef	LK	28.813%	
251	Patch Reef	LK	28.121%	
373	Patch Reef	LK	26.981%	
574	Offshore Shallow	LK	26.384%	
364	Patch Reef	LK	25.630%	
403	Patch Reef	LK	24.544%	
362	Patch Reef	LK	23.736%	
511	Offshore Shallow	UK	23.489%	
371	Patch Reef	LK	22.896%	
361	Patch Reef	LK	22.357%	
402	Patch Reef	LK	21.966%	
263	Patch Reef	LK	21.380%	
372	Patch Reef	LK	20.098%	
262	Patch Reef	LK	18.971%	
374	Patch Reef	LK	18.735%	
244	Patch Reef	MK	18.539%	
332	Patch Reef	UK	18.445%	
354	Patch Reef	MK	18.324%	

What the Table Shows

Table displays stony coral percentage cover across stations, highlighting Patch Reef habitats as dominant, especially in the Lower Florida Keys region. Coral cover varies across subregions and habitats. (For full table refer to the report link.)

Key Takeaways

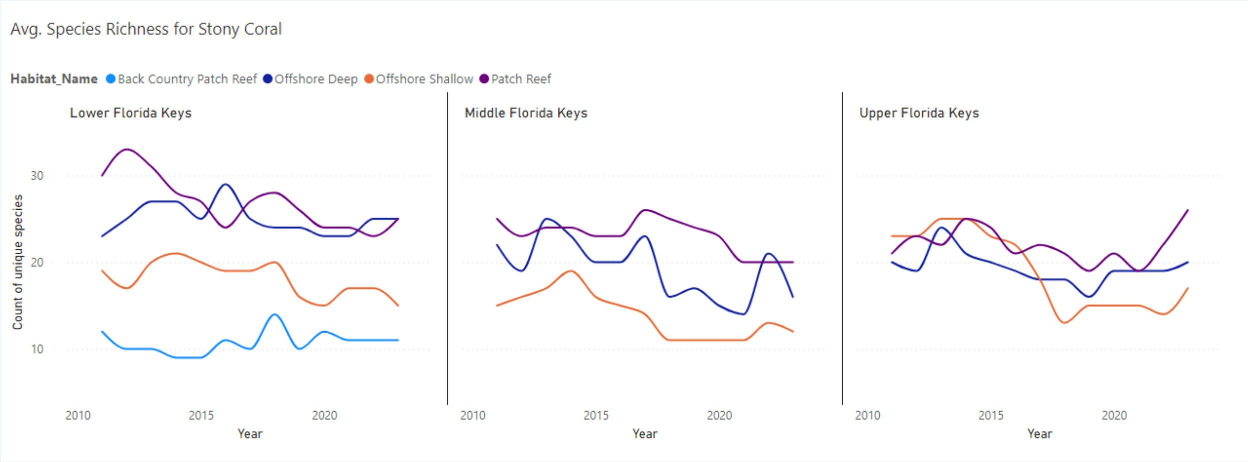
- Coral cover at **Patch Reef stations** is consistently high but declining, particularly post-2010.
- The **Middle Florida Keys (MK**) and **Upper Florida Keys (UK)** show low cover, hinting at higher vulnerability compared to **Lower Keys (LK)**.

What Can We Do Next?

Prioritize Conservation

- Focus restoration efforts on stations and habitats showing steady declines, such as **Patch Reef habitats in UK and MK**.
- Proactively target low-performing stations (e.g., those below 20% cover) for habitat support.

Trends in Species Richness



What the Chart Shows

The chart tracks how many different **stony coral species** (like the variety of plants in a garden) are found in different parts of the **Florida Keys** — broken down by **habitat types** (like different "neighbourhoods" under the sea) and over time.

Key Takeaways

- **Patch Reefs are the busiest neighbourhoods.**
  These reefs have the most types of corals possibly because they are biodiversity hotspots — a mix of conditions with lots of species. — but in the **Middle and Lower Keys**, even these are slowly losing their diversity.
- **Offshore reefs are surviving.**
  They've lost many species steadily over time, possibly due to stress from warming

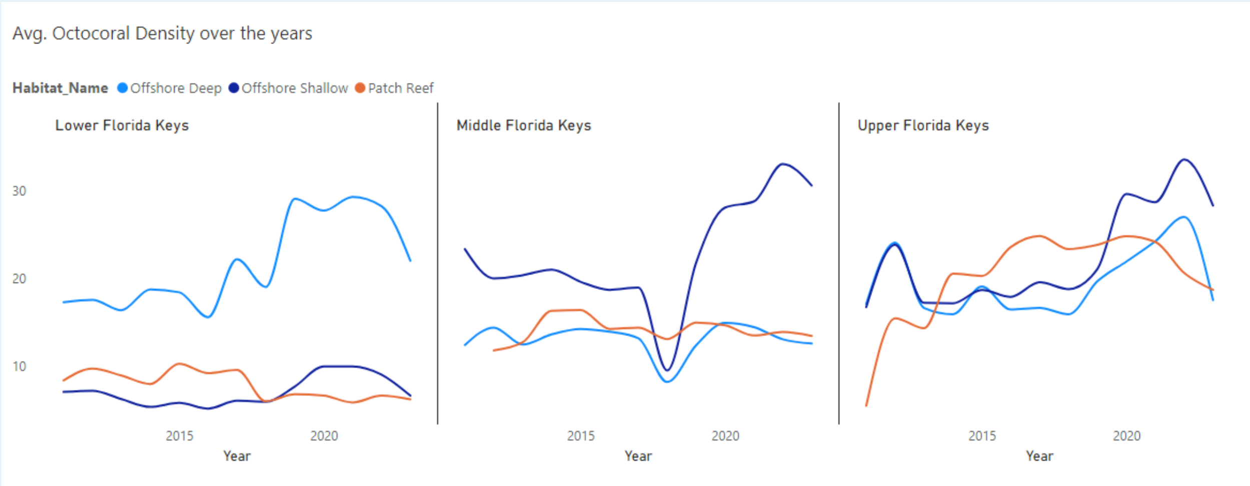
oceans or lack of light.

- **Back Country Reefs are struggling.**
  These shallow-water areas, closer to land, are only present at Lower Keys region These have the lowest number of species — possibly due to hostile environments via runoff or pollution.
- **Some signs of hope in the Upper Keys!**
  Close to 2022, there's a small comeback in coral diversity in the Upper Keys' Patch Reefs. Something might be working there — maybe cleaner water, successful restoration, or fewer local stressors (lockdown effects).

What Can We Do Next?

- **Protection Priority**
  Focus conservation efforts on Patch Reef habitats, which support the highest coral diversity but show concerning declines in the Middle Keys.
- **Regional Management**
  Adopt region-specific approaches—recovery strategies for the declining Middle Keys, resilience-building for the fluctuating Upper Keys, and maintenance protocols for the relatively stable Lower Keys.

Analysing Octocoral Density



Avg. Octocoral Density across stations

StationID	Habitat_Name	Subregion	Density	Yearly trend
503	Offshore Shallow	UK	41.77	
334	Patch Reef	UK	38.08	
543	Offshore Shallow	MK	37.87	
554	Offshore Shallow	MK	36.85	
814	Offshore Deep	LK	36.14	
813	Offshore Deep	LK	33.11	
504	Offshore Shallow	UK	31.42	
544	Offshore Shallow	MK	29.65	
724	Offshore Deep	UK	29.04	
333	Patch Reef	UK	28.31	
522	Offshore Shallow	UK	27.89	
523	Offshore Shallow	UK	27.41	
552	Offshore Shallow	MK	27.05	
541	Offshore Shallow	MK	26.71	
553	Offshore Shallow	MK	25.56	
542	Offshore Shallow	MK	25.55	
721	Offshore Deep	UK	25.12	
524	Offshore Shallow	UK	24.25	

What the Chart Shows

The graph tracks the **average number of soft corals (octocorals) species per meter (or density)** across three regions of the Florida Keys — **Lower**, **Middle**, and **Upper** — over time (2011–2023), split by **habitat type** (Offshore Deep, Offshore Shallow, and Patch Reef).

Each line shows how **crowded or sparse** octocoral colonies are in each habitat over the years.

The table reports the density at several stations in different regions and habitats. (For full table refer to the report link.)

Key Findings

Regional Density Patterns:

- Lower Keys: Offshore Deep habitats consistently show the highest octocoral density, increasing significantly around 2017 before declining after 2020.
- Middle Keys: Offshore Shallow habitats experienced dramatic **growth** after 2018, surpassing other habitat types.
- Upper Keys: All habitat types show **increasing trends** over time, with Offshore Shallow showing the most dramatic increase after 2018.

Uniform Decline Event
All regions and most habitat types show a noticeable dip in octocoral density around 2018, suggesting a widespread environmental event affected the entire Florida Keys region.

Recovery Resilience
The recovery patterns after the 2018 decline vary significantly by region and habitat type, with Middle and Upper Keys Offshore Deep habitats showing the strongest recovery and growth.

What Can We Do Next?

