**Supplementary Material for**

**Ecological indicators for coral reef fisheries management**

Authors:

Kirsty L Nash and Nicholas AJ Graham

***File includes:***

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Figure S1: Effects of fishing on community level density indicators across different scales of analysis

Figure S2: Effects of fishing on community level density indicators across different types of fishing gradient

**Table S1.** Summary of publications returned in literature search that were selected for inclusion in the review. See methods section for specific criteria used for selecting publications for inclusion.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **#** | **Ref** | **Year** | **Journal** | **Location** | **In-depth review** |
| 1 | Aburto-Oropeza | 2011 | PLOS One | Gulf of California | Y |
| 2 | Alcala & Russ | 1990 | ICES Jr Mar Sci | Philippines | N |
| 3 | Alcala et al. | 2005 | Can Jr Fish Aq Sci | Philippines | N |
| 4 | Amand et al | 2004 | Aq Liv Res | New Caledonia | N |
| 5 | Aswani & Sabetian | 2010 | Cons Biol | Solomon Islands | Y |
| 6 | Aswani et al. | 2007 | Coral Reefs | Solomon Islands | Y |
| 7 | Babcock et al. | 2010 | PNAS | Kenya and Philippines | N |
| 8 | Bartlett et al. | 2009 | Cons Biology | Vanuatu | N |
| 9 | Beets | 1997 | Proc 8th Int Coral Reef Symp | US Virgin Islands | Y |
| 10 | Brewer et al. | 2009 | Biol Cons | Solomon Islands | N |
| 11 | Campbell & Pardede | 2006 | Fish Res | Indonesia | Y |
| 12 | Chiappone et al. | 2000 | MEPS | Caribbean | Y |
| 13 | Clua & Legendre | 2008 | Aq Liv Res | Tonga | Y |
| 14 | Craig et al. | 2008 | Fish Res | American Samoa | N |
| 15 | Currie et al. | 2012 | African Jr Mar Sci | S.Africa & Mozambique | Y |
| 16 | Daw et al. | 2011 | Coast Manag | Western Indian Ocean | N |
| 17 | DeMartini et al. | 2008 | MEPS | Northern Line Islands | Y |
| 18 | Dulvy et al. | 2002 | Jr Expt Mar Biol Ecol | Fiji | Y |
| 19 | Dulvy et al. | 2004 | Can Jr Fish Aq Sci | Fiji | Y |
| 20 | Dulvy et al. | 2004 | Ecol Lett | Fiji | Y |
| 21 | Edwards et al. | 2014 | Proc B | Global | Y |
| 22 | Eklof et al. | 2009 | MEPS | Kenya | Y |
| 23 | Ferraris et al. | 2005 | MEPS | New Caledonia | N |
| 24 | Francini-Filho & Moura | 2008 | Fish Res | Brazil | N |
| 25 | Freed & Granek | 2014 | Coast Manag | Comoros | Y |
| 26 | Friedlander & DeMartini | 2002 | MEPS | Hawaii | Y |
| 27 | Friedlander et al. | 2007 | Ecol App | Hawaii | Y |
| 28 | Friedlander et al. | 2007 | MEPS | Hawaii | Y |
| 29 | Galal et al. | 2002 | Mar & FW Res | Egypt | N |
| 30 | Gascuel et al | 2005 | ICES Jr Mar Sci | New Caledonia | N |
| 31 | Goetze et al. | 2011 | Coral Reefs | Fiji | Y |
| 32 | Graham et al. | 2005 | Coral Reefs | Fiji | Y |
| 33 | Graham et al. | 2007 | Cons Biol | Seychelles | N |
| 34 | Grigg | 1994 | MEPS | Hawaii | Y |
| 35 | Guillemot et al. | 2014 | Ecol Ind | New Caledonia | Y |
| 36 | Harborne et al. | 2008 | Jr App Ecol | Bahamas | Y |
| 37 | Hawkins & Roberts | 2004 | Cons Biol | Caribbean | Y |
| 38 | Hawkins et al. | 2007 | Aq Cons: Mar & FW Ecosys | Caribbean | Y |
| 39 | Huntington et al. | 2010 | PLOS One | Belize | Y |
| 40 | Januchowski-Hartley et al. | 2011 | PLOS One | PNG | Y |
| 41 | Jennings & Polunin | 1996 | Jr App Ecol | Fiji | Y |
| 42 | Jennings & Polunin | 1997 | Coral Reefs | Fiji | Y |
| 43 | Jennings et al. | 1995 | Coral Reefs | Seychelles | Y |
| 44 | Jennings et al. | 1996 | Biol Cons | Seychelles | Y |
| 45 | Karnauskas & Babcock | 2014 | Ecol Indic | Belize | Y |
| 46 | Karnauskas et al. | 2011 | Fish Res | Navassa | Y |
