Mission: Iconic Reefs and National Coral Reef Monitoring Program Benthic Analyses

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2025-12-15

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1 Introduction

Mission: Iconic Reefs (M:IR) is a multi-institutional initiative designed to restore ecological function and biodiversity across key reef sites in the Florida Keys. Led by NOAA in collaboration with federal, state, academic, institutional, and non-profit partners, M:IR targets nearly three million square feet of reef at seven key coral reefs in the Florida Keys National Marine Sanctuary (FKNMS): Carysfort (North and South), Horseshoe Reef, Cheeca Rocks, Sombrero Reef, Newfound Harbor, Looe Key, and Eastern Dry Rocks (Figure 1). Across these reefs, M:IR aims to restore coral cover to an average of 25% across the seven sites – an inititaitve unparalleled in scope and scale that will require hundreds of thousands of coral restoration outplants and over a decade of phased intervention.

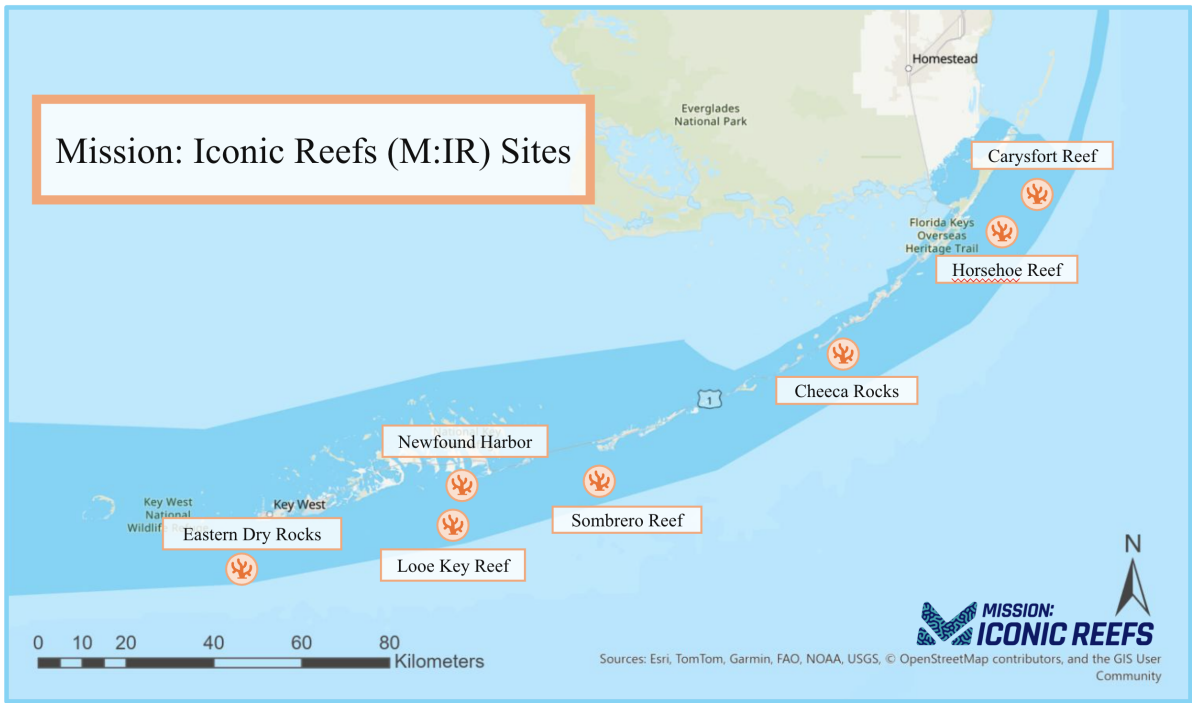


Figure 1: Map of the Florida Keys showing the sites of Mission: Iconic Reefs

These Iconic reefs were selected for restoration due to their diversity in reef types, levels of anthropogenic disturbances, initial coral cover, connectivity to other habitat types, geographic distribution, and cultural significance. Restoration progress at these reefs is informed by ongoing monitoring of coral reef benthic communities and coral populations at M:IR sites using a range of metrics, such as coral cover, size structure, mortality prevalence, and diversity. Such multi-metric monitoring is essential to evaluating whether current restoration practices are effective in establishing and maintaining a healthy coral reef, as restoration 'success'

encompasses a range of ecological and management metrics rather than a single measurement (e.g., coral cover) (Goergen et al., 2020).

In addition to monitoring within the M:IR reefs, it is also important to assess the surrounding reefs in the Florida Keys to interpret restoration progress. The National Coral Reef Monitoring Program (NCRMP), which conducts standardized reef assessments across the Florida Keys on a biennial basis, provides a solid framework for comparison. To align with this program, the M:IR team applied NCRMP survey methodology within its Iconic Sites in 2022 and 2024 to complement NCRMP surveys. These surveys focused on shallow (<30 m), hard-bottom reef habitats, using a stratified-random, one-stage design within 50 m × 50 m grid cells to ensure representative sampling across depth and rugosity strata (Ault et al., 2021). The survey design ensures that survey sites are allocated by cross-shelf zone, rugosity type, and depth strata, with sites distributed around the Florida Keys from nearshore to offshore to a maximum depth of 30 m. The NCRMP sample grid was spatially joined with the seven distinct M:IR zones (Figure 1). Survey sites were proportionally allocated within NCRMP strata to maintain consistent representation across habitats.

Corals and benthic communities were monitored using two different NCRMP surveys: the Benthic Community Assessment survey and the Coral Demographics survey (NOAA CRCP 2022a, 2022b, 2024a, 2024b). The Benthic Community Assessment survey includes: 1) benthic cover (%) estimates along a 15-m transect with a line point intercept method, 2) presence/absence of Endangered Species Act (ESA)-listed coral species (NOAA National Marine Fisheries Service, 2014), 3) abundance of key macroinvertebrates, and 4) reef rugosity measurements within a 15 m x 2 m belt-transect area (NOAA CRCP 2022a, 2024b). At the same site, coral demographics were surveyed within a 10 m x 1 m belt-transect area (NOAA CRCP 2022b, 2024b). NCRMP coral demographic survey data were combined with complementarily allocated survey data from Florida Fish and Wildlife Conservation Commission's Disturbance Response Monitoring (DRM). In all coral demographics surveys, all live coral colonies □ 4 cm were counted, identified to species, measured to the nearest centimeter, and estimates were made of the proportion per colony of any present mortality (recent or old), disease (absent, present: slow, fast), and/or bleaching (none, total, partial, paling). Only live coral colonies were included in the survey; dead colonies with 100% mortality were not surveyed (e.g., colonies killed by coral disease). Juvenile corals (< 4 cm) were reported for species richness only and were not included in counts, size measurements, or estimates of condition (NOAA CRCP 2022b); in 2024, juveniles of select coral species were counted (NOAA CRCP 2024b). In 2024, NCRMP benthic surveys also included large area imaging (LAI) collected at most survey sites; analyses of these LAI data are in progress and not presented here.

To allow for direct comparisons of benthic communities inside the M:IR restoration areas with control, non-restored areas across the Florida Keys reefs, the NCRMP dataset was restricted to strata types and depth zones (0-12 m) found within M:IR sites. Statistical comparisons were conducted using a two-tailed t-test between M:IR and NCRMP estimates for each survey year (2022 or 2024) and between years for M:IR and NCRMP. This report focuses on coral

populations and benthic community metrics; a separate report can be found for fish population assessments (Blondeau et al., 2025).

NCRMP analyses scripts for corals and benthic communities are open source and available at NCRMP Benthic R package (Groves et al., 2025).

2 Benthic Survey Effort

In 2022, a total of 584 surveys occurred (Table 1) across 403 sites (Viehman et al., 2023). In 2024, 771 surveys occurred across 542 sites (Grove et al., in prep).

Table 1. Number of demographic (Demo) and benthic community assessment (BCA) surveys completed by M:IR, NCRMP, and DRM in 2022 and 2024.

	M:IR		NCRMP		DRM
Year	*Demo*	*BCA*	*Demo*	*BCA*	*Demo*
2022	90	89	95	92	218
2024	100	100	129	129	313
Total	***379***		***445***		***531***

2.1 Coral Demography

For the purpose of this comparison, surveys were divided into two groups: inside M:IR and outside. Almost all of the inside (M:IR) surveys were completed by the M:IR team; however, if an NCRMP or DRM sample happened to fall within the boundaries of an M:IR iconic reef, it was added to the inside group. The inverse occurred if an M:IR survey happened to fall outside the M:IR boundary.

Table 2. The number of coral demographic sites sampled inside and outside M:IR areas in each stratum (includes DRM data).

Study Area	Strata	Strata Description	2022	2024
Inside (M:IR)	CFK01	Inshore reef, all relief types and depths	12	10
Inside (M:IR)	CFK02	Mid-channel patch reef, all relief types and depths	16	12
Inside (M:IR)	CFK03	Offshore patch reef, all relief types and depths	7	11
Inside (M:IR)	CFK04	Forereef, low relief, shallow (0-6 m)	–	4

(continued)

Study Area	Strata	Strata Description	2022	2024
Inside (M:IR)	CFK05	Forereef, high relief, shallow (0-6 m)	25	38
Inside (M:IR)	CFK06	Forereef, low relief, mid-shallow (6-12 m)	4	12
Inside (M:IR)	CFK07	Forereef, high relief, mid-shallow (6-12 m)	34	34
Outside (NCRMP + DRM)	CFK01	Inshore reef, all relief types and depths	27	24
Outside (NCRMP + DRM)	CFK02	Mid-channel patch reef, all relief types and depths	79	109
Outside (NCRMP + DRM)	CFK03	Offshore patch reef, all relief types and depths	37	42
Outside (NCRMP + DRM)	CFK04	Forereef, low relief, shallow (0-6 m)	4	31
Outside (NCRMP + DRM)	CFK05	Forereef, high relief, shallow (0-6 m)	21	45
Outside (NCRMP + DRM)	CFK06	Forereef, low relief, mid-shallow (6-12 m)	19	33
Outside (NCRMP + DRM)	CFK07	Forereef, high relief, mid-shallow (6-12 m)	60	61

2.2 Benthic Composition

Disturbance Response Monitoring (DRM) only performs coral demographic surveys (Table 1) and therefore DRM surveys are not included in the summary of Benthic Community Assesement surveys (Table 3).

Table 3. Number of Benthic Community Assessment (BCA) sites sampled inside and outside M:IR areas in each stratum.