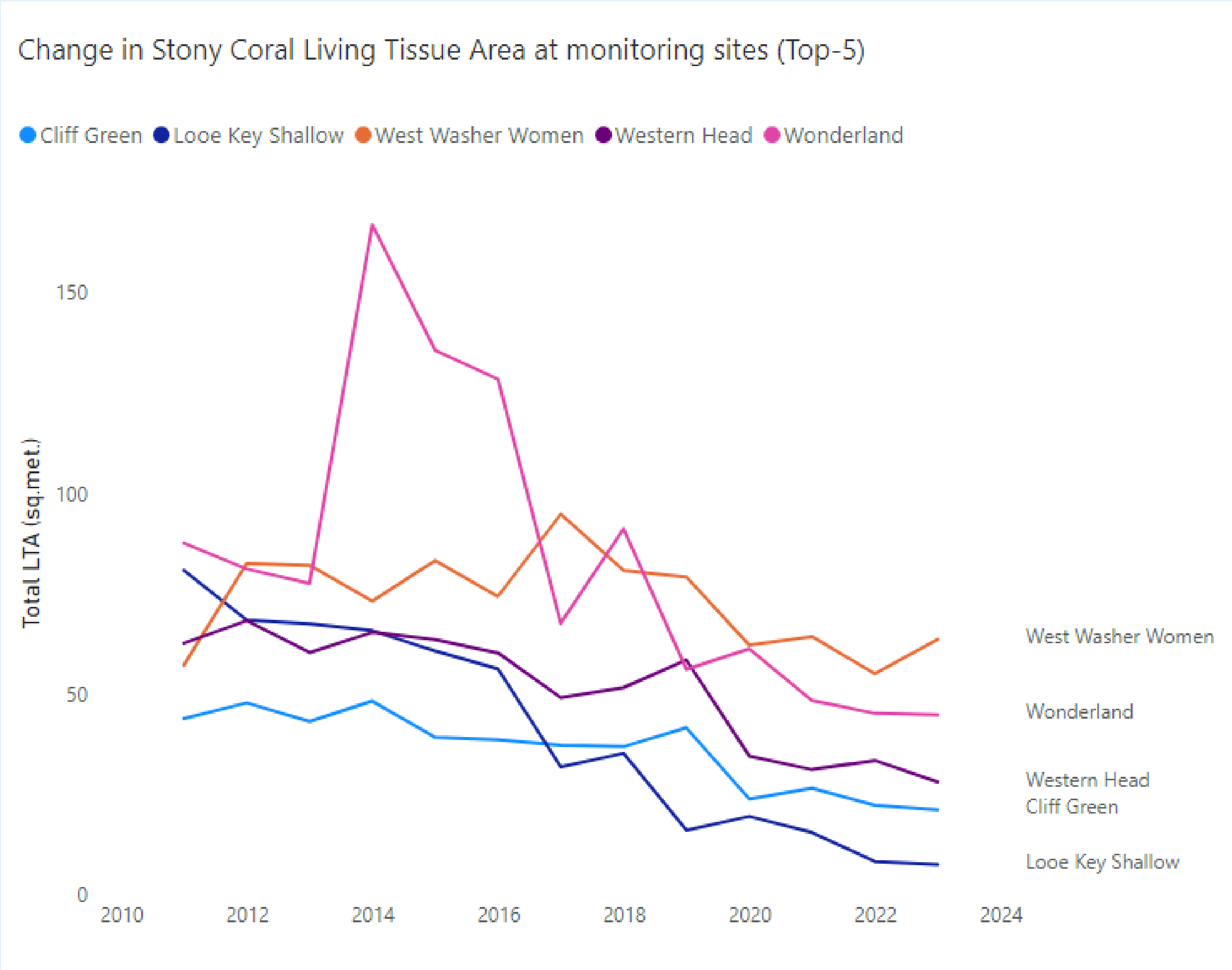
- **Focus monitoring and protection on Offshore Shallow reefs.**
  They're showing the strongest recovery and can serve as "anchor points" for reef health.
- **Investigate why Patch Reefs are lagging** in the Lower and Middle Keys.
  These habitats might need more help — like better water quality or reduced human

disturbance.

- **Prepare for future stress events.**
  The 2017–2018 dip shows reefs are still vulnerable — we need to build early warning systems and response plans.

Living Tissue area at Monitoring Sites for Stony Corals

SiteName	Habitat	Subregion	Avg LTA
Wonderland	Patch Reef	LK	84.09
West Washer Women	Patch Reef	LK	73.36
Western Head	Patch Reef	LK	51.37
Looe Key Shallow	Offshore Shallow	LK	41.09
Cliff Green	Patch Reef	LK	36.25
West Turtle Shoal	Patch Reef	MK	33.04
Red Dun Reef	Patch Reef	LK	31.87
Thor	Patch Reef	MK	31.63
Dustan Rocks	Patch Reef	MK	30.52
Grecian Rocks	Offshore Shallow	UK	26.40
Rawa Reef	Patch Reef	MK	20.14
Burr Fish	Patch Reef	UK	12.57
Turtle	Patch Reef	UK	12.44
Molasses Shallow	Offshore Shallow	UK	11.96
Sand Key Shallow	Offshore Shallow	LK	11.41
Smith Shoal	Back Country Patch Reef	LK	10.79
Western Sambo Shallow	Offshore Shallow	LK	10.21
Tennessee Deep	Offshore Deep	MK	10.14
Eastern Sambo Shallow	Offshore Shallow	LK	9.77
Two Patches	Patch Reef	UK	9.06
Looe Key Deep	Offshore Deep	LK	8.44
Carysfort Deep	Offshore Deep	UK	8.44



What the Visuals Show

- **Line Chart:** Tracks how **total living tissue area (LTA)** of stony corals has changed over time (2011–2023) at **top five monitoring sites**.

- **Table:** Lists the **average LTA** at many sites, along with **habitat** and **subregion** information. (For full table refer to the report link.)

Key Findings

- **Wonderland** and **West Washer Women** (both **Patch Reefs** in the **Lower Keys**) have the **highest average LTA** — over **70 sq. meters** — suggesting healthier or more established coral communities.
- **Looe Key Shallow**, **Cliff Green**, and **Western Head** show **moderate LTA** but a clear

declining trend over time.

- Sites like **Carysfort Deep**, **Looe Key Deep**, and **Eastern Sambo Shallow** have **very low LTA** (below 10 sq. meters) — some of the **lowest coral tissue coverage** across the Keys.

Trends Over Time (From Line Chart)

- **Wonderland** had a sharp peak (~160 sq. m) around 2014–2016, but then a **steep decline**.
- Most of the sites **downward trend** since 2015, indicating a **widespread decline** in stony coral tissue area.

Implications

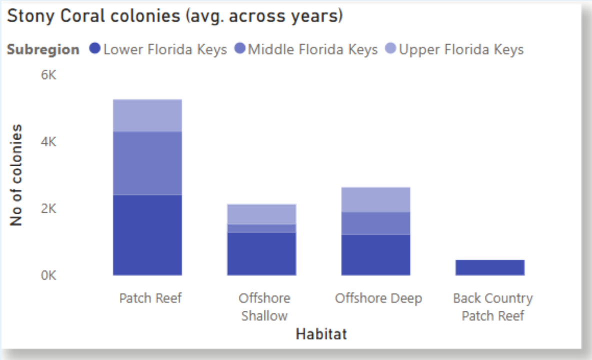
- **Site conditions matter.** Some areas like Wonderland supported high coral growth — these may have had better water quality or protection initially.
- The **general downward trend** is concerning and signals ecosystem-wide coral loss.

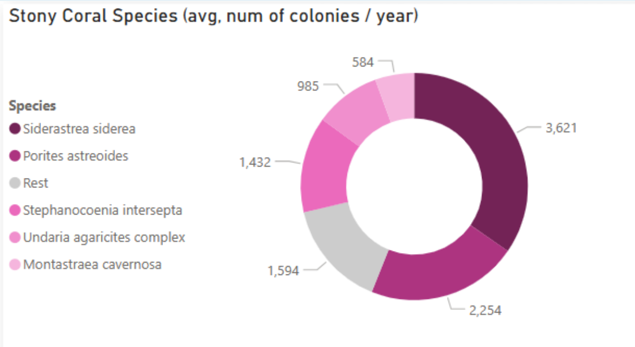
What Can We Do Next?

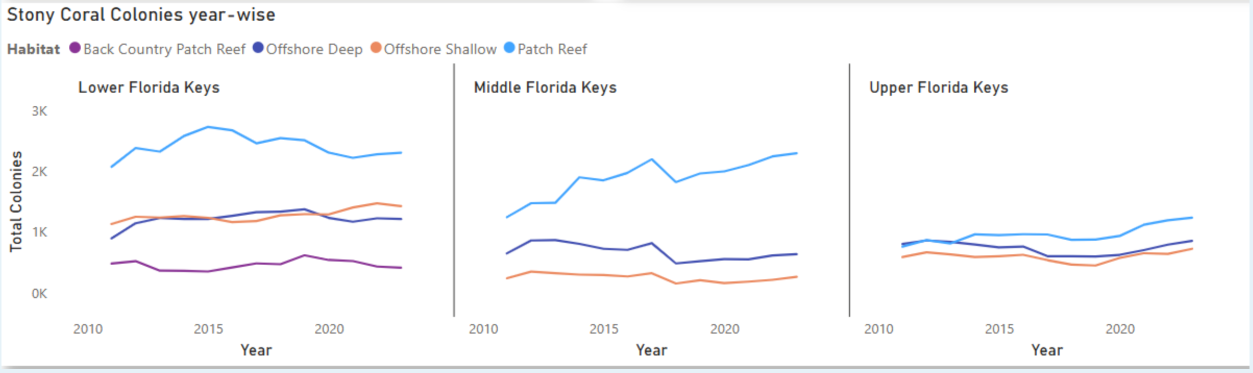
- **Prioritize high-potential sites** (e.g., Wonderland, West Washer Women) for targeted protection or restoration — they've shown the capacity to support more coral, but are slowly declining.
- **Adapting patterns or measures** from patch reefs of the **Lower Keys** for more sites, where some of the best-performing sites exist.

Spatial and Temporal Patterns in Coral Distribution

1. Stony Coral







What the Visuals Show

- **Top-left bar chart:** Average number of stony coral colonies per **habitat**, across **regions**.
- **Top-right donut chart:** The **most common stony coral species**, by average number of colonies per year.
- **Bottom line charts:** How coral colony counts changed **over time (2011–2023)** across **habitats and regions** (Lower, Middle, Upper Keys).