| 47 | Karnauskas et al. | 2011 | MEPS | Belize | N |
| 48 | Karr et al. | 2015 | Jr App Ecol | Caribbean | Y |
| 49 | Klomp et al. | 2001 | Proc Gulf Caribb Fish Instit | Caribbean | N |
| 50 | KrOnen et al. | 2012 | Ocean Coast Manag | Pacific Islands | Y |
| 51 | Letourneur et al. | 2000 | Aq Liv Res | New Caledonia | N |
| 52 | Lindfield | 2014 | PLOS One | Guam | Y |
| 53 | Mateos-Molina et al. | 2014 | Fish Res | Puerto Rico | N |
| 54 | McClanahan | 1994 | Coral Reefs | Kenya | Y |
| 55 | McClanahan | 2008 | Oecologia | Kenya | N |
| 56 | McClanahan | 2014 | MEPS | Kenya | N |
| 57 | McClanahan & Arthur | 2001 | Ecol App | Kenya & Tanzania | N |
| 58 | McClanahan & Graham | 2005 | MEPS | Kenya | N |
| 59 | McClanahan & Humphries | 2012 | MEPS | Kenya | Y |
| 60 | McClanahan &Kaunda-Arara | 1996 | Cons Biol | Kenya | Y |
| 61 | McClanahan et al. | 1997 | Environ Cons | Kenya | N |
| 62 | McClanahan et al. | 1999 | Biol Cons | Kenya & Tanzania | Y |
| 63 | McClanahan et al. | 2001 | Coral Reefs | Belize | Y |
| 64 | McClanahan et al. | 2007 | Ecol App | Kenya | N |
| 65 | McClanahan et al. | 2009 | MEPS | Western Indian Ocean | N |
| 66 | McClanahan et al. | 2011 | MEPS | Belize | N |
| 67 | McClanahan et al. | 2011 | PNAS | Indian Ocean | Y |
| 68 | McClanahan et al. | 2015 | Cons Biol | Indian Ocean | Y |
| 69 | Micheli et al. | 2014 | Biol Cons | Bahamas | Y |
| 70 | Miller & Gerstner | 2002 | Biol Cons | Navassa | N |
| 71 | Mora | 2008 | Proc B | Caribbean | Y |
| 72 | Ohman et al. | 1997 | Env Biol Fish | Sri Lanka | N |
| 73 | O'Leary et al. | 2013 | MEPS | Kenya | N |
| 74 | Pet-Soede et al. | 2001 | Fish Res | Sulawesi | Y |
| 75 | Pinca et al. | 2012 | Fish Fisheries | Pacific Islands | Y |
| 76 | Polunin & Roberts | 1993 | MEPS | Saba & Belize | Y |
| 77 | Preuss et al. | 2009 | ICES Jr Mar Sci | New Caledonia | N |
| 78 | Roberts | 1995 | Cons Biol | Saba | Y |
| 79 | Roberts et al. | 2001 | Science | St. Lucia | N |
| 80 | Russ & Alcala | 1989 | MEPS | Philippines | N |
| 81 | Russ & Alcala | 1996 | Ecol App | Philippines | N |
| 82 | Russ & Alcala | 2003 | Ecol App | Philippines | N |
| 83 | Russ & Alcala | 1998a | Coral Reefs | Philippines | N |
| 84 | Russ & Alcala | 1998b | Coral Reefs | Philippines | N |
| 85 | Russ et al. | 2004 | Ecol App | Philippines | Y |
| 86 | Sandin et al. | 2008 | PLOS One | Northern Line Islands | Y |
| 87 | Smith et al. | 2011 | Fish Res | Caribbean | N |
| 88 | Stallings | 2009 | PLOS One | Caribbean | Y |
| 89 | Stamoulis & Friedlander | 2013 | Fish Res | Hawaii | N |
| 90 | Tilot et al. | 2008 | Aq Cons: Mar & FW Ecosys | Red Sea | Y |
| 91 | Tittensor et al. | 2007 | Ecol Lett | Pacific & Indian Ocean | Y |
| 92 | Tyler et al. | 2009 | Biol Cons | Tanzania | Y |
| 93 | Tyler et al. | 2011 | Aq Cons: Mar & FW Ecosys | Tanzania | Y |
| 94 | Valles & Oxenford | 1994 | PLOS One | Caribbean | Y |
| 95 | Walmsley & White | 2003 | Env Cons | Philippines | Y |
| 96 | Walsh et al. | 2012 | Jr Fish Biol | Northern Line Islands | N |
| 97 | Wantiez et al. | 1997 | Coral Reefs | New Caledonia | Y |
| 98 | Watson & Ormond | 1994 | MEPS | Kenya | Y |
| 99 | Westera et al. | 2003 | Jr Expt Mar Biol Ecol | Ningaloo | Y |
| 100 | Williams & Polunin | 2000 | Env Cons | Caribbean | N |
| 101 | Williams et al. | 2006 | MEPS | Hawaii | N |
| 102 | Williams et al. | 2008 | Env Cons | Hawaii | Y |
| 103 | Wilson et al. | 2008 | Global Change Biol | Fiji | N |
| 104 | Wilson et al. | 2010 | Ecol App | Fiji | Y |
| 105 | Wilson et al. | 2012 | Mar Env Res | Ningaloo | Y |