Study Area	Strat	Strat Description	2022	2024
Inside (M:IR)	CFK01	Inshore reef, all relief types and depths	8	10
Inside (M:IR)	CFK02	Mid-channel patch reef, all relief types and depths	12	12
Inside (M:IR)	CFK03	Offshore patch reef, all relief types and depths	7	8
Inside (M:IR)	CFK04	Forereef, low relief, shallow (0-6 m)	–	3
Inside (M:IR)	CFK05	Forereef, high relief, shallow (0-6 m)	24	33
Inside (M:IR)	CFK06	Forereef, low relief, mid-shallow (6-12 m)	4	9
Inside (M:IR)	CFK07	Forereef, high relief, mid-shallow (6-12 m)	32	28
Outside (NCRMP)	CFK01	Inshore reef, all relief types and depths	10	9
Outside (NCRMP)	CFK02	Mid-channel patch reef, all relief types and depths	21	13
Outside (NCRMP)	CFK03	Offshore patch reef, all relief types and depths	9	8
Outside (NCRMP)	CFK04	Forereef, low relief, shallow (0-6 m)	–	6
Outside (NCRMP)	CFK05	Forereef, high relief, shallow (0-6 m)	7	9
Outside (NCRMP)	CFK06	Forereef, low relief, mid-shallow (6-12 m)	9	7
Outside (NCRMP)	CFK07	Forereef, high relief, mid-shallow (6-12 m)	10	28

3 Benthic Community Composition

Temporal trends in benthic cover of functional groups such as coral and macroalgae cover provide information on changes to the benthic community composition over time.

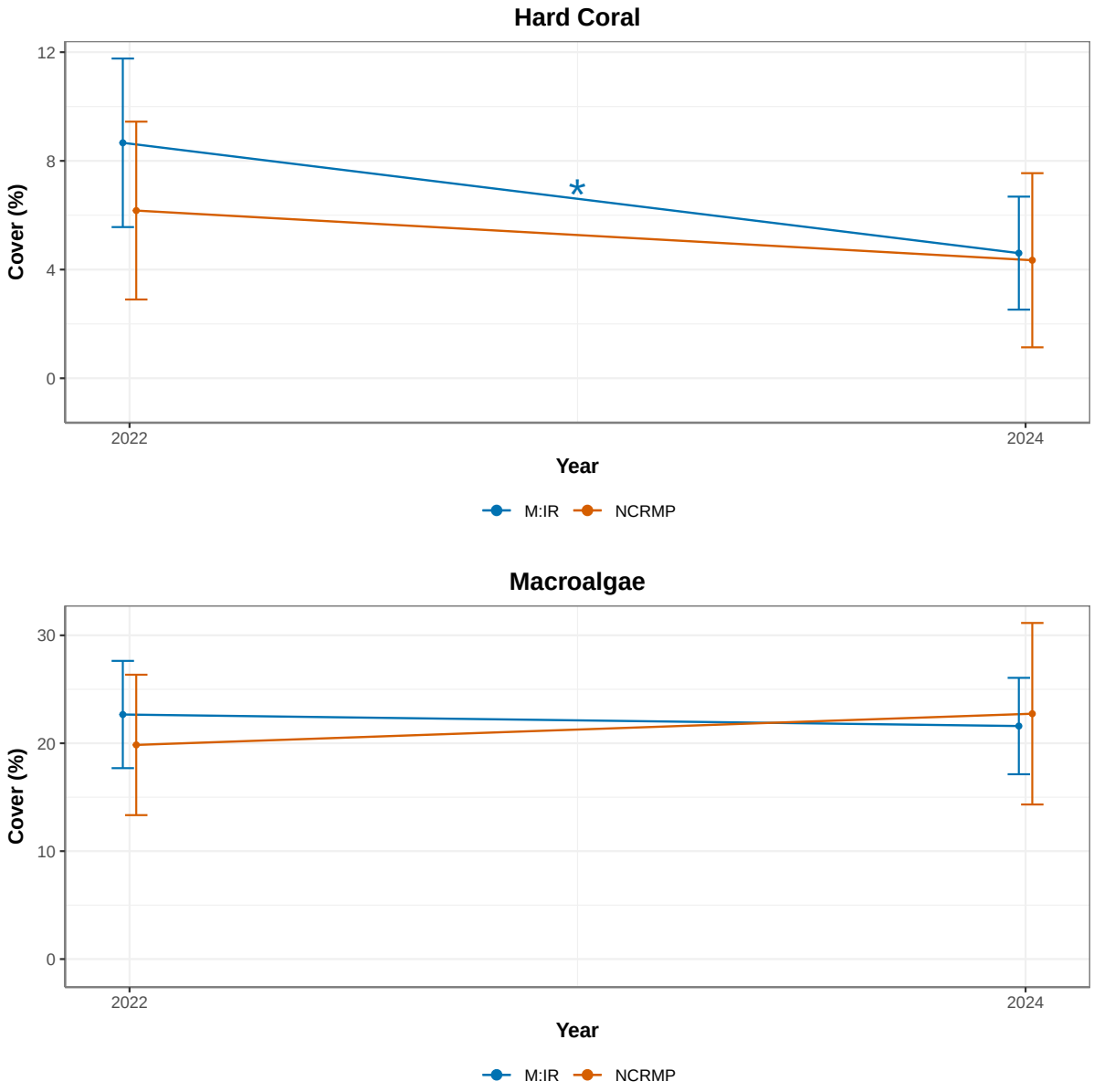
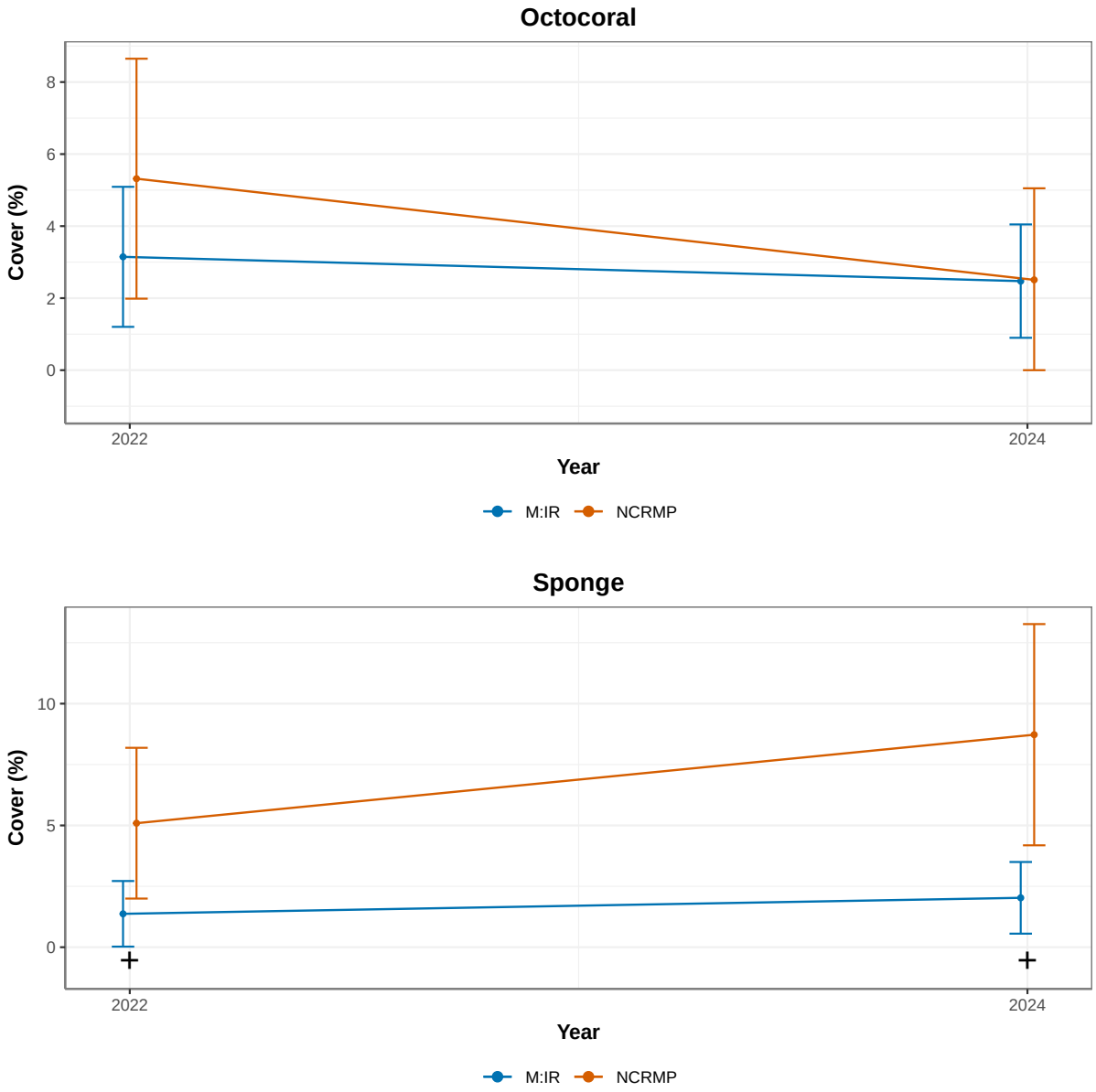


Figure 2. Cover estimates for main benthic groups inside and outside M:IR areas for 2022 and 2024. A black plus (+) indicates a significant difference between groups in that survey year (i.e., 2022 or 2024). A colored asterisk (*) indicates significance difference between years for the given group (i.e., M:IR or NCRMP).



