

SUPPLEMENTARY MATERIALS FOR

REEF-FISH ABUNDANCE, BIOMASS, AND BIODIVERSITY

INSIDE AND OUTSIDE NO-TAKE MARINE ZONES IN THE
FLORIDA KEYS NATIONAL MARINE SANCTUARY: 1999–2018

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TABLES S1–S14

Table S1. The number of Primary Sampling Units per year and type of no-take marine zones in the Florida Keys domain.

Year	Ecological Reserve	Not Protected	Sanctuary Preservation Area	Research Only	Total
1999	10	104	40	7	161
2000	18	152	49	9	228
2001	17	207	70	10	304
2002	16	275	56	8	355
2003	11	157	63	5	236
2004	4	89	31	2	126
2005	15	187	46	8	256
2006	18	230	69	10	327
2007	14	242	54	7	317
2008	16	289	62	9	376
2009	19	406	77	14	516
2010	16	279	71	13	379
2011	12	312	67	11	402
2012	16	302	82	16	416
2014	13	313	89	17	432
2016	12	299	82	11	404
2018	18	321	82	13	434
total	246	4,166	1,090	170	5,672

Table S2. The number of Primary Sampling Units per year and strata in the Florida Keys domain.

Year	High relief	Linear reef	Patch reef	Total
1999	39	85	37	161
2000	41	124	63	228
2001	79	144	81	304
2002	53	216	86	355
2003	59	115	62	236
2004	42	59	25	126
2005	47	138	71	256
2006	51	189	87	327
2007	48	185	84	317
2008	44	223	109	376
2009	57	309	150	516
2010	23	260	96	379
2011	32	281	89	402
2012	26	263	127	416
2014	40	236	156	432
2016	52	206	146	404
2018	70	211	153	434
Total	803	3,244	1,622	5,669

Table S3. The number of Primary Sampling Units per year grouped by strata and level of protection.

	High Relief		Linear Reef		Patch Reef		
Year	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected	Total
1999	31	8	17	68	9	28	161
2000	32	9	26	98	18	45	228
2001	46	33	37	107	14	67	304
2002	27	26	39	177	15	72	356
2003	31	28	33	82	15	48	237
2004	25	17	9	50	3	23	127
2005	29	18	31	107	9	62	256
2006	26	25	53	136	18	69	327
2007	31	17	31	154	13	71	317
2008	23	21	50	173	14	95	376
2009	30	27	62	247	18	132	516
2010	12	11	74	186	14	82	379
2011	15	17	58	223	17	72	402
2012	17	9	65	198	32	95	416
2014	24	16	73	163	22	134	432
2016	31	21	55	151	19	127	404
2018	31	39	61	150	21	132	434
Total	461	342	774	2,470	271	1,354	5,672

Table S4. The number of Primary Sampling Units by strata and type of no-take marine zone per year. ER = Ecological Reserve, RO = Research Only, SPA = Sanctuary Preservation Area, None = not a no-take marine reserve.

	High Relief				Linear Reef				Patch Reef				
Year	ER	RO	SPA	None	ER	RO	SPA	None	ER	RO	SPA	None	Total
1999	3	0	28	8	6	0	11	68	1	0	8	28	161
2000	2	0	30	9	6	1	19	98	10	0	8	45	228
2001	5	0	41	33	6	4	27	107	6	0	8	67	304
2002	2	0	25	26	6	3	30	177	9	0	6	72	356
2003	3	0	28	28	1	0	32	82	7	0	8	48	237
2004	2	0	23	17	1	3	8	50	1	0	2	23	130
2005	4	0	25	18	5	2	23	107	6	0	3	62	255
2006	2	0	24	25	8	0	43	136	8	0	10	69	325
2007	4	0	27	17	5	0	26	154	5	0	8	71	317
2008	2	0	21	21	7	1	42	173	7	0	7	95	376
2009	2	0	28	27	9	3	50	247	8	0	10	132	516
2010	1	0	11	11	11	2	61	186	4	0	10	82	379
2011	2	0	13	17	2	2	54	223	8	0	9	72	402
2012	1	0	16	9	7	1	57	198	8	0	24	95	416
2014	2	1	21	16	5	1	95	135	6	0	42	108	432
2016	2	4	26	20	4	0	73	129	6	0	38	102	404
2018	5	2	25	38	4	0	66	141	9	0	29	115	434
Total	44	7	412	340	93	23	717	2,411	109	0	230	1,286	5,672

Table S5. Listing of species ranked by percent of total abundance observed in reef visual census from the Florida Keys domain between 1999 – 2018.

