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

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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.

| Year | High Relief |   | Linear Reef |   | Patch Reef |   |       |   |       |   |       |   |       |
|------|-------------|---|-------------|---|------------|---|-------|---|-------|---|-------|---|-------|
|      | 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.

| Year | High Relief | Linear Reef | Patch Reef |
|------|-------------|------------|------------|
|      | 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 \(p_i\): |
|--------------------------------|--------------------------|--------------------------------|
| **Species richness** \(x \equiv \sum_{i=1}^{s} p_i^0\) | \(x\)                    | \(\sum_{i=1}^{s} p_i^0\)       |
| **Gini Simpson** \(x \equiv 1 - \sum_{i=1}^{s} p_i^2\) | \(1/(1-x)\)              | \(\frac{1}{\sum_{i=1}^{s} p_i^2}\) |
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 ≤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 ≤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 ≤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).

| Variable  | df | SS     | MS     | R² | 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).

| Variable      | df | SS     | MS     | R² | 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 ≤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       |