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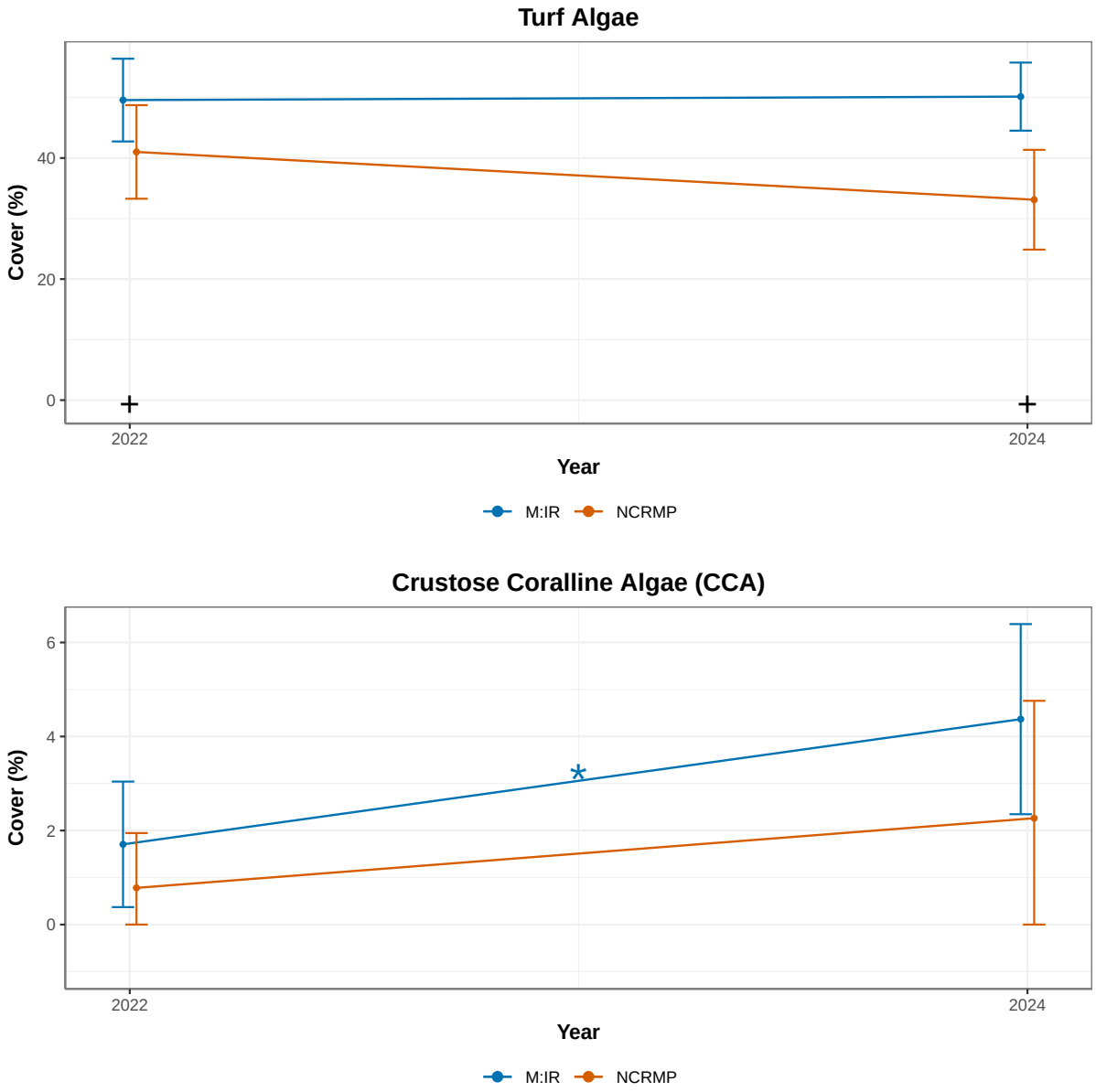

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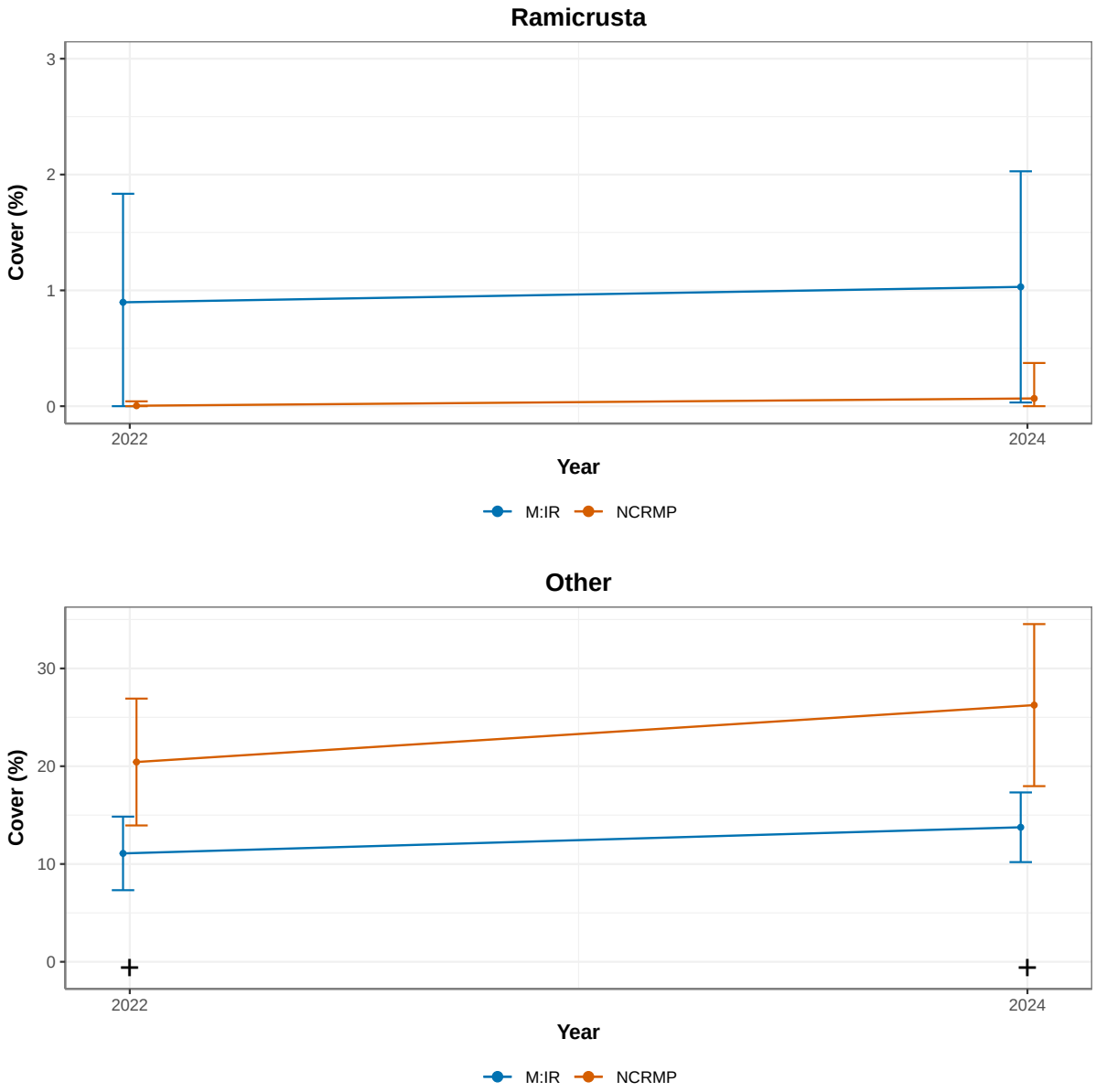

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4 Coral Demography

Although several metrics reported here encompass all observed coral species, ten focal species are highlighted as particularly important to M:IR's goal: *Acropora palmata*, *Acropora cervicornis*, *Colpophyllia natans*, *Dendrogyra cylindrus*, *Dichocoenia stokesii*, *Diploria labyrinthiformis*, *Meandrina meandrites*, *Montastraea cavernosa*, *Pseudodiploria clivosa*, and *Pseudodiploria strigosa*. These species have experienced drastic population declines and are targeted for restoration at the M:IR sites. Specifically, most were severely affected by White Band Disease (*Acropora* spp.) or Stony Coral Tissue Loss Disease (SCTLD).

The following table summarizes the number of observations across all strata and survey years of each focal species and identifies the most abundant species encountered.

Table 4. Number of colonies observed for focal M:IR species and the most commonly encountered non-focal species in 2022 and 2024.

Species	Colonies in 2022	Colonies in 2024
Siderastrea siderea	3,868	5,618
Porites astreoides	2,657	2,132
Stephanocoenia intersepta	1,345	1,534
Agaricia agaricites	884	237
Porites porites	776	558
**Montastraea cavernosa*	437	645
Orbicella faveolata	266	237
Orbicella annularis	211	156
Siderastrea radians	182	328
Porites furcata	160	77
Porites divaricata	118	100
**Dichocoenia stokesii*	106	137
**Colpophyllia natans*	103	76
Solenastrea bournoni	79	113
**Acropora cervicornis*	74	13
**Diploria labyrinthiformis*	50	65
**Pseudodiploria strigosa*	50	46
Eusmilia fastigiata	45	75
**Pseudodiploria clivosa*	23	31
**Acropora palmata*	14	0
**Meandrina meandrites*	5	11

4.1 Focal Species

The stratified random surveys are designed to optimize sampling efficiency and provide high precision estimates of coral population metrics at relatively low sample sizes (Smith et al., 2011). The effectiveness of restoration can be quantified by comparison of these metrics between M:IR sites and similar habitats outside these restoration areas.

The following figures for these metrics are grouped by each focal species. Significant statistical differences using a two-tailed t-test are indicated for differences between survey years (2022 vs. 2024) and between areas (M:IR vs. NCRMP) for density, old mortality, and mean colony size.

Acropora cervicornis

Colony density, mortality, size, and size class distribution (2022 vs. 2024)