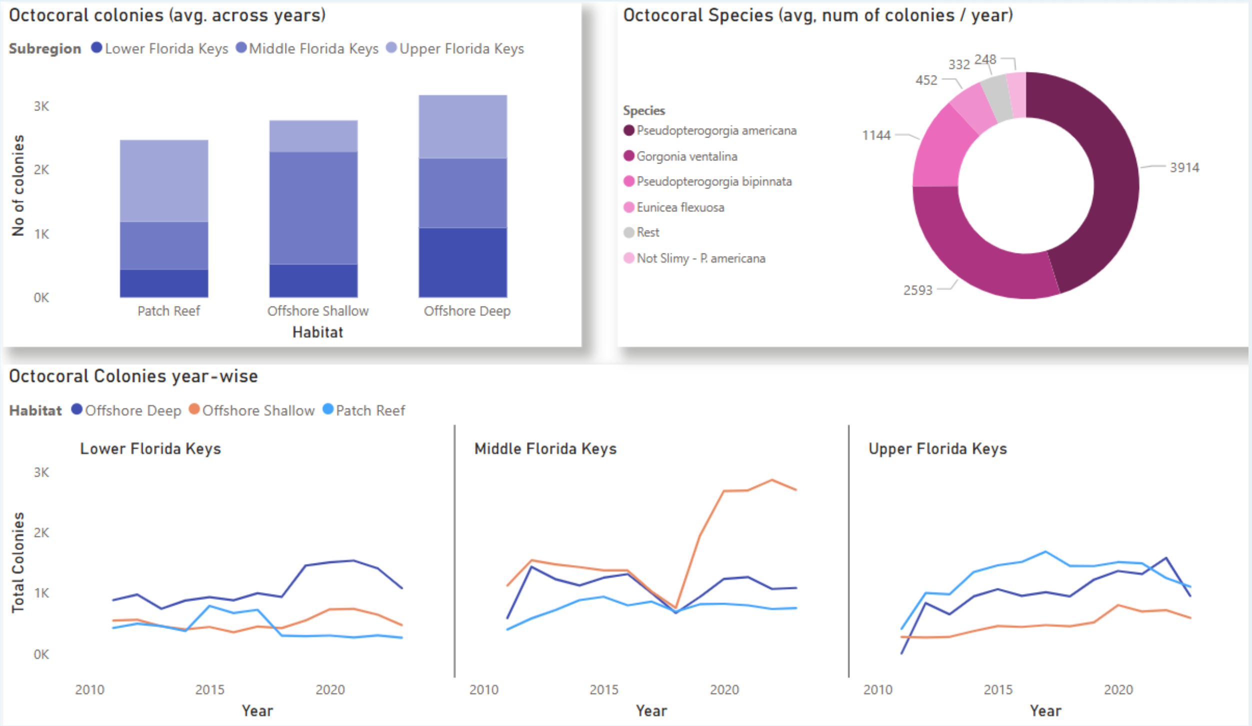
Key Findings

- **Patch Reefs** support the **highest number of stony coral colonies**, especially in the **Lower Florida Keys** — nearly 3x higher than other habitats.
- ***Siderastrea siderea*** and ***Porites astreoides*** are the most prominent stony coral species. — likely due to its resilience to stress.
- Coral numbers are **stable or rising** in Patch Reefs, especially in Mid/Upper Keys.
- Back Country and some offshore reefs are ‘At-Risk’ zones showing **persistently low colony counts.**

What Can We Do Next?

- **Focus conservation on Patch Reefs**, especially those in the Lower and Middle Keys — they support the most corals and are still thriving.
- **Habitat Connectivity**: Establish protected corridors between high-density Patch Reef habitats and the less populated Offshore habitats to promote larval dispersal and coral recruitment across the ecosystem.

2. Octocoral



What the Visuals Show

- Top-left bar chart: Average number of octocoral colonies per **habitat**, across three Florida Keys **regions**.
- Top-right donut chart: The **most common octocoral species**, by average colony count per year.
- Bottom line charts: Change in octocoral colony counts over time (2011–2023), across **habitats and regions**.

Key Findings

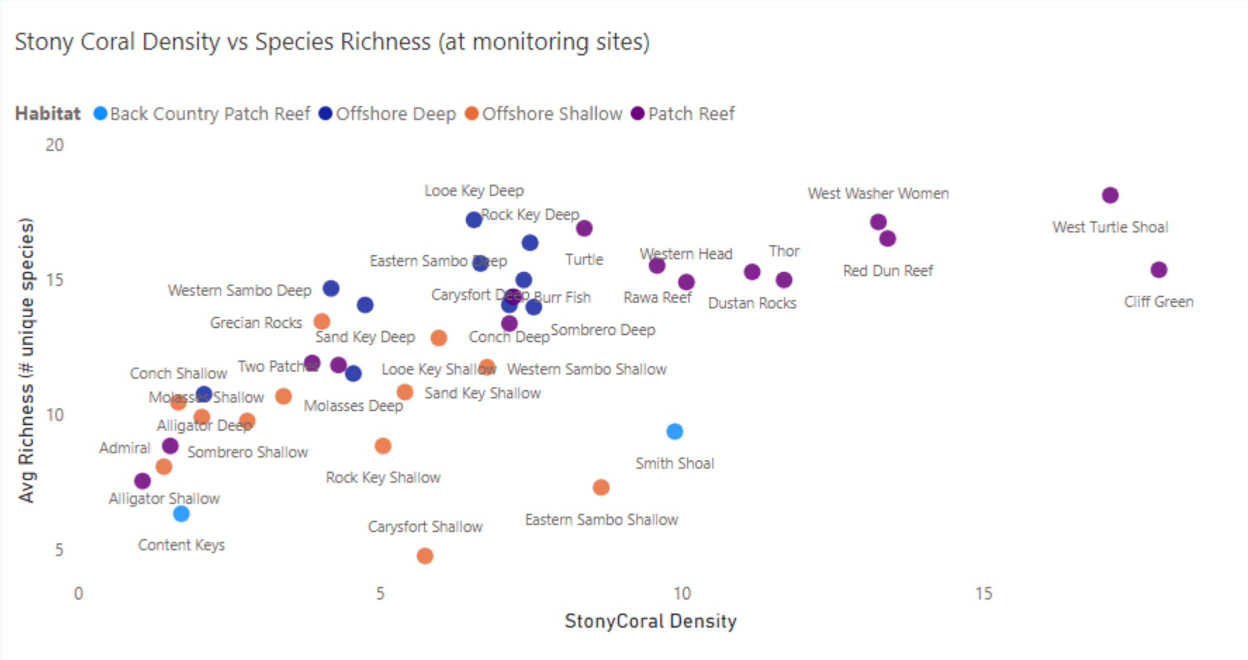
- Unlike stony corals, octocorals prefer **offshore** environments (their relatively **higher presence**), where water is clearer and deeper.
- Just like stony corals, a **few species dominate** the octocoral population, with ***P. americana*** leading by a large margin — likely due to its fast growth and adaptability.
- Octocoral populations are growing more in offshore areas in the Middle and Lower Keys, but **Patch Reefs** in the **Upper Keys** are an **exception**, showing strong support for soft corals.
- Growth peaked around 2020, especially in offshore areas, then dipped slightly.

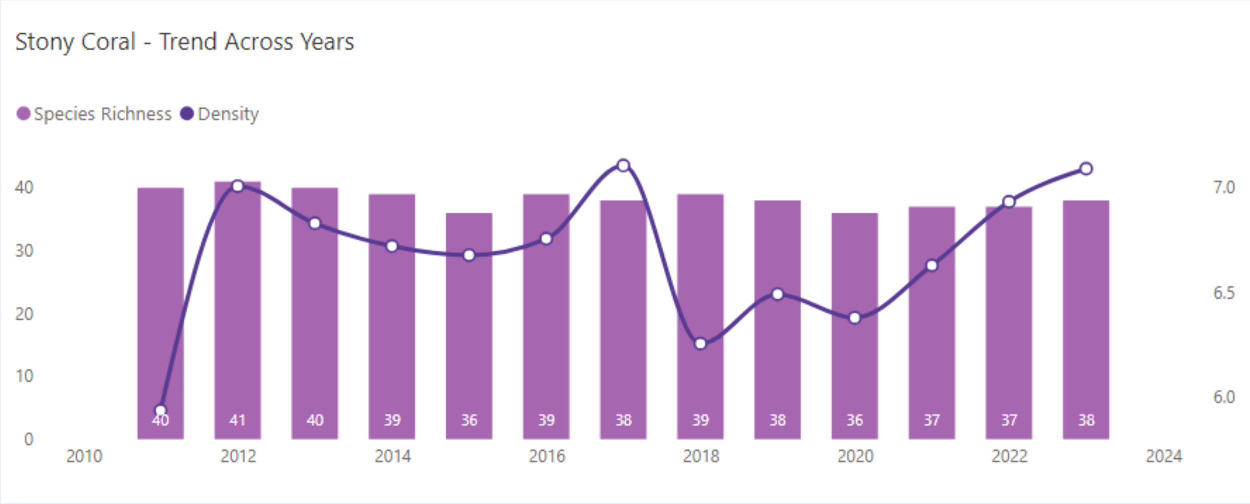
What Can We Do Next?

- Protect Upper Keys Patch Reefs, which are unusually productive for octocorals.
- Focus species-specific studies on *P. americana* and *G. ventalina* — they're key to understanding soft coral dynamics.

Relationships and Correlations

Stony Coral Density and Species Richness at monitoring sites





What the Visuals Show

- **Scatter plot (top):**
  Shows the relationship between **stony coral density (x-axis)** and **species richness (y-axis)** for **individual monitoring sites**, grouped by habitat type.

- **Bar + Line chart (bottom):**
  Displays the **yearly trend** in average **species richness (bars)** and **density (line)** across all sites (2011–2023).