» .csv file available online at https://tos.org/oceanography/assets/docs/34-2_medina-table-S5.csv

Table S6. Conversion of common indices to true diversities (Jost, 2006).

Index x:	Diversity in terms of x:	Diversity in terms of p _i :
<i>Species richness</i> $x \equiv \sum_{i=1}^s p_i^0$	x	$\sum_{i=1}^s p_i^0$
<i>Gini Simpson</i> $x \equiv 1 - \sum_{i=1}^s p_i^2$	1/(1-x)	$\frac{1}{\sum_{i=1}^s p_i^2}$

Table S7. Functional traits of reef fish used to characterize functional niche (from Stuart-Smith et al., 2013)

Functional Trait	Category	Type	Units
Maximum length	Body size – resource partitioning	Numeric	Total length (cm), continuous
Trophic breadth	Trophic niche – resource partitioning	Numeric	Number of prey phyla consumed. Range from 1-8
Trophic group	Trophic niche – resource partitioning	Factor	Browsing herbivore, scraping herbivore, benthic invertivore, planktivore, higher carnivore
Water column position	Behavior – space and habitat partitioning	Factor	Benthic, demersal, site-attached pelagic, roaming pelagic
Gregariousness	Behavior – space and habitat partitioning	Ordered Factor	Index 1–3, representing singleton, paired to sometimes forming small schools, always schooling
Diel activity pattern	Behavior – resource partitioning, predator avoidance	Factor	Diurnal, Nocturnal
Preferred substrate	Habitat use – resource partitioning, predator avoidance	Factor	Hard substrate, soft substrate
Habitat Complexity	Habitat use – space and habitat partitioning	Factor	Typically associated with habitats characterized by low, medium, high structural complexity

Table S8. Species trait matrix for all reef fish (320) used for functional diversity metrics (developed from Stuart Smith et al., 2013 guidelines).

» .csv file available online at: https://tos.org/oceanography/assets/docs/34-2_medina-table-S8.csv

Table S9. Dunn (1964) Kruskal-Wallis multiple comparison of abundance, biomass, richness, Simpson diversity, and functional diversity by strata. Numbers in bold are significantly different ($p \leq 0.001$).

Index	Comparison	Z	P.unadj	P.adj
Abundance	High Relief - Linear Reef	15.44	8.05E-54	1.61E-53
Abundance	High Relief - Patch Reef	21.93	1.16E-106	3.47E-106
Abundance	Linear Reef - Patch Reef	11.10	1.20E-28	1.20E-28
Biomass	High Relief - Linear Reef	21.89	3.26E-106	9.79E-106
Biomass	High Relief - Patch Reef	17.89	1.32E-71	2.63E-71
Biomass	Linear Reef - Patch Reef	-2.99	2.77E-03	2.77E-03
Richness	High Relief - Linear Reef	24.05	7.84E-128	1.57E-127
Richness	High Relief - Patch Reef	27.72	1.17E-168	1.17E-168
Richness	Linear Reef - Patch Reef	8.15	3.61E-16	3.61E-16
Simpson	High Relief - Linear Reef	12.20	2.89E-34	8.67E-34
Simpson	High Relief - Patch Reef	5.60	2.14E-08	2.14E-08
Simpson	Linear Reef - Patch Reef	-7.88	3.23E-15	6.45E-15
Functional	High Relief - Linear Reef	17.66	8.71E-70	1.74E-69
Functional	High Relief - Patch Reef	2.86	4.29E-03	4.29E-03
Functional	Linear Reef - Patch Reef	-18.85	3.04E-79	9.12E-79

T-test results for mean abundance of high-relief reefs in SPA/RO and ER ($t = 3.58$, $p = 0.002$). We can see the Figure 3 SPA/RO is higher.