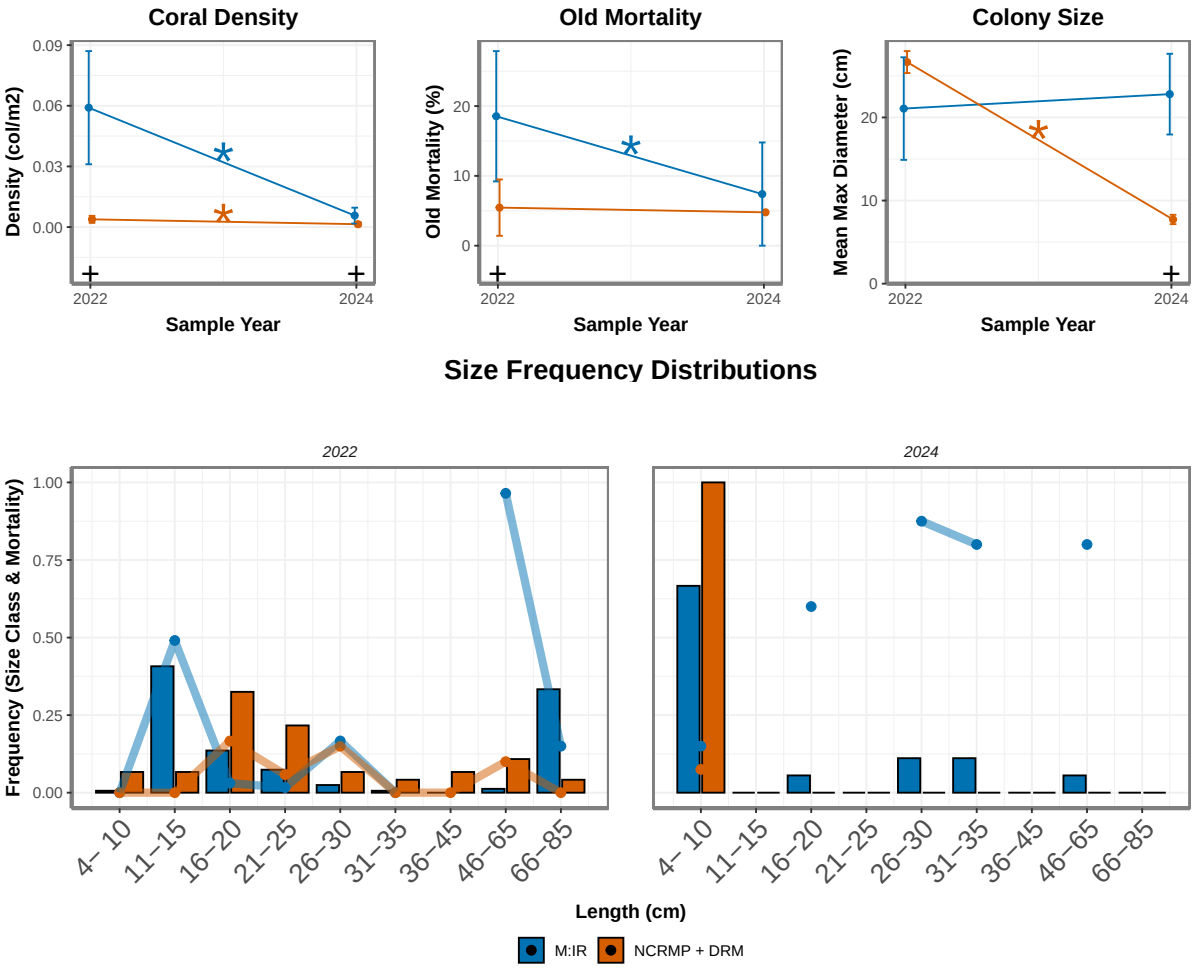
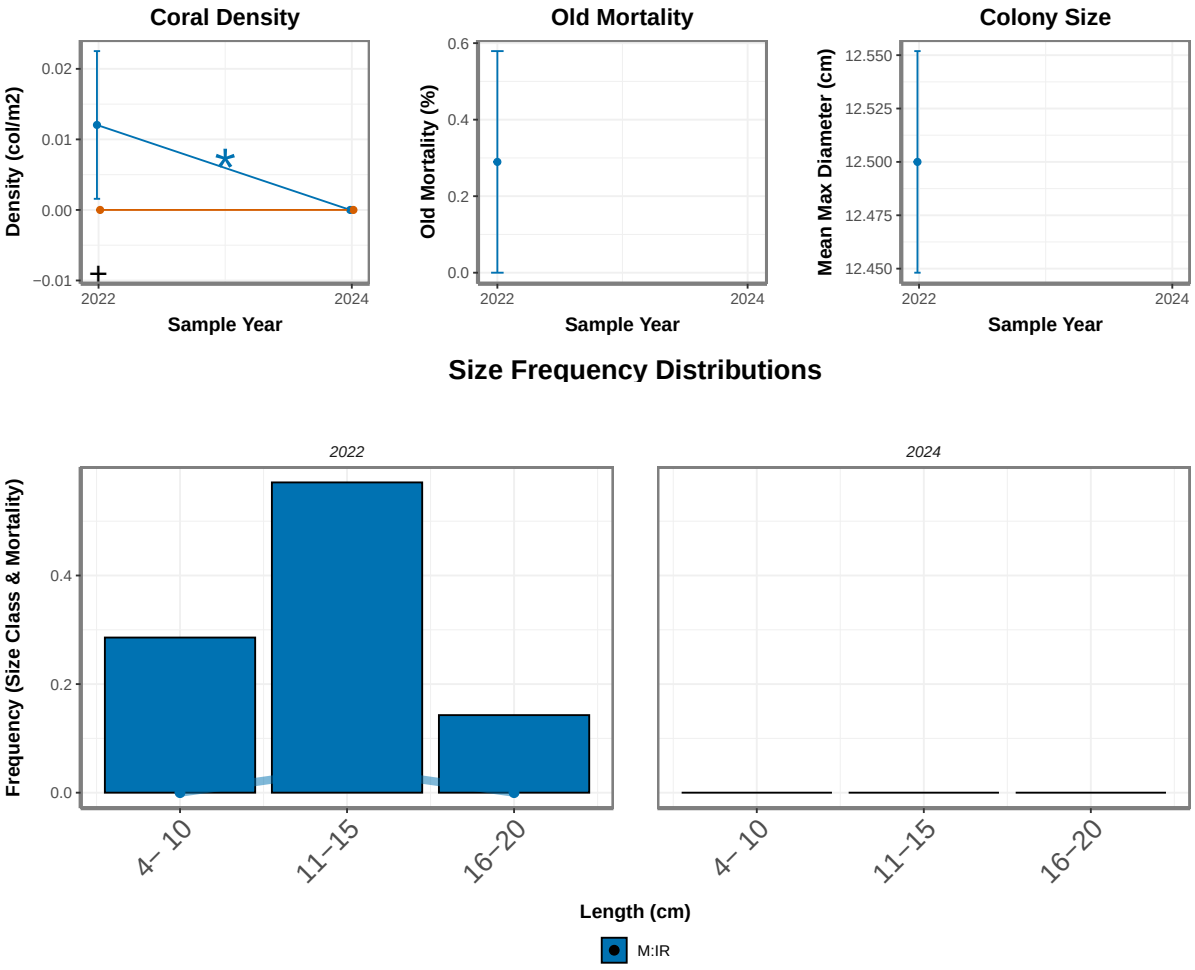


Figure 3. Coral density, old mortality, colony size, and size frequency distribution for focal M:IR species across sample years (2022 and 2024) and survey types (M:IR and NCRMP + DRM). A black plus (+) indicates a significant difference in cover estimates between groups in that survey year (i.e., 2022 or 2024). A colored asterisk (*) indicates significance between years for the given group (i.e., M:IR or NCRMP). Note: Y axis bounds vary by species.

Acropora palmata

Colony density, mortality, size, and size class distribution (2022 vs. 2024)



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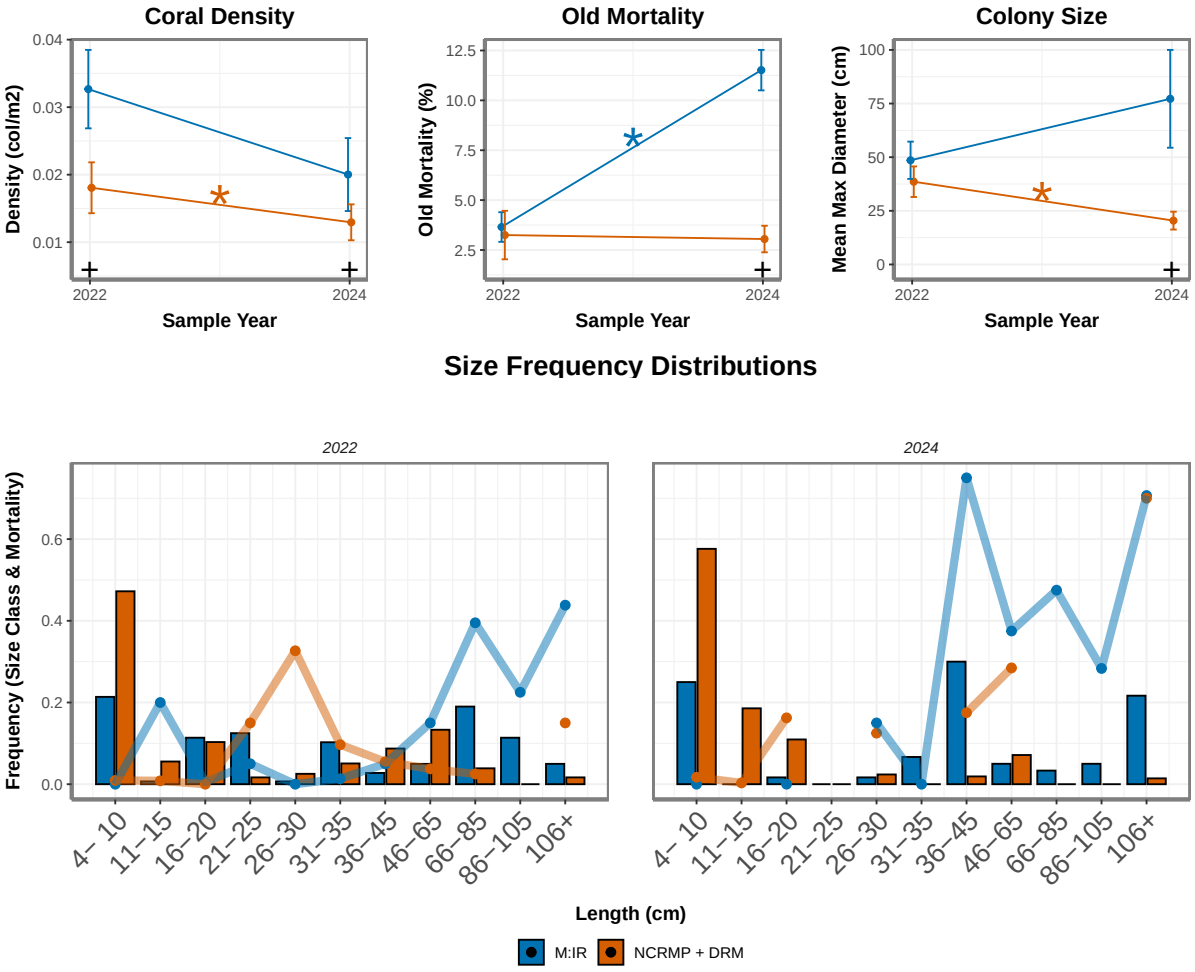
Colpophyllia natans

Colony density, mortality, size, and size class distribution (2022 vs. 2024)