**Table S2.** Summary of gradients used in publications incorporated into initial review (n=105).

|  |  |
| --- | --- |
| **Gradient** | **Number of publications** |
| Spatial | 72 |
| Temporal | 8 |
| Both | 25 |

**Table S3.** Summary of survey techniques used in publications incorporated into initial review (n=105).

|  |  |
| --- | --- |
| **Type of Fishery-Independent Survey** | **Number of publications** |
| Underwater data collection | 102 |
| Fishery-independent catch data | 3 |

**Table S4.** Summary of indicators used in publications incorporated into initial review (n=105).

|  |  |
| --- | --- |
| **Indicator Type** | **Number of publications** |
| **Density-based indicators** |  |
| Biomass | 68 |
| Abundance | 63 |
| Abundance variability | 1 |
| Biomass variability | 1 |
| **Size-based indicators** |  |
| Size distribution | 17 |
| Mean size | 13 |
| Size spectra intercept | 9 |
| Size spectra slope | 8 |
| Mean max size | 5 |
| Size at maturity | 1 |
| Size composition | 1 |
| Size distribution (Lmax) | 1 |
| Size to achieve optimum yield | 1 |
| **Life history-based indicators** |  |
| Growth rate | 3 |
| Age at maturity | 2 |
| Generation time | 2 |
| Lifespan | 2 |
| Natural mortality | 2 |
| Sex ratio | 1 |
| **Function-based indicators** |  |
| Proportion of functional group | 7 |
| Composition of functional groups | 6 |
| Mean trophic level | 4 |
| Grazing rate | 3 |
| Functional redundancy | 1 |
| Functional richness | 1 |
| **Community-based indicators** |  |
| Richness | 41 |
| Community composition | 28 |
| Diversity | 7 |
| Proportion of target individuals | 1 |
| **Behavioural indicators** |  |
| Flight initiation distance | 1 |
| **Ecosystem indicators** |  |
| Coral | 33 |
| Algae | 25 |
| Urchins | 13 |
| Structural complexity | 11 |
| Benthos | 7 |
| Mobile invertebrates (other than urchins) | 3 |