Key Findings

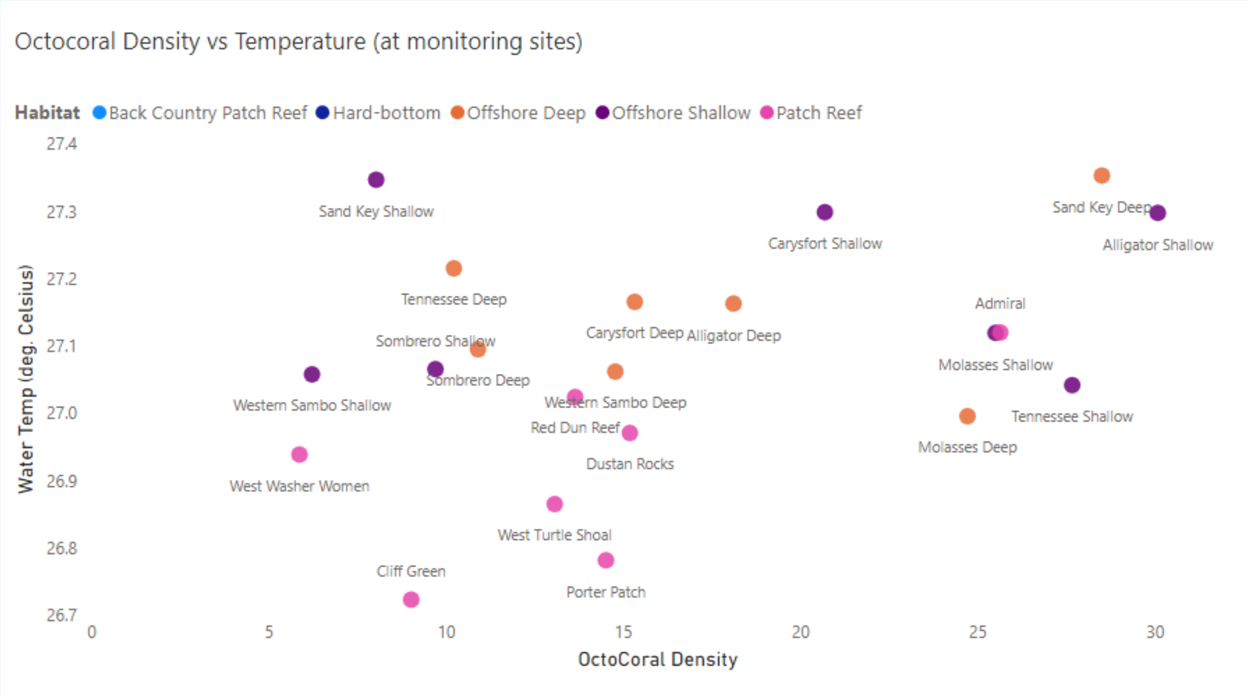
- There's a **positive correlation** between coral density and species richness — especially strong at the monitoring sites in **Patch Reef habitats**, indicating they support **both a large number of colonies and a greater variety of species**.
- **Species richness** (bars) is relatively **stable** over time, hovering around 36–41 species per year.
- **Coral density** (line) **declined slightly** from 2012–2019 (**ocean acidification, disease outbreak*), dropped notably around 2019–2020, and has **gradually rebounded** (**restoration effects and adaptive capacity of few species*) since then.

Recommendations

- **Track high-performing sites** like West Turtle Shoal and West Washer Women — they can serve as benchmarks.
- **Watch for density dips** even when species richness stays steady — it can signal hidden stress or early decline.

***possible causes revealed from studies conducted**

Correlation between Octocoral Density and Water Temperatures



What the Chart Shows

Chart depicting the relationship between **octocoral density (x-axis)** and **average water temperature (y-axis)** for **individual monitoring sites**, grouped by habitat type.

Key Findings

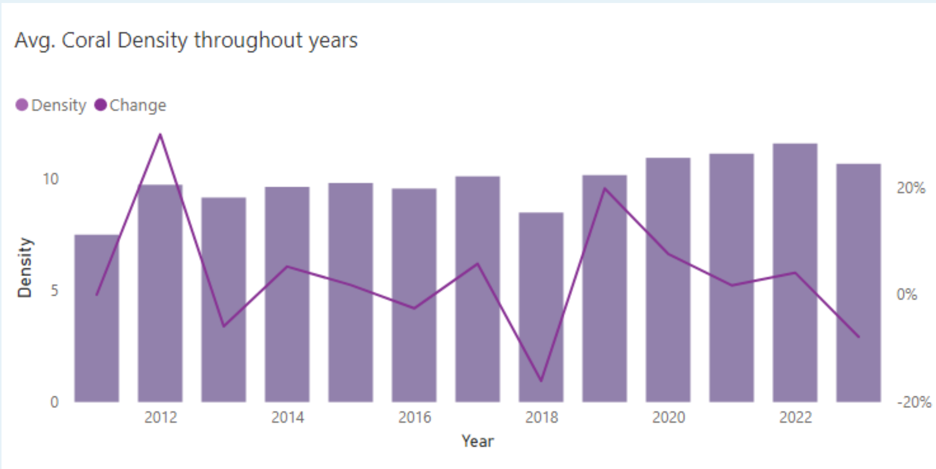
- **Water temperatures** stay within a **small range** (26.7-27.4°C) across all sites, showing the whole region has fairly uniform temperatures.
- Despite similar temperatures, some sites have up to **6 times more** octocorals than others, with Sand Key Deep and Alligator Shallow having the most.
- **Octocoral density does not consistently increase or decrease with water temperature (a weak correlation)** — other factors may have a stronger influence.

Recommendations

- Create **site-specific** protection **plans** rather than one-size-fits-all approaches since each site has unique conditions.
- Pay special attention to **corals thriving in warmer** waters as they might have adaptations that could help other reefs survive climate change.
- **Investigate local conditions** at high-density sites (e.g., water clarity, current, substrate) for better insight into octocoral success.

Regional Comparison

Density



Avg. Coral Density across stations

Station	SiteName	Density	Recent Change	Yearly Trend
503	Carysfort Shallow	23.41	-11.87% ▼	
814	Sand Key Deep	20.03	-18.49% ▼	
334	Admiral	19.98	11.11% ▲	
543	Alligator Shallow	19.68	10.97% ▲	
504	Carysfort Shallow	19.44	-11.71% ▼	
554	Tennessee Shallow	18.98	-2.71% ▼	
813	Sand Key Deep	18.47	-17.53% ▼	
343	West Turtle Shoal	17.32	0.00% ▬	
342	West Turtle Shoal	17.20	-6.02% ▼	
544	Alligator Shallow	15.79	-7.91% ▼	
724	Molasses Deep	15.60	-36.52% ▼	
383	Cliff Green	15.54	1.72% ▲	
333	Admiral	15.00	-21.05% ▼	
354	Dustan Rocks	14.77	5.28% ▲	
812	Sand Key Deep	14.70	-15.50% ▼	
381	Cliff Green	14.41	-0.71% ▼	
243	Thor	14.34	1.19% ▲	

What the Charts Show

- **Top chart** (Bar + Line):
  Shows the **average coral density by year** (bars) and **annual percent change** (line) across all stations combined.

- **Bottom table**:
  Lists **individual stations** ranked by **average coral density**, along with **recent change**, **long-term trend**, and mini sparkline charts for each.

Key Insights

- Coral density has generally **increased since 2011**, with small dips in **2018** and a strong rebound by **2020–2022**.
- **Carysfort Shallow (23.41)** and **Sand Key Deep (20.03)** have the **highest average coral density**, but both show **recent declines** (–11.9% and –18.5% respectively).
- Stations like **Admiral** and **Alligator Shallow** are showing **positive recent changes** (around +11%), indicating localized improvements.
- **Molasses Deep** has the most severe drop (–36.5%), highlighting a station potentially under **high stress**.
- Some stations like **Cliff Green** show **small but consistent growth**, which could reflect successful recovery or resilience.

[Note: To explore the full table for all the stations, go to the report link mentioned at the start of the report]

Implications

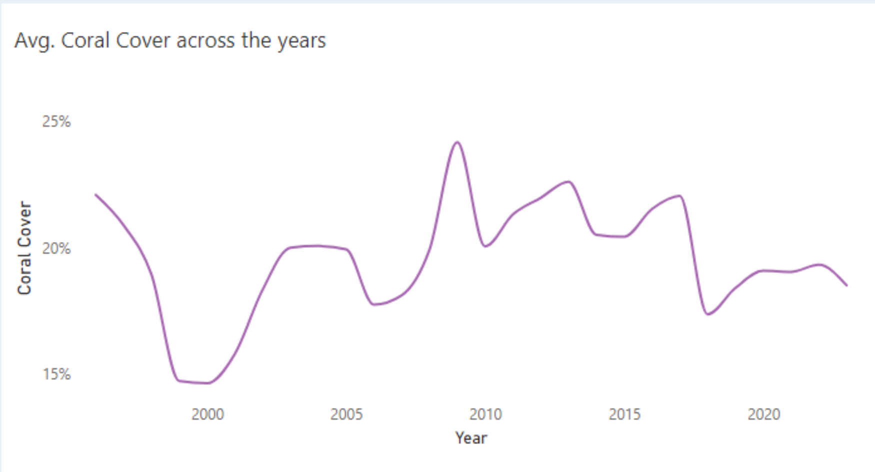
- While average coral density has improved over the decade, **not all sites are following the same trend**.
- Some **high-density sites are declining**, suggesting that **high coral numbers don't guarantee stability**.
- The mixed patterns show that coral health is **highly site-specific**, affected by **localized stressors or protections**.

What Can we Do?

- **Study improving stations** (e.g., Admiral, Cliff Green) to identify what's working — these could serve as models for restoration.

- Use a **site-by-site management approach** rather than general policies, since reef conditions are not uniform across the Keys.