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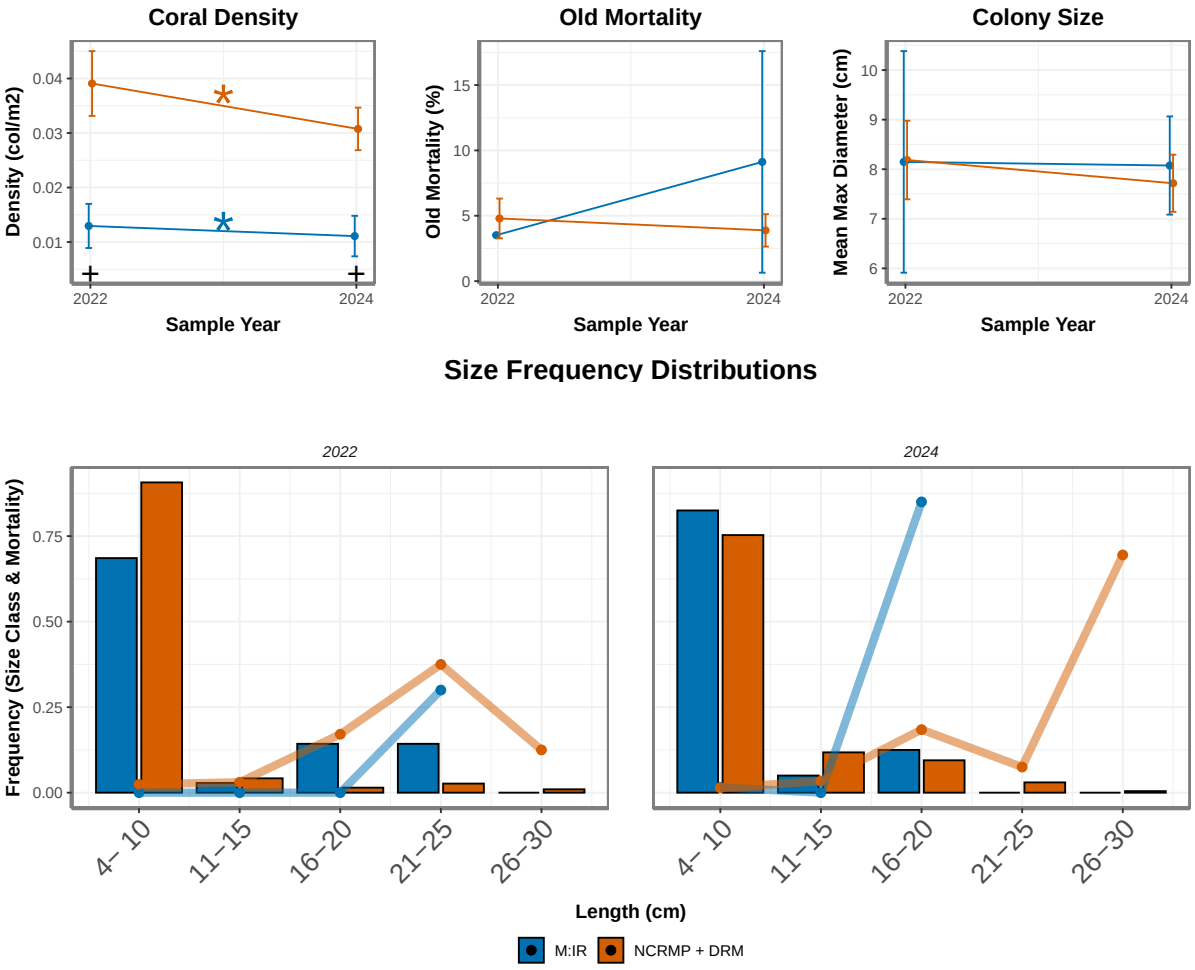
Dichocoenia stokesii

Colony density, mortality, size, and size class distribution (2022 vs. 2024)



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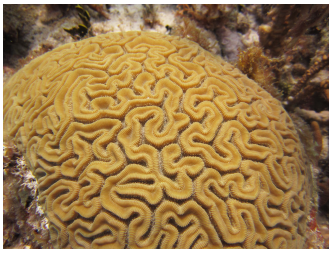
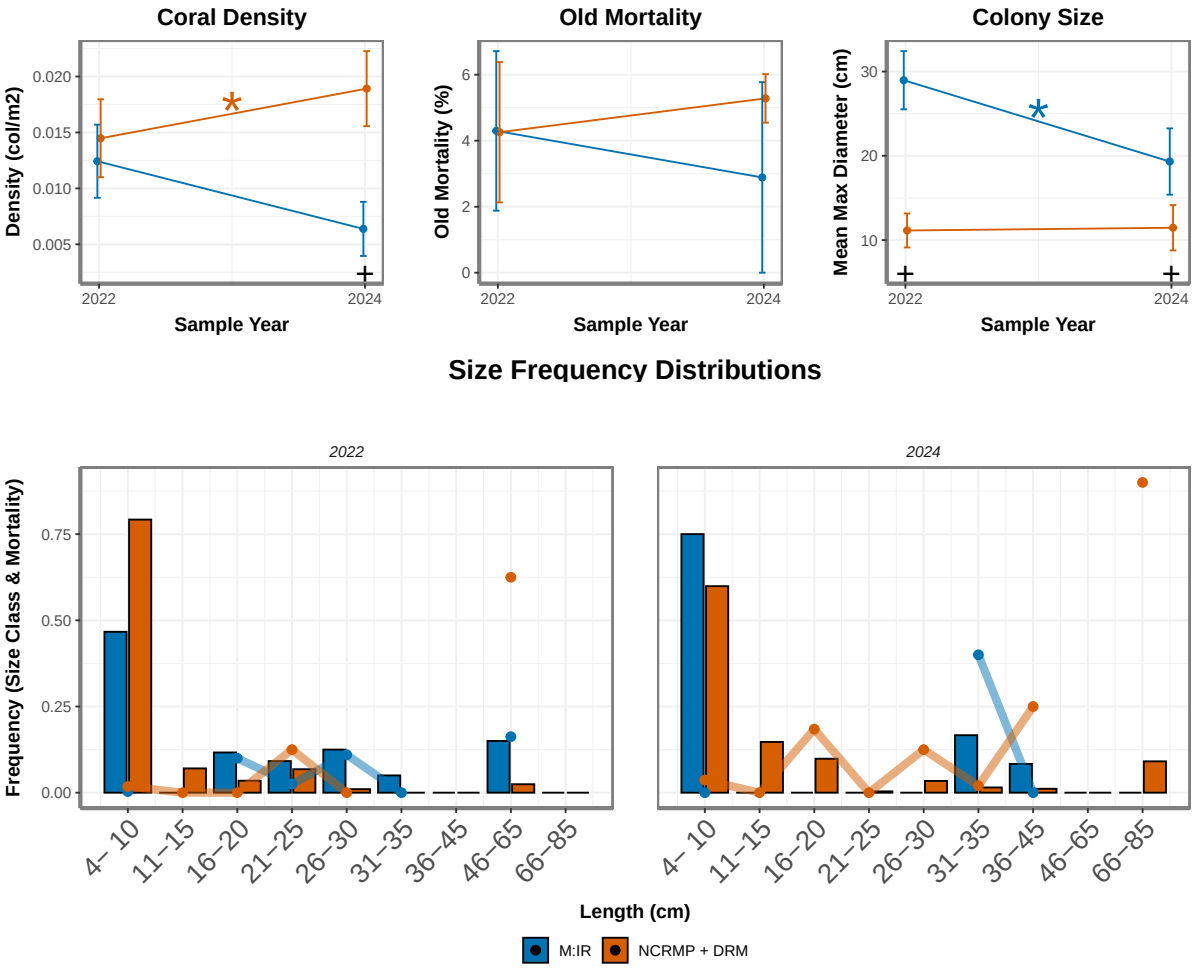
Diploria labyrinthiformis

Colony density, mortality, size, and size class distribution (2022 vs. 2024)





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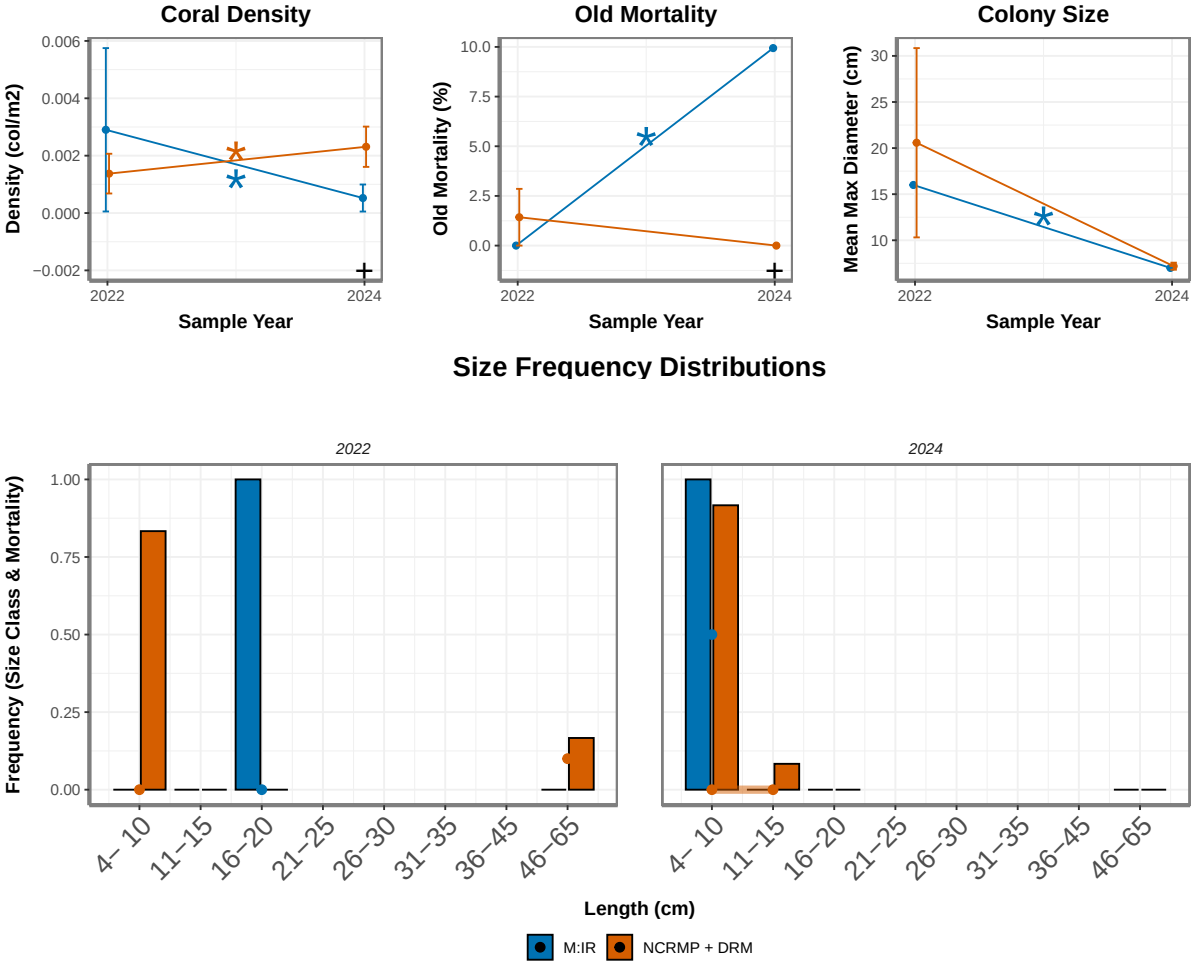
Meandrina meandrites