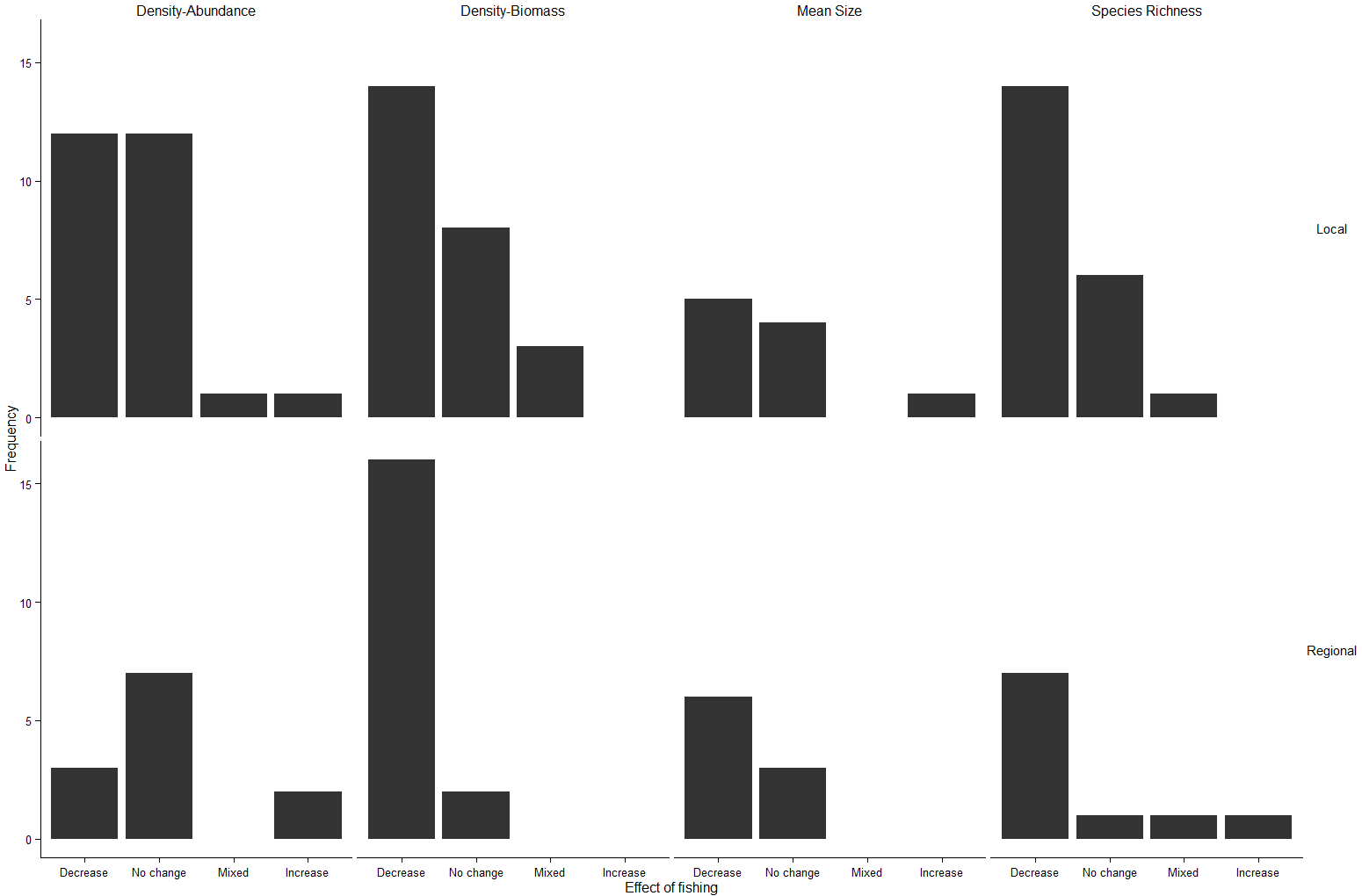
**Table S5.** Summary of the scale of analyses used in publications in in-depth review (n=65). We assigned studies to these scale categories based on the spatial extent of the study

|  |  |
| --- | --- |
| **Scale** | **Number of publications** |
| Local | 42 |
| Regional | 21 |
| Local and regional | 1 |
| Regional and global | 1 |

**Table S6.** Methods for estimating A) Density, B) Community, C) Size, D) Life-history, E) Function and F) Ecosystem indicators.