Percent Cover



Avg. Coral Cover across stations

Station	SiteName	Coral Cover	Recent Change	Yearly Trend
364	West Washer Women	46.84%	-14.05% ▼	
304	Turtle	46.82%	-11.85% ▼	
363	West Washer Women	46.48%	1.63% ▲	
383	Cliff Green	45.70%	-9.13% ▼	
263	Red Dun Reef	45.14%	-3.94% ▼	
354	Dustan Rocks	44.11%	-1.91% ▼	
362	West Washer Women	43.61%	-19.19% ▼	
303	Turtle	43.58%	-16.61% ▼	
361	West Washer Women	43.43%	-3.62% ▼	
301	Turtle	43.18%	-4.60% ▼	
344	West Turtle Shoal	43.05%	-12.52% ▼	
382	Cliff Green	42.97%	1.54% ▲	
252	Wonderland	42.19%	0.50% ▲	
334	Admiral	42.15%	-6.38% ▼	
381	Cliff Green	41.57%	-22.06% ▼	
352	Dustan Rocks	41.26%	3.11% ▲	
342	West Turtle Shoal	40.49%	14.00% ▲	

What the Charts Show

- **Avg. Coral Cover Over Years,** showing how coral cover has fluctuated from 1996 to 2023, showing an overall unstable trend.
- **Average Coral Cover at different station with** recent changes from last year and year-wise trendlines.

Key Insights

- **Fluctuating Coral Cover:** Coral cover has not shown consistent improvement; instead, it follows a rise-fall pattern, suggesting sensitivity to periodic stress (e.g., bleaching events, storms, disease).
- **Recent Decline:** In the last few years, coral cover appears to be trending slightly down again.
- *Top performers*: West Washer Women (46.84%), Turtle (46.82%) — but note, both have **recent negative changes** (up to -14%).
- *Most positive changes*: Site 342 (West Turtle Shoal: +14%), 256 (Dustan Rocks: +3.11%), and 382 (Cliff Green: +1.54%) — these are exceptions.
- **Widespread Decline**: Most stations (especially Cliff Green, Admiral, and Turtle) have seen substantial recent declines, ranging from ~-4% to -22%.
- **Some Resilience**: A few sites show upward trends, possibly due to local conservation or natural resistance.

[Note: To explore the full table for all the stations, go to the report link mentioned at the start of the report]

Implications

- **Unstable Coral Health**: Coral cover in the Florida Keys is not recovering reliably over time — there are temporary recoveries, but overall instability.
- **Localized Stress or Protection**: The mixed trends across sites suggest that local conditions (water quality, protection measures, human activity) may be driving differences.
- **Urgent Management Needs**: Stations with steep recent declines may be approaching thresholds beyond which recovery becomes difficult.

What Can We Do?

- **Targeted Monitoring**: Focus on declining stations like Admiral, Cliff Green, and Turtle — investigate local stressors (pollution, temperature spikes, disease).

- **Replicate Successes**: Study sites like West Turtle Shoal and Dustan Rocks where recent increases were noted — understand what's working.
- **Possible Local Interventions**: Strengthen marine protected areas (MPAs), reduce local runoff/pollutants, support coral restoration and outplanting where cover is low.

Species Composition

Octocoral Species (avg. num of colonies / year)

Species	Admiral	Alligator Deep	Alligator Shallow	Carysfort Deep	Dustan Rocks	Molasses Deep	Porter Patch	Sand Key Deep	Tennessee Shallow	Western Sambo Deep
Pseudopterogorgia americana	302	316	323	6	228	314	272	437	466	287
Gorgonia ventalina	489	55	347	1	119	60	98	106	150	68
Pseudopterogorgia bipinnata	8	21		537	1	217	4	13	1	92
Eunicea flexuosa	24	15	91		20	5	40	46	25	7
Not Slimy - P. americana	3	21	3		43	19	9	25	98	29
Pseudoplexaura porosa	17	3	5	2	28	3	25	6	9	1
Eunicea calyculata	4	6	14	1	4	3	9	36	4	3
P. bipinnata/P. kallos		2		4		34		2		9

Stony Coral Species (avg. num of colonies / year)

sciName	Cliff Green	Dustan Rocks	Eastern Sambo Shallow	Rawa Reef	Red Dun Reef	Smith Shoal	Thor	West Turtle Shoal	West Washer Women	Western Head
Siderastrea siderea	360	158	12	177	212	13	125	283	181	154
Porites astreoides	32	94	315	14	41	211	127	79	61	12
Stephanocoenia intersepta	210	82		63	135	7	80	128	130	114
Montastraea cavernosa	57	57	1	26	33	12	21	59	88	66
Oculina diffusa	10	1		1	1	105		2	1	19
Colpophyllia natans	16	7	1	23	15		7	22	21	11
Porites porites	2	5	7	5	2	2	36	50	11	
Undaria agaricites complex	4	4	8	6	6	29	4	24	8	2
Orbicella faveolata	12	6	2	8	9		1	4	12	7
Dichocoenia stokesii	8	16		4	6		3	7	1	9

What the Charts Show

- **Octocoral Table:** Displays average number of colonies per year for soft coral species across stations.
- **Stony Coral Table:** Shows similar data for hard coral species across different stations.

(Top 10 Stations and Top Species by colonies)

Key Insights

Octocorals:

- *Gorgonia ventalina* and *Pseudopterogorgia americana* are the most widespread and abundant species.
- Tennessee Shallow and Sand Key Deep host the highest species richness.
- Some species, like *P. bipinnata*, are highly localized (e.g., Carysfort Deep).
- Certain stations (e.g., Dustan Rocks, Molasses Deep) show low species diversity.

Stony Corals:

- *Siderastrea siderea* dominates most sites, especially Cliff Green and West Turtle Shoal.
- *Porites astreoides* is also common but more site-specific (e.g., Eastern Sambo, Smith Shoal).
- A few sites (e.g., West Washer Women, West Turtle Shoal) show broader species diversity.
- Rare species like *Orbicella faveolata* and *Dichocoenia stokesi* are sparsely distributed.

[Note: To explore the full table for all the stations, go to the report link mentioned at the start of the report]

Implications

- **Species Clustering**: Some species thrive only at specific sites, hinting at microhabitat preferences (e.g., depth, flow, light).
- **Shifting Composition Risk**: Dominance by fewer species (especially in hard stony corals) may lower ecosystem resilience to stress.
- **Octocorals vs. Stony Corals**: Octocorals appear more evenly distributed and diverse; stony corals show stronger species dominance patterns.

What Can We Do Now?

- **Preserve High-Diversity Sites** (e.g., Tennessee Shallow, West Washer Women) to maintain reef complexity.
- **Study Specialist Species** (e.g., *P. bipinnata* in Carysfort) for insights into niche conditions and stressors.
- **Monitor Rare Stony Coral Species** (e.g., *Orbicella faveolata*) closely — these may require targeted protection/restoration.

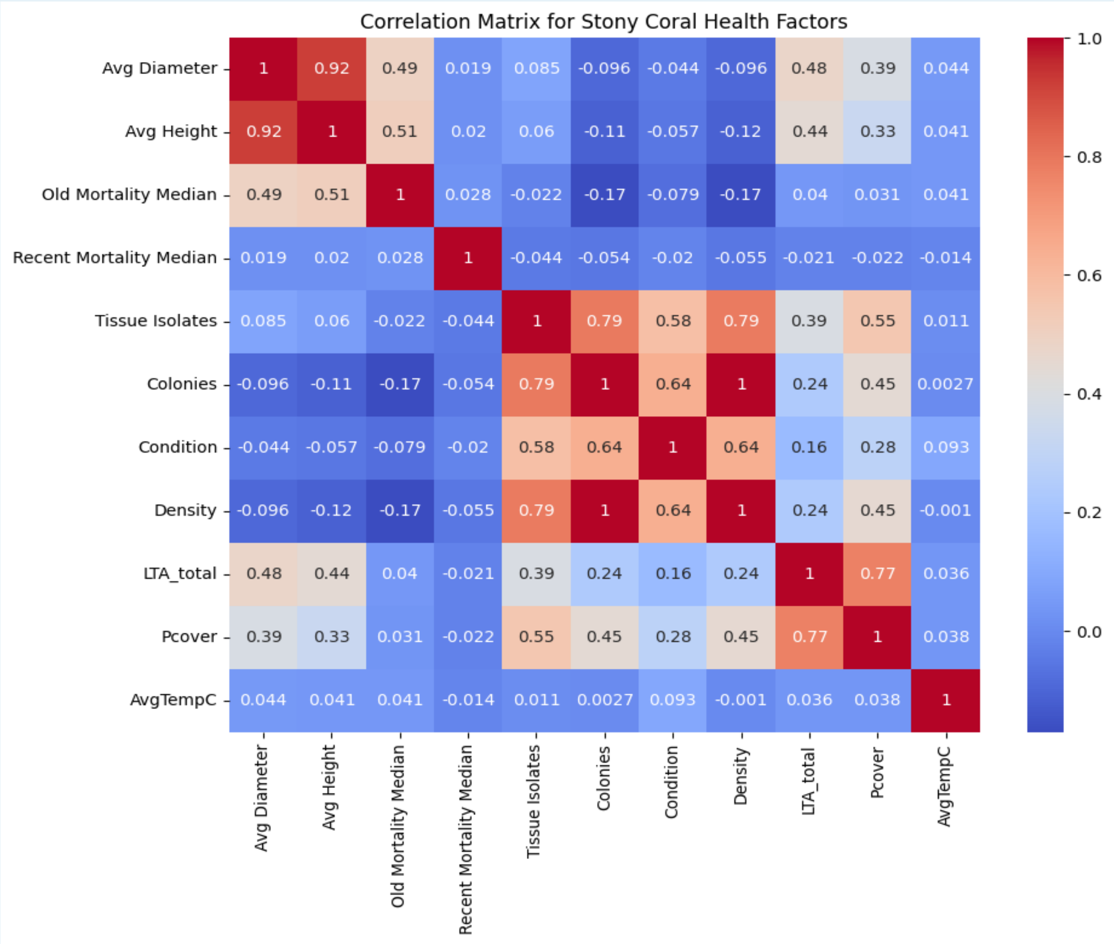
Future Outlook

Data preparation:

For the next section attributes were merged and joins from multiple tables for both the stony coral and the octocoral groups. Each record in the table consists of various measured values (percent cover, density, colonies with condition, etc.) for each species at a particular station on a day.