Colony density, mortality, size, and size class distribution (2022 vs. 2024)



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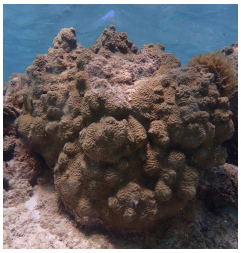
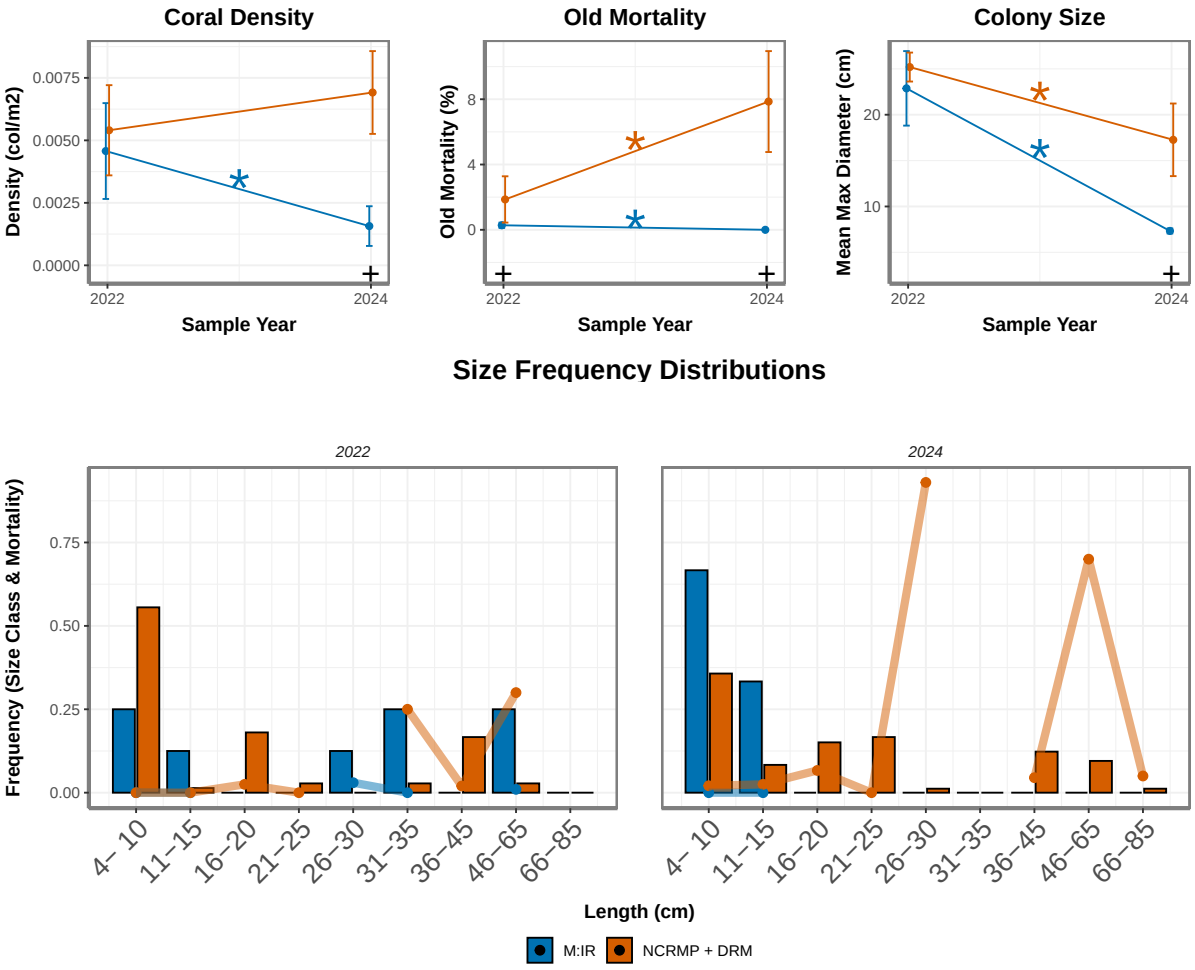
Pseudodiploria clivosa

Colony density, mortality, size, and size class distribution (2022 vs. 2024)





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Pseudodiploria strigosa

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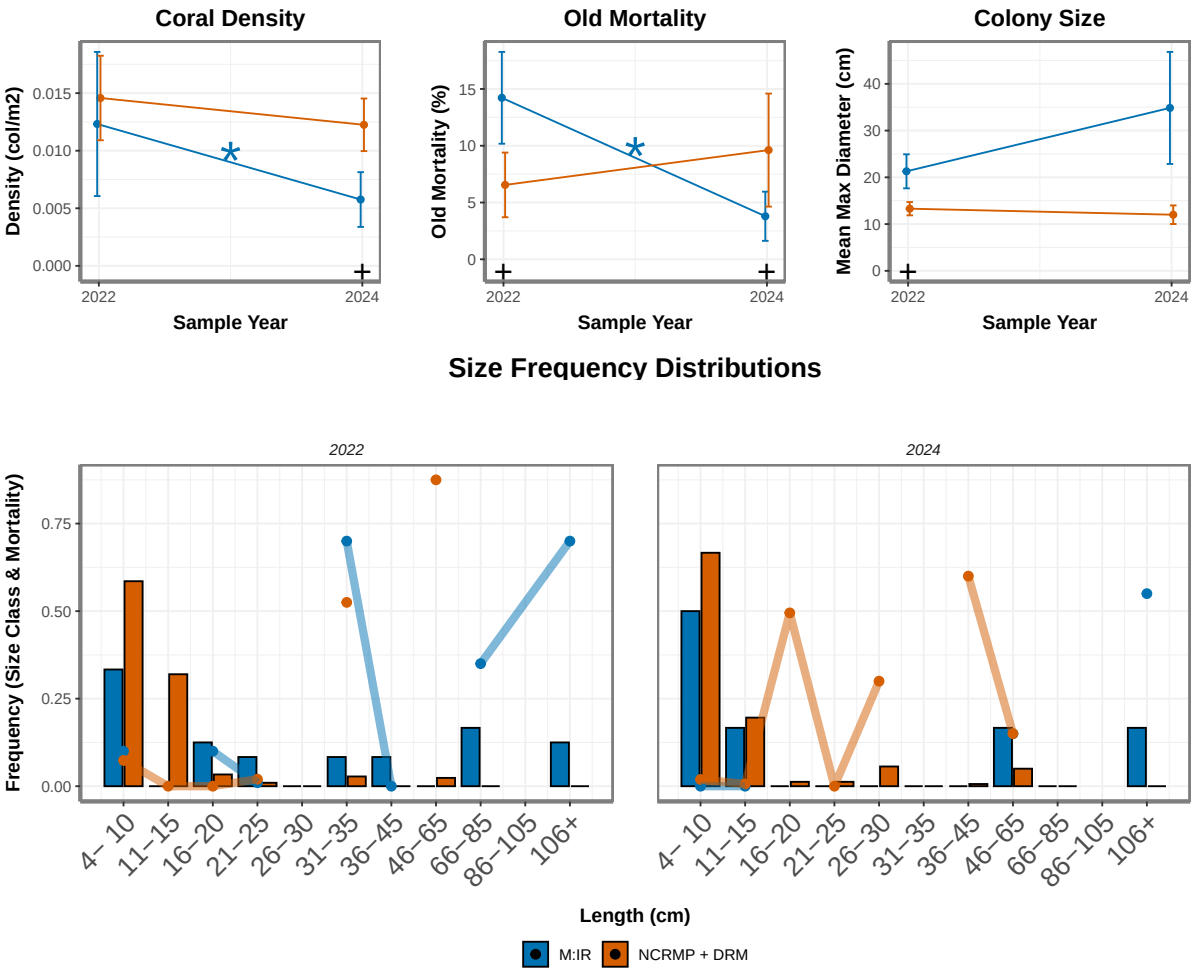

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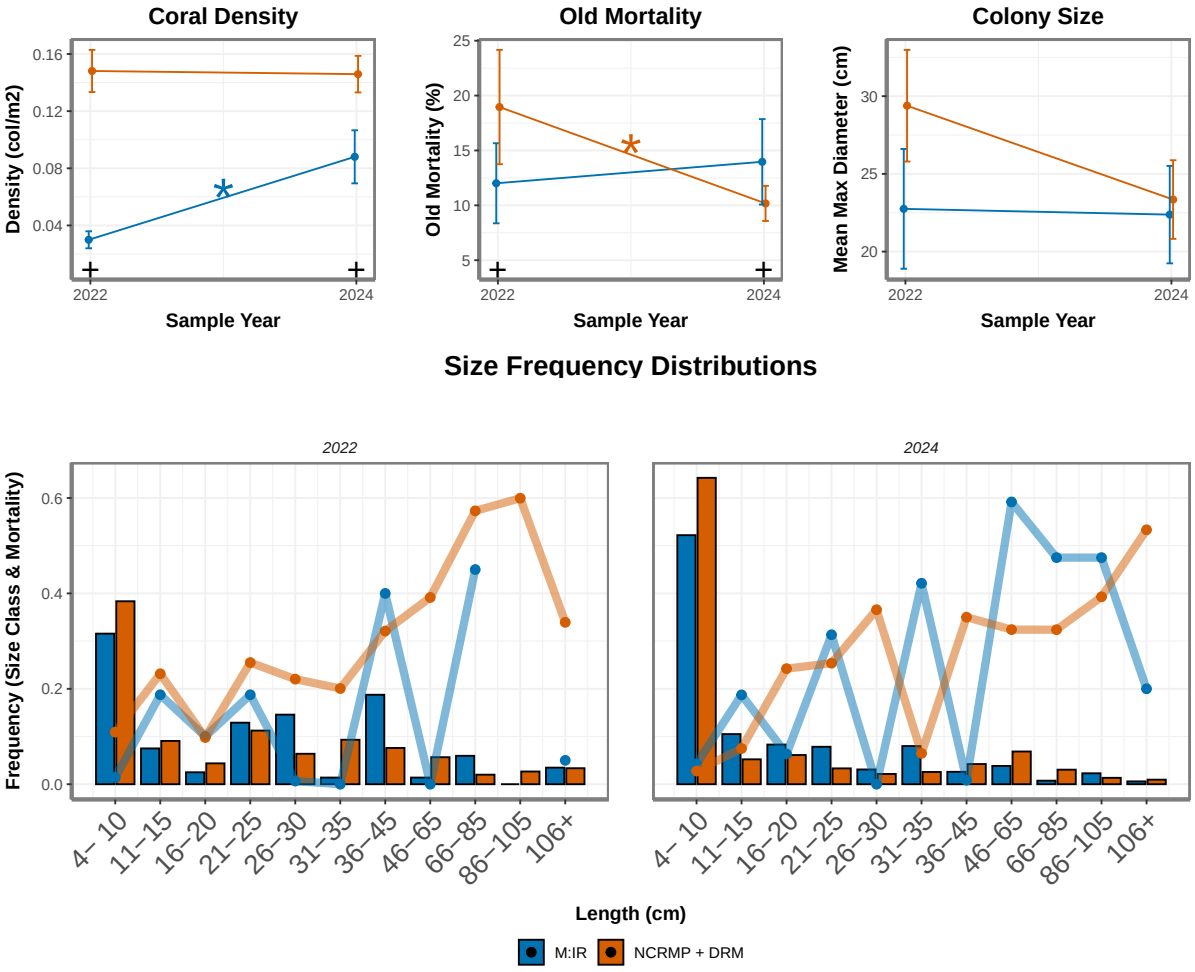
Montastraea cavernosa