Table S10. Tested for differences between levels of protection using the nonparametric Kruskal-Wallis rank sum test. Numbers in bold are significantly different ($p \leq 0.001$).

Index	chi-squared	df	p-value
Abundance	88.034	1	2.2E-16
Biomass	180.95	1	2.2E-16
Richness	112.68	1	2.2E-16
Simpson	21.737	1	3.128E-06
Functional	8.6104	1	.003343

Table S11. P-values from a two tailed t-test evaluating the overall differences in abundance, biomass, and biodiversity metrics grouped by sampling year and protected (no-take marine zones) and unprotected areas. Numbers in bold are significantly different ($p \leq 0.05$).

Year	Abundance	Biomass	Species Richness	Simpson Diversity	Functional Diversity
1999	0.012	0.008	<0.001	0.56	0.06
2000	<0.001	<0.001	<0.001	0.036	0.07
2001	0.008	0.003	<0.001	0.189	0.16
2002	0.18	0.15	0.05	0.007	0.03
2003	0.33	<0.001	<0.001	0.437	0.009
2004	0.19	0.002	<0.001	0.04	0.002
2005	0.12	0.007	<0.001	0.06	0.09
2006	0.03	0.002	<0.001	0.37	0.30
2007	0.002	<0.001	0.001	0.5	0.67
2008	0.78	0.05	0.33	0.93	0.87
2009	0.001	0.37	0.37	0.18	0.55
2010	0.81	0.56	0.82	0.13	0.63
2011	0.37	0.49	0.91	0.92	0.75
2012	0.57	0.20	0.09	0.12	0.76
2014	0.001	<0.001	0.01	0.24	0.76
2016	0.04	0.02	0.006	0.50	0.27
2018	0.11	0.005	0.11	0.92	0.03

Table S12. Permutation-based Multivariate Analysis of Variance (MANOVA) results reporting significant differences between the calculated indices (abundance, biomass, richness, Simpson diversity, and functional diversity) and strata (linear reefs, high-relief reefs, patch reefs). The input data met the assumptions of multivariate dispersion. Numbers in bold are significantly different ($p < 0.05$).

Permutation-based MANOVA						
Variable	df	SS	MS	R ²	F-model	p-value
Strata	2	414253	207127	0.46	21.1	0.001
Residual	48	470609	9804	0.53	–	–
Total	50	884862	–	1.00	–	–
iterations = 999						

Table S13. Permutation-based Multivariate Analysis of Variance (MANOVA) results reporting significant differences between the calculated indices (abundance, biomass, richness) and MPA type (Sanctuary Preservation Area, Ecological Reserve, or unprotected). The input data met the assumptions of multivariate dispersion. Numbers in bold are significantly different ($p < 0.05$).

Permutation-based MANOVA						
Variable	df	SS	MS	R ²	F-model	p-value
MPA Type	2	677894	338947	0.15	13.392	0.001
Residual	150	3796543	25310	0.84	-	-
Total	152	4474438	-	1.00	-	-
iterations = 999						

Table S14. Dunn (1964) Kruskal-Wallis multiple comparison of abundance, biomass, richness by strata. Numbers in bold are significantly different ($p \leq 0.001$).

Index	Comparison	Z	P.unadj	P.adj
Abundance	High Relief - Linear Reef	4.12	3.71E-05	7.41E-05
Abundance	High Relief - Patch Reef	5.39	6.89E-08	2.07E-07
Abundance	Linear Reef - Patch Reef	1.26	.20	.20
Biomass	High Relief - Linear Reef	4.84	1.30E-06	3.90E-06
Biomass	High Relief - Patch Reef	3.28	1.02E-03	2.04E-03
Biomass	Linear Reef - Patch Reef	-1.55	.12	.12
Richness	High Relief - Linear Reef	7.17	7.71E-13	1.54E-12
Richness	High Relief - Patch Reef	7.84	4.39E-15	1.3E-14
Richness	Linear Reef - Patch Reef	0.68	.05	.05