Key factors in coral health, density and richness

1. Stony Coral



What the Correlation Matrix Shows

The matrix displays how closely related each pair of variables is. Values range from:

- +1 = strong positive correlation
- 0 = no correlation
- –1 = strong negative correlation

Key Analyses

a) Coral Health

We'll focus on: Condition (diseased colonies), Old Mortality & Recent Mortality, Tissue Isolates

Notable correlations:

- **Tissue Isolates ↔ Condition (0.58)**
  → Corals with fragmented tissue are more likely to show visible disease — makes sense, as fragmentation is a **sign of degradation.**
- **Tissue Isolates ↔ Colonies (0.79)** and **↔ Density (0.79)**
  → In areas with more colonies and high density, fragmentation is more common — this could indicate **competition**, **crowding stress**, or **disease spread**.
- **Tissue Isolates ↔ LTA (0.39)**
  → Moderate positive correlation suggests that even fragmented colonies can still contribute meaningfully to total tissue area, though **not optimally.**
- **Tissue Isolates ↔ Old/Recent Mortality (very low: ~0)**
  → Fragmentation may precede mortality but isn't directly tied to death in the short term.

Conclusion:
A **high number of tissue isolates** signals **stress and disease presence**, especially in **high-density environments**. It's a key **early warning indicator** of declining coral health.

b) Colony Density

Focus on: Density, Colonies, Tissue Isolates, Condition

Strong relationships:

- **Density ↔ Colonies (1)** – expected.
- **Density ↔ Tissue Isolates (0.79)** – more corals → more fragmentation.
- **Density ↔ Condition (0.64)** – denser areas may face more disease.

Conclusion:
High coral density is a double-edged sword: it is supported by **more colonies**, but also increases **tissue fragmentation and disease risk**.

c) Species Richness and Cover

Focus on: Percentage cover (as a proxy for richness), Living Tissue Area (LTA), Colonies

- **Key correlations:**
    - **Pcover ↔ LTA_total (0.77)** – strong link: healthy coral tissue supports more cover and likely more species.
    - **Pcover ↔ , Density, Colonies (0.45)** and **↔ Tissue Isolates (0.55)** – moderate relationships.
    - **Pcover ↔ Condition (0.28)** – weak but present.

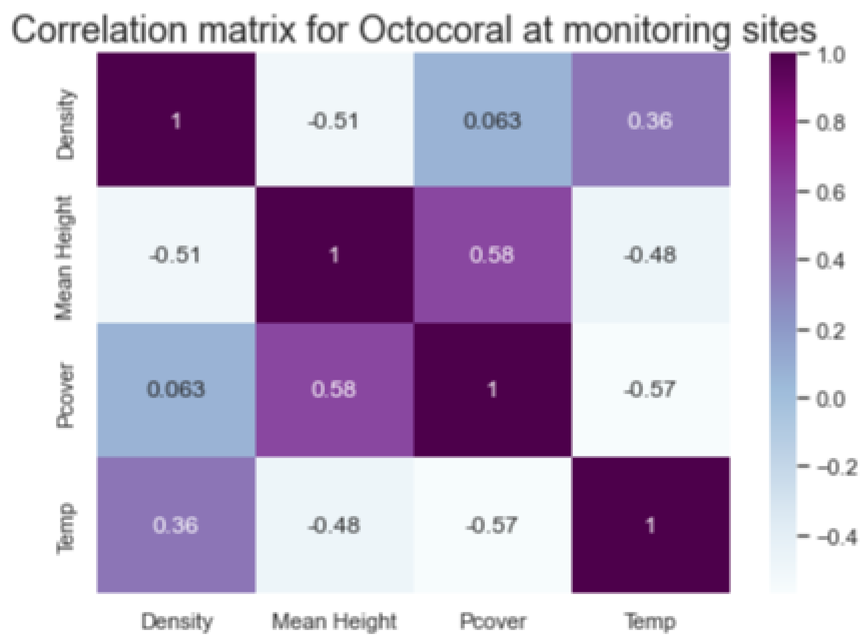
Conclusion:
High species richness correlates most strongly with **more continuous living tissue (LTA)** and **more colonies**. Fragmentation (tissue isolates) still contributes, but less efficiently.

Possible Actions

- **Monitor tissue isolates closely** — it's a sensitive early indicator of stress or disease before full mortality sets in.

- **Avoid over-densification in restoration** — crowded reefs may experience more fragmentation and health issues.
- **Promote continuous tissue growth** in coral outplanting to reduce fragmentation and boost resilience.

2. Octocoral



What the Chart Shows

This correlation matrix displays the relationships between four key octocoral measurements at monitoring sites: Density, Mean Height, Percent Cover (Pcover), and Average Temperature (Temp).

Key Insights

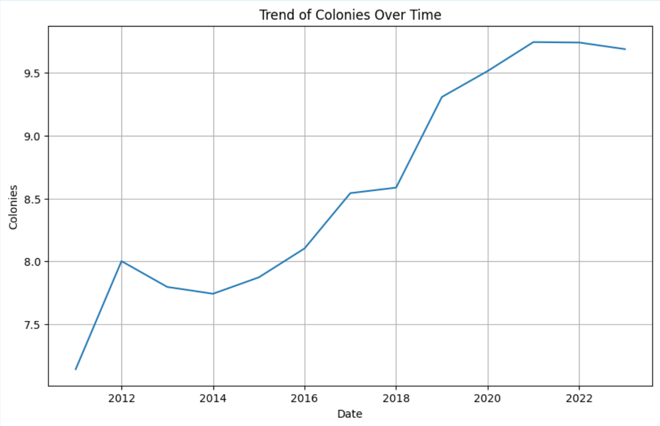
- **Height vs. Density Trade-Off**: There's a moderate negative correlation (-0.51) between octocoral density and mean height, suggesting corals grow either in **dense patches of shorter colonies** or as **taller, more widely spaced colonies**.
- **Temperature Effects**: Temperature shows a moderate positive relationship with density (0.36) but negative relationships with both mean height (-0.48) and percent cover (-0.57), indicating **warmer waters favour more numerous but shorter corals** with **less overall coverage**.
- **Height and Coverage Link**: Mean height and percent cover show a strong positive correlation (0.58), meaning **taller octocorals** tend to provide **more total coverage** of the reef surface.
- **Density Independence**: Octocoral density has almost no relationship with percent cover (0.063), revealing that **higher numbers** of corals **don't necessarily translate to greater reef coverage**.

Recommendations

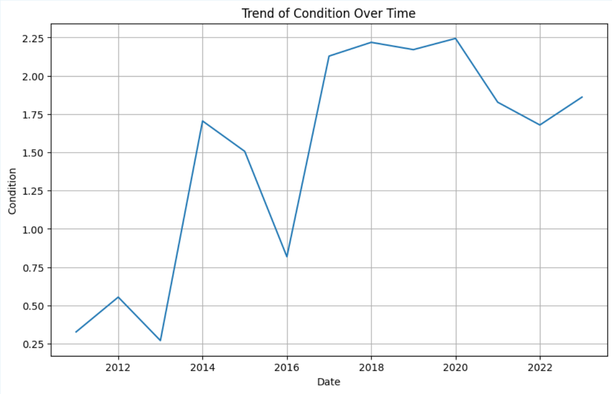
- **Target Protection**: Focus protection efforts on sites with taller octocorals and higher coverage, as these represent more developed, mature reef communities that may be more vulnerable to warming.
- **Temperature Management**: Where possible, prioritize cooling strategies for sites with taller octocorals, as these appear most negatively affected by temperature increases.
- **Site Selection**: When choosing new restoration sites, consider areas with moderate temperatures that can support a balance between coral density and height growth.

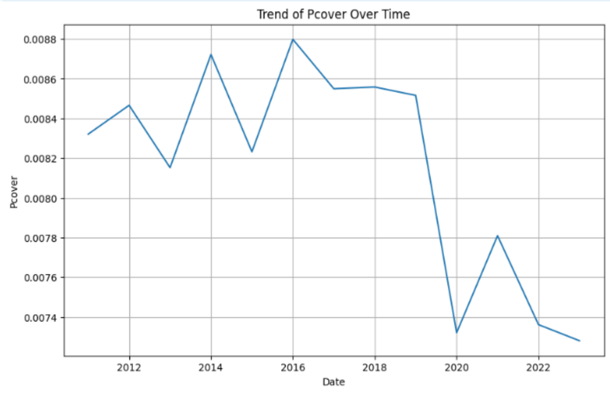
Indicators for declining population

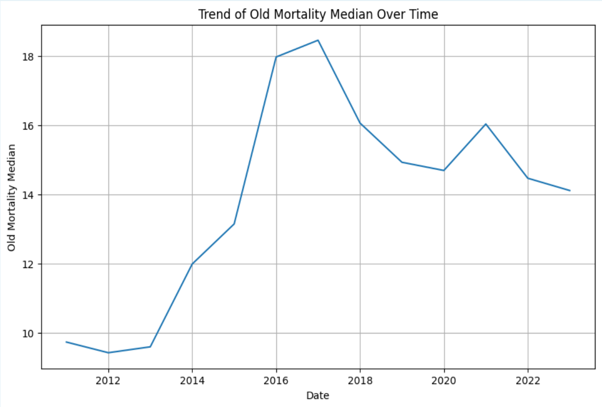
1. Stony coral



Average number of octocoral colonies per species at each station.







Trends for stony corals measures over the years.

What the Charts Show

These line charts depict the trend for stony*coral parameters* from 2011-2023: colony count, diseased colonies, precent cover and mortality across monitoring sites in the Florida Keys.