Colony density, mortality, size, and size class distribution (2022 vs. 2024)



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4.2 Coral Density

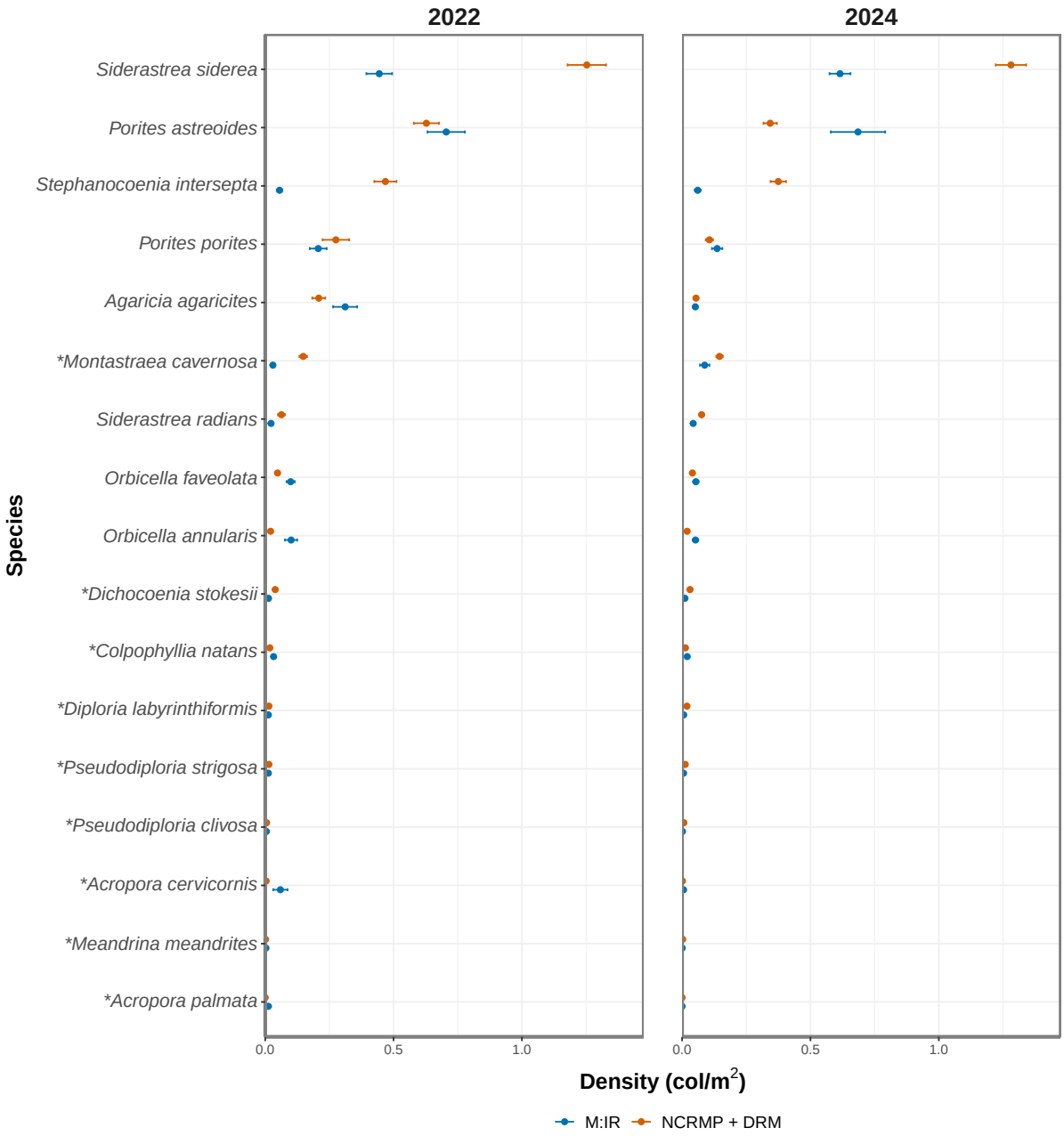

Figure 4. Species-specific coral density (colonies/m2) outside (NCRMP + DRM) and inside M:IR areas in 2022 and 2024. Focal M:IR species are denoted with a (*).

4.3 Old Mortality

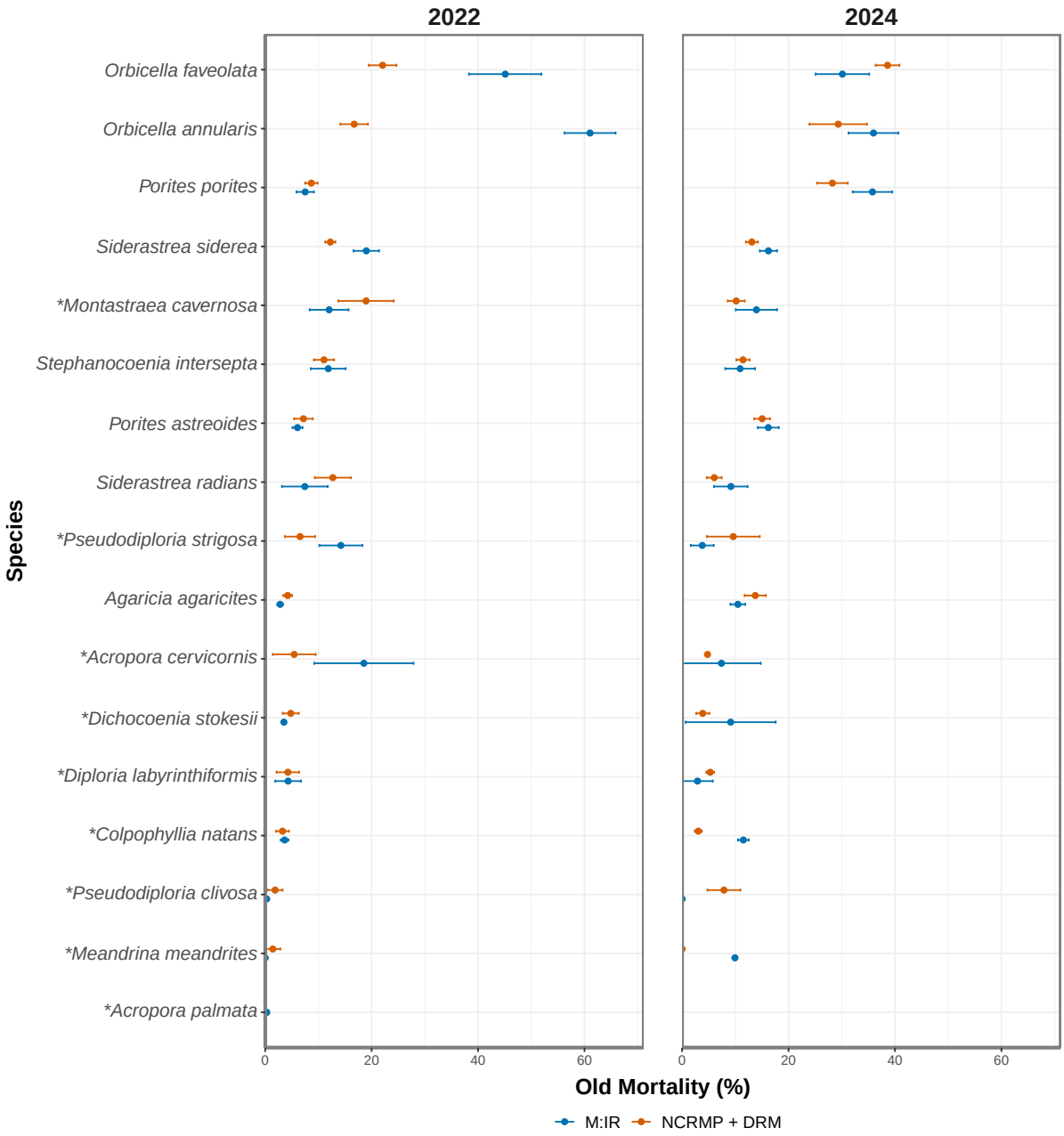

Figure 5. Percent old mortality (± SEM) by coral species outside (NCRMP + DRM) and inside M:IR areas in 2022 and 2024. Focal M:IR species are denoted with a (*).