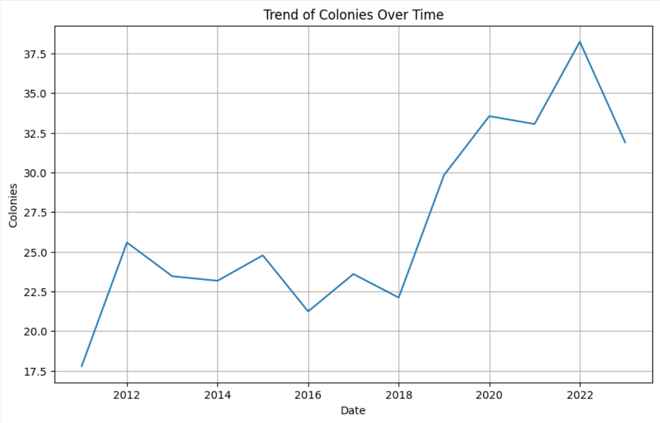
Key Insights

- **Increase in Coral Diseases-** A sudden rise in the number of colonies with disease or abnormal conditions can lead to population decline or slow growth (also indicated by correlation matrix earlier (0.64) between diseased colonies and total colonies).
- **Declining Percent Cover Despite Stable Colony Count** - When percent cover (Pcover) decreases while colony numbers remain stable or increase, it indicates smaller or less healthy colonies.
- **Higher mortality rates**- The increase in mortality rate is always an indicator of upcoming population decline or growth in case of decreasing mortality.

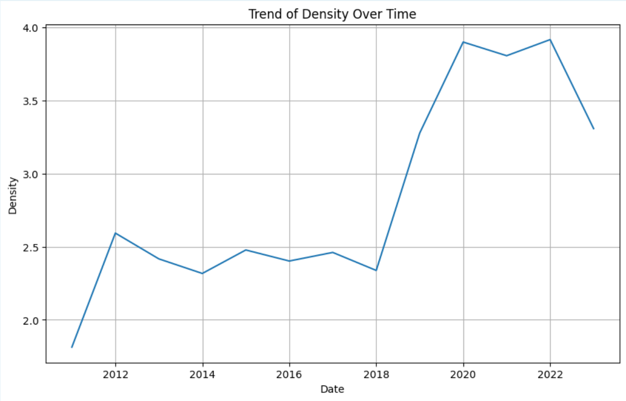
What Can We Do?

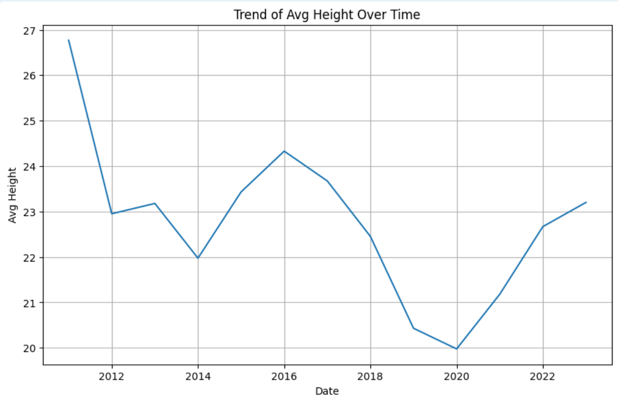
- Implement rapid quarantine zones around diseased colonies and apply targeted recovery treatments.
- Establish coral fragment nurseries to enhance tissue growth and supplement corals with beneficial microbes to improve tissue health.
- Develop early-stage coral rescue protocols before complete mortality occurs.

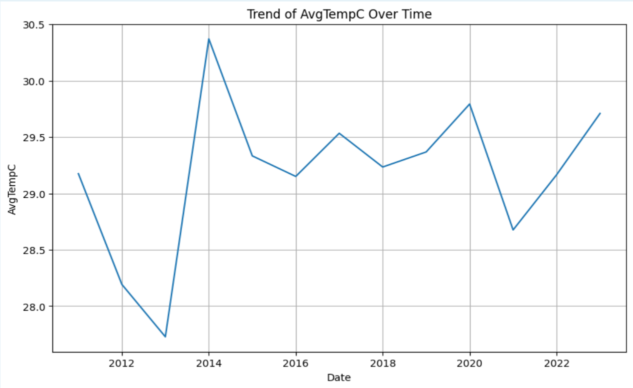
2. Octocoral



Average number of octocoral colonies per species at each station.







Trends for octocorals measures (height in cm and density) and water temperature (degree celsius) over the years.

What the Charts Show

These four line charts track key *octocoral metrics* from 2011-2023: average height, colony count, density, and water temperature (AvgTempC) across monitoring sites in the Florida Keys.

Key Insights and Early Indicators

- **Temperature spikes precede height reduction** - The 2014 temperature peak (~30.3°C) was followed by a **drop in coral colonies** from 2015-2018. A similar pattern around 2020 for temperatures.
- **Height reduction precedes population changes** - The **steady decline in coral height** from 2016-2020 occurred before the **dramatic increase in colony count** and density (2018-2020).
- **Recent height recovery with population decline** - Since 2020**, height** has been **recovering** while **colony count and density** have recently **decreased**, suggesting a quality-vs-quantity dynamic.

What Can we Do?

- **Use temperature as an early warning system** - Monitor water temperature continuously, with alerts when approaching 30°C, as **temperature spikes** appear to **precede** negative impacts on **coral population**.
- **Track coral height as a leading indicator** - Implement regular height measurements as decreases in average height appear to signal **stress** before population-level changes occur.
- **Create an integrated early warning index** - Combine temperature, height, and rate-of-change metrics into a single monitoring tool that can trigger tiered response protocols before significant population declines occur.

Modelling evolution of coral reefs over next 5 years

Data preparation:

- Attributes/features were merged and joins from multiple tables for both the stony coral and the octocoral groups. Each record in the table consists of various **measured values (percent cover, density, colonies with condition, etc.) for each species at a particular station on a day**.
- The datasets were first **cleaned by removing null or incomplete records** to ensure model reliability.
- Categorical features such as **habitat** and **subregion** were **encoded numerically** to be suitable for machine learning models.
- Based on prior correlation analysis, the following variables were selected as **key predictors** of coral colony numbers:
    - Stony coral: Tissue Isolates, Colonies with some condition, Density, Living Tissue Area, Percent Cover, and Average Temperature
    - Octocoral: Average Height, Density, Average Temperature

Machine Learning Models

Following machine learning models were trained using the cleaned and feature-selected dataset:

a) Random Forest Regressor (for stony coral and octocoral)

- A tree-based ensemble model used to capture **nonlinear relationships** between coral health factors and colony numbers.
- Well-suited for structured ecological data and handles both variance and feature interaction effectively.
- Parameters: n_estimators = 300; remaining default settings from the library used.

b) LSTM (Long Short-Term Memory) Neural Network (for stony coral)

- A deep learning model tailored for **time series prediction**, capable of learning long-term dependencies.

- Trained on **sequential data**, allowing it to understand temporal patterns in how environmental and biological factors affect colony numbers.

- Parameters: time steps (lookback period for a prediction): 30; epochs: 50; batch size: 32; optimizer: adam; trainable parameters: approx. 30, 000.

c) XGBoost Regressor (for octocoral)

- A gradient boosting model that offers **high accuracy** on tabular data and handles missing patterns or variable interactions well.
- Preferred here due to its **robust performance** with smaller datasets and strong predictive power.
- Parameters: n_estimators = 100; learning rate: 0.1; remaining default settings from the library used.

For both models, the **target variable was the number of colonies**, and predictions were generated for **2024–2028** using simulated future values (based on historical trends) of the input features.

Time Series Forecasting Models

To complement ML predictions, two traditional statistical time series models were used, relying solely on **historical trends of colony counts (2011–2023) and no extra variables**:

a) ARIMA (Auto Regressive Integrated Moving Average)

- Captures **trend and seasonality** in coral colony data using autoregressive and moving average components.
- Requires no external features; forecasts were based solely on past colony values.

b) Exponential Smoothing

- A model that places **more weight on recent observations**, effectively smoothing fluctuations over time.

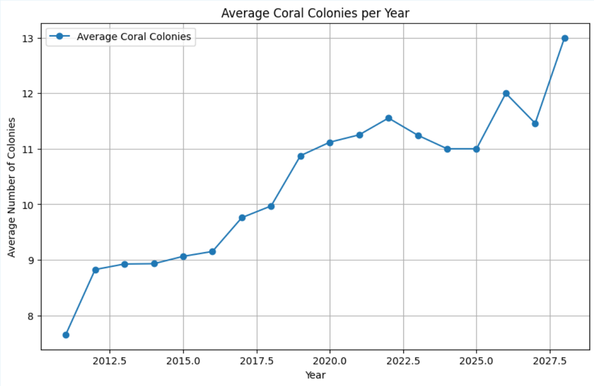
- Used for short-term forecasting of colony trends under the assumption of consistent historical patterns.

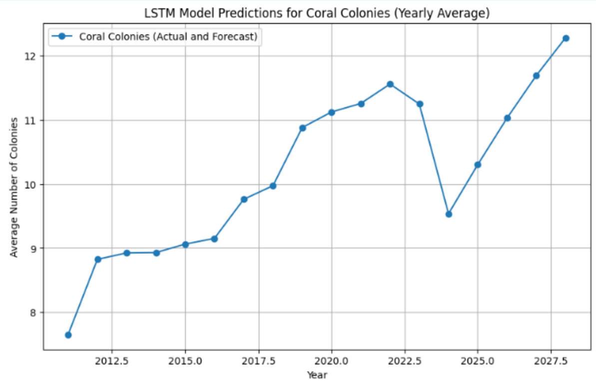
Simulation and Prediction

- For the ML models, **future environmental and reef health conditions** were simulated based on observed trends from previous years.
- All four models were then used to **predict coral colony numbers** annually from **2024 to 2028**, offering both factor-driven and trend-driven perspectives on reef evolution.