4.4 Coral Size

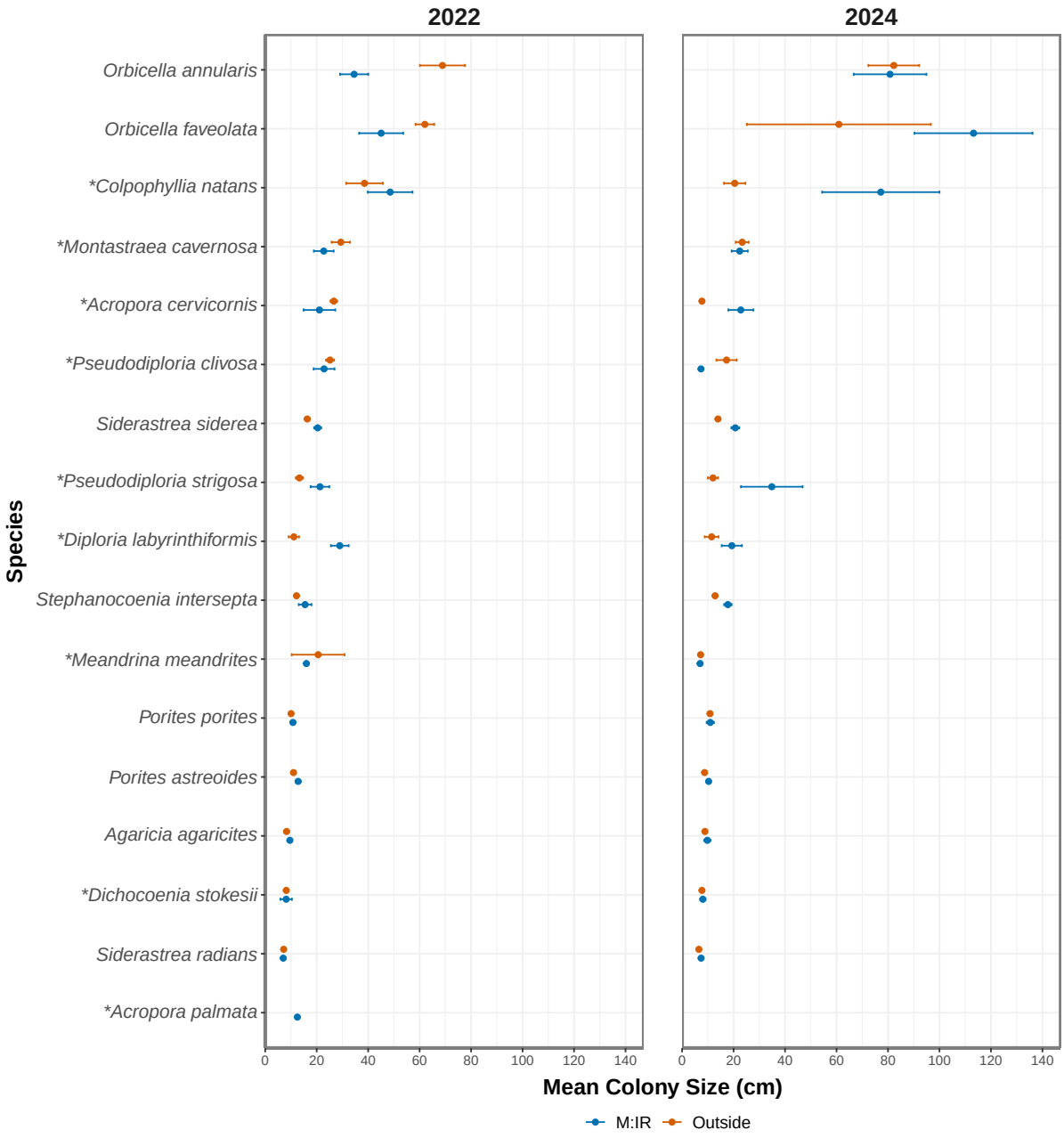

Figure 6. Maximum diameter (cm) ± SEM by coral species outside (NCRMP + DRM) and inside M:IR areas in 2022 and 2024. Focal M:IR species are denoted with a (*).

4.5 Bleaching Estimates

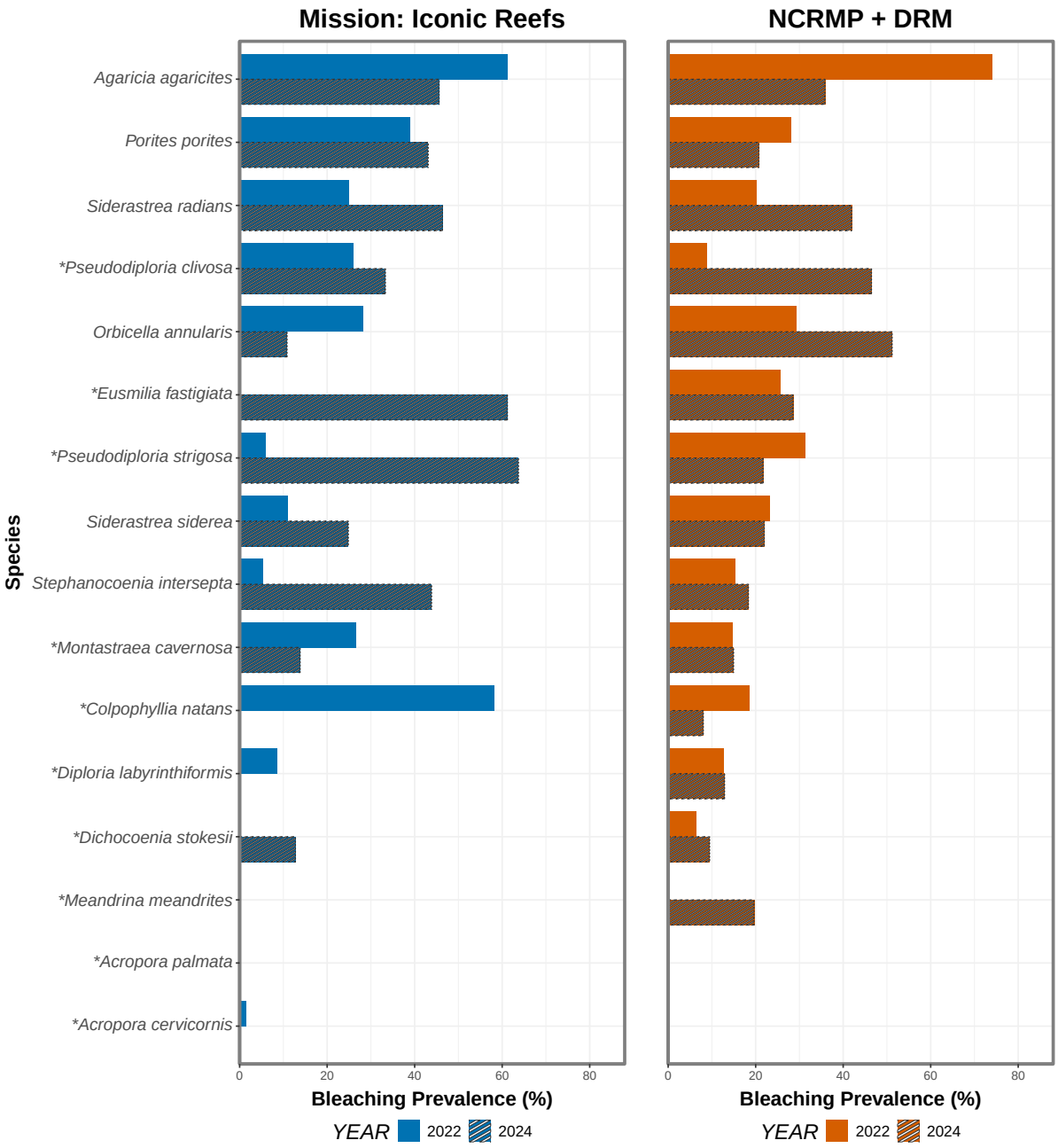

Figure 7. Species-specific bleaching frequency observed outside (NCRMP + DRM) and inside M:IR areas. Focal M:IR species are denoted with a (*).

4.6 Disease Estimates

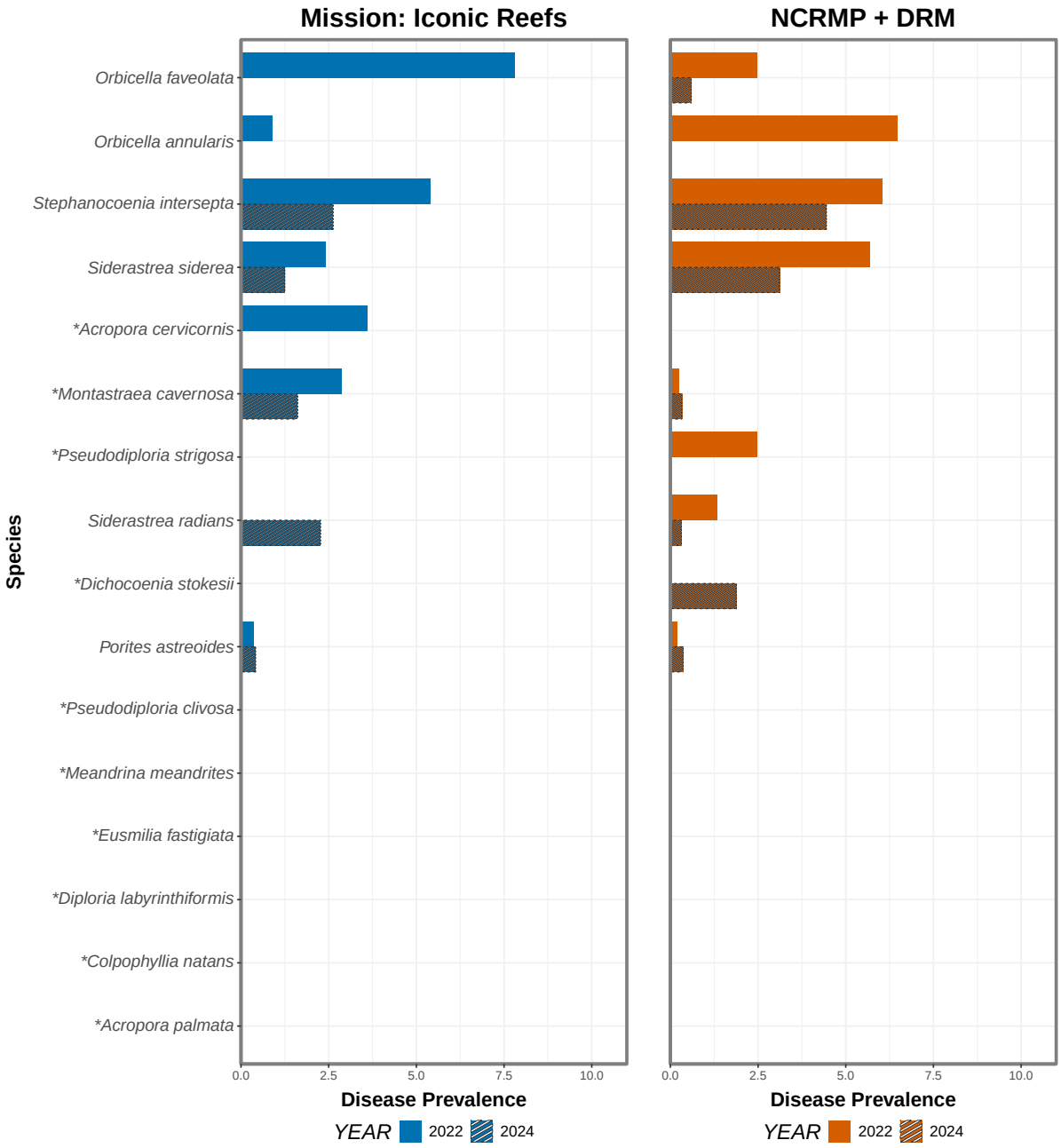

Figure 8. Species-specific disease frequency observed outside (NCRMP + DRM) and inside M:IR areas. Focal M:IR species are denoted with a (*).

5 Point of Contact

NCRMP Atlantic Benthic Team Lead: **Shay Viehman** (shay.viehman@noaa.gov)

6 References

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