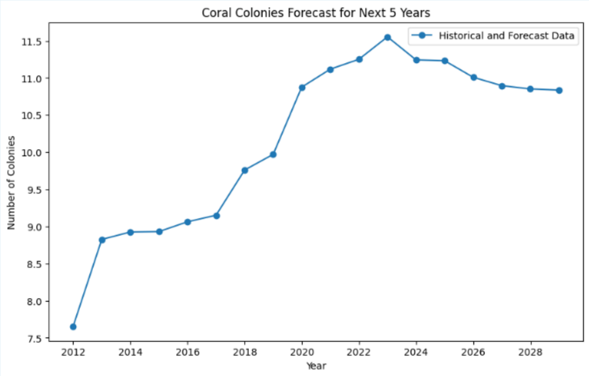
Results

1. Stony coral

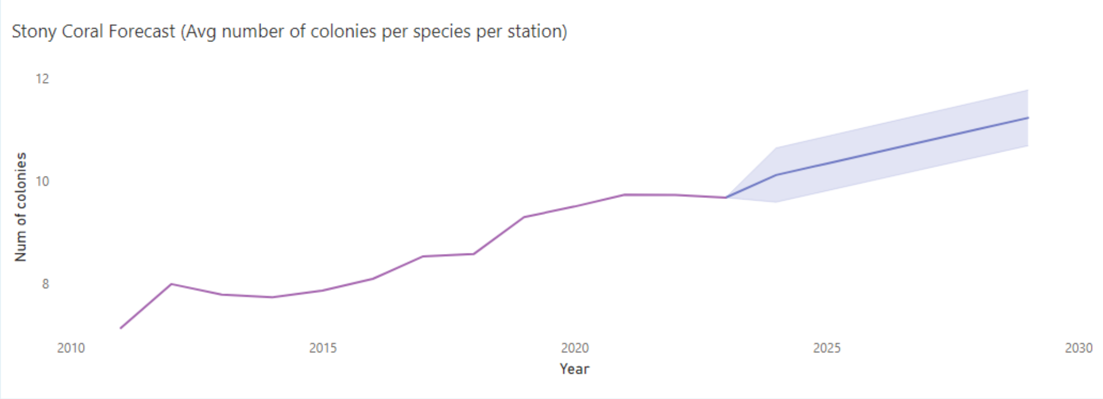




Random Forest predictions LSTM predictions



ARIMA forecast



Exponential Smoothing Forecast

Model-wise summary

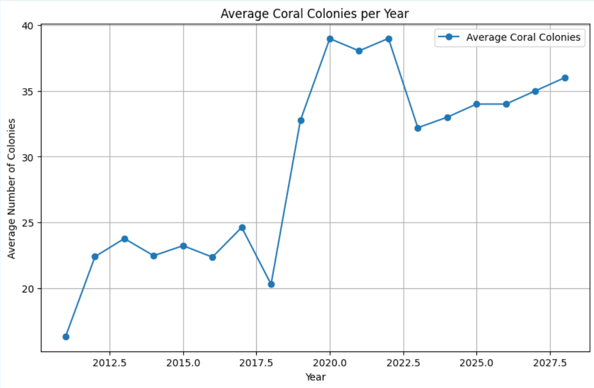
Model	Forecast Pattern (2024–2028)	Key Insights
Random Forest	Steady increase from ~11 to **13 colonies per species / station** by 2028.	Indicates optimistic growth assuming continued ecological trends.
LSTM Neural Network	Initial **dip in 2024**, followed by a **strong rebound** to >12 colonies.	Captures short-term stress and recovery cycles.
ARIMA	Mild **decline then flattening** around ~11 colonies.	Suggests a natural plateau without external influence.
Exponential Smoothing	**Gradual rise** to just under 11 colonies by 2028.	Follows recent upward trends with moderate optimism.

Conclusions

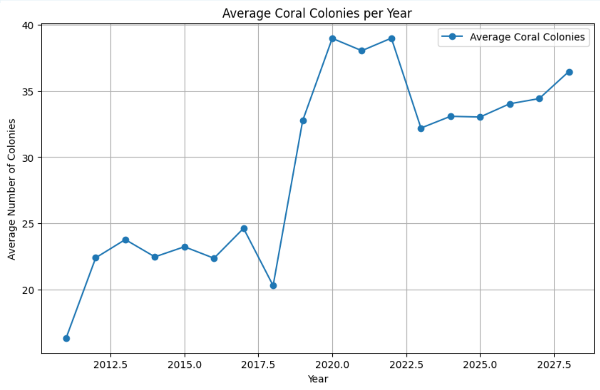
- Stony Coral colonies are expected to **remain stable or increase** over the next five years.
- **Models using ecological predictors (RF, LSTM)** offer more **optimistic scenarios**, highlighting the importance of continued reef health improvements (e.g., low fragmentation, higher tissue area).
- **Trend-based models (ARIMA, ES)** provide **conservative forecasts**, valuable for understanding outcomes under “no-change” conditions.

- The **diversity of modelling approaches** builds confidence in predictions — showing that **even in varying scenarios, no sharp declines are expected**.
- There are however other accompanying factors like percent cover and possible diseased conditions (as discussed in previous section on indicators) they are also crucial for overall coral health

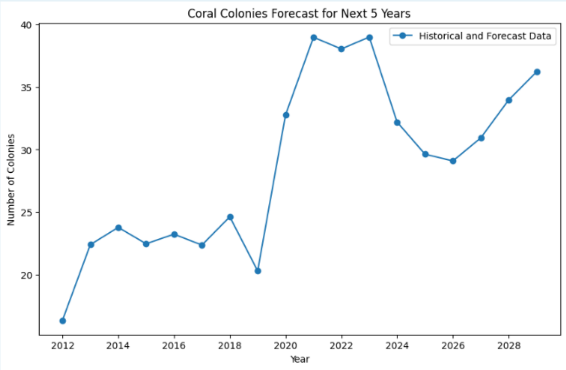
2. Octocoral



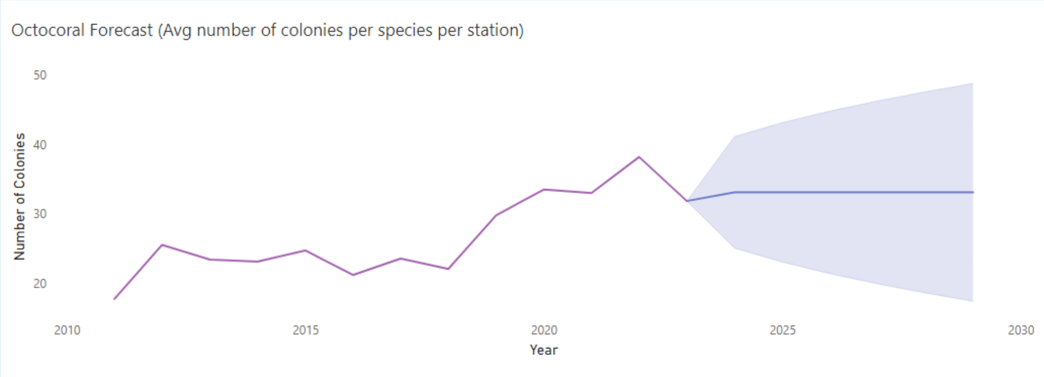
Random Forest prediction



XG Boost prediction



ARIMA forecast



Exponential Smoothing forecast

Model-wise summary

Model	Forecast Pattern (2024–2028)	Key Insights
Random Forest	Mild growth from ~32 to 36 colonies by 2028.	Indicates gradual recovery post-2023 plateau.
XGBoost Regressor	Similar to RF: stable trend followed by steady increase.	Suggests resilience and moderate regrowth in octocoral numbers.
ARIMA	Dip in 2024–2026, followed by a strong rebound by 2028.	Reflects cyclic variation, possibly echoing past disturbance.
Exponential Smoothing	Predicts a flat central trend (~33 colonies) with uncertainty band (25–48).	Highlights stable base trend but high variability in outcomes.

Conclusions

- All models indicate that octocoral populations are likely to remain stable or improve modestly over the next five years.
- No model forecasts a major collapse, even after recent fluctuations post-2022.
- Models based on ecological variables (RF, XGBoost) reflect resilience and regrowth, especially with improved reef conditions.
- Time-series models (ARIMA, ES) highlight possible short-term dips but agree on eventual stabilization or rebound.
- The wide uncertainty band in exponential smoothing possibly due to limited past data.
- Due to limited number of variables for octocoral, there may be other factors that can still impact octocoral growth and health.

Conclusion

In this report, I set out to better understand the current state and future of coral reefs in the Florida Keys by analyzing long-term monitoring data. My approach was structured yet exploratory, driven by visuals, patterns, and grounded ecological reasoning. Through a combination of visual analysis, machine learning, and time series forecasting, I've addressed key questions related to coral reef health, diversity, and resilience.

I began with a deep exploratory analysis of both stony and octocorals, where I examined how stony coral cover, species richness, and tissue area have changed across time and space. I also explored how octocoral density has evolved across regions and habitats. These initial insights revealed important spatial differences and long-term shifts in coral composition — with patch reefs generally favoring stony corals, and offshore habitats better supporting octocorals.

Next, I focused on uncovering relationships within the data. By evaluating the link between coral density and species richness at site level, and further examining how octocoral density is affected by temperature, I was able to identify key environmental drivers and early stress indicators. I then compared coral reef parameters — including density, richness, and cover — across stations, revealing that trends vary significantly by location. Some high-density reefs are showing recent decline, while others are improving, underscoring the need for site-specific management.

To project where reefs may be headed, I built models to forecast coral colonies through 2028. For stony corals, I applied Random Forest, LSTM, ARIMA, and Exponential Smoothing models, while for octocorals, I used Random Forest, XGBoost, ARIMA, and Exponential Smoothing due to limited data. These models provided multiple perspectives — from ecological factor-driven to trend-based — helping me simulate realistic future scenarios under different assumptions.

Throughout the report, I've highlighted key insights from each chart, followed by implications and practical recommendations. This process allowed me to address the core objectives of the analysis: identifying trends, understanding ecological relationships, comparing reef conditions across regions, and forecasting the potential evolution of coral populations.

Ultimately, this analysis offers a data-informed view of both risk and opportunity. While some sites show signs of stress, others are improving — and understanding these dynamics can help guide smarter, localized conservation strategies in the years to come.