|  |  |  |
| --- | --- | --- |
| **Indicator Estimation** | | **Key References** |
| **A) Density-based indicators** |  | |
| **Density**  N is abundance or biomass; A is survey area | Other ecosystems   * Rochet and Trenkel (2003)   Coral reefs   * Jennings et al. (1995) * Karnauskas and Babcock (2014) | |
| **Density variability**  CV is coefficient of variation; sd is standard deviation | Other ecosystems   * Shin et al. (2010) * Shannon et al. (2010)   Coral reefs   * Freed and Granek (2014) | |
| **B) Size-based indicators** |  | |
| **Density or proportion large fish**  N > Ref Size is abundance or biomass of individuals larger than reference size; A is survey area | Other ecosystems   * Shin et al. (2005) * Greenstreet et al. (2011)   Coral reefs   * Guillemot et al. (2014) | |
| **Mean size**  L is length or weight of individuals; N is abundance or biomass | Other ecosystems   * Link et al. (2002) * Trenkel and Rochet (2003)   Coral reefs   * Dulvy et al. (2004) * Clua and Legendre (2008) | |
| **Mean maximum size**  Lmaxi is maximum length or weight of species i;  Ni is abundance or biomass of species i | Other ecosystems   * Fulton et al. (2005) * Link (2005)   Coral reefs   * Dulvy et al. (2004) * Babcock et al. (2013) | |
| **Mean length at maturity**  Lmati is mean length at maturity of species i ;  Ni is abundance or biomass of species i | Other ecosystems   * Jennings et al. (1999) * Greenstreet and Rogers (2006)   Coral reef   * McClanahan and Humphries (2012) * Taylor et al. (2014) | |
| **Mean length at sex change**  L∆i is mean length at sex change of species i;  Ni is abundance or biomass of species i | Coral reefs   * Taylor (2014) | |
| **Size spectra – slope and midpoint**  L is length or weight of individuals; N is abundance or biomass; Normalise data by dividing density in size class by width of class | Other ecosystems:   * Gislason and Rice (1998)   Coral reefs:   * Dulvy et al. (2004) * Graham et al. (2005) | |
| **Size distribution**  Frequency distribution of biomass or abundance of different length or weight classes | Other ecosystems   * Trenkel and Rochet (2003) * Blanchard et al. (2005)   Coral reefs   * Polunin and Roberts (1993) | |
| **Ratio: Mean length to Mean length at maturity** | Other ecosystems   * Froese (2004)   Coral reefs:   * Babcock et al. (2013) | |
| **C) Life history-based indicators** |  | |
| **Mean age at maturity**  tmi is mean age at maturity of species i;  Ni is abundance or biomass of species i | Other ecosystems   * Rochet and Trenkel (2003) * Greenstreet and Rogers (2006)   Coral reefs   * Taylor et al. (2014) * McClanahan et al. (2015) | |
| **Mean lifespan**  tmaxi is maximum age of species i;  Ni is abundance or biomass of species i | Other ecosystems   * Shin et al. (2010) * Henriques et al. (2014)   Coral reefs   * Taylor et al. (2014) * McClanahan et al. (2015) | |
| **Growth rate**  k is von Bertalanffy growth parameter for species i;  Ni is abundance or biomass of species i | Other ecosystems   * Jennings et al. (1999) * Greenstreet and Rogers (2006)   Coral reefs   * McClanahan and Humphries (2012) * McClanahan et al. (2015) | |
| **Generation time**  G is generation time of species i; Ni is abundance or biomass of species i | Coral reefs   * McClanahan and Humphries (2012) * McClanahan et al. (2015) | |
| **D) Community composition indicators** |  | |
| **Community composition**  Species densities may be compared among sites using distances matrices e.g. Bray-Curtis dissimilarity and may be visualized using non-metric multidimensional scaling (nMDS). Differences may be assessed using Analysis of Similarities (ANOSIM) | Other ecosystems   * Rochet and Trenkel (2003)   Coral reefs   * Clua and Legendre (2008) * Vallès and Oxenford (2014) | |
| **Diversity**  Or  pi is the proportion abundance of species i;  Hill’s N1 emphasises richness whereas Hill’s N2 emphasises evenness | Other ecosystems   * Gislason and Rice (1998) * Greenstreet and Rogers (2006)   Coral reefs   * Jennings et al. (1995) * Babcock et al. (2013) | |
| **W-statistic for Abundance-Biomass Curves**  Bi is the biomass of species rank i; Ni is the abundance of species rank i; S is the number of species | Other ecosystems   * Warwick (1986) * Yemane et al. (2005) | |
| **E) Functional indicators** |  | |
| **Functional richness**  FG is number of functional groups | Coral reefs   * Micheli et al. (2014) | |
| **Functional diversity**  Range of different indicators based on distribution of biomass or abundance within trait space. Examples include functional identity; functional evenness; functional divergence; functional dispersion | Other ecosystems   * Villéger et al. (2008) * Laliberté and Legendre (2010)   Coral reefs   * Mouillot et al. (2012) | |
| **Density or proportion of functional group**  NFG is abundance or biomass of functional group; A is survey area | Other ecosystems:   * Henriques et al. (2014)   Coral reefs:   * Sandin et al. (2008) * McClanahan et al. (2011) | |
| **F) Ecosystem indicators** |  | |
| **Benthic community composition**  Percentage cover of benthic taxa may be compared among sites using distances matrices e.g. Euclidean distances and may be visualized using principle component analysis (PCA). Differences may be assessed using Analysis of Similarities (ANOSIM) | Coral reefs   * Westera et al. (2003) * Friedlander et al. (2007) | |
| **Crustose coralline algae cover**  CCA is area covered by crustose coralline algae; A is survey area | Coral reefs   * McClanahan and Arthur (2001) * Dulvy et al. (2002) | |
| **Hard coral cover**  HC is area covered by hard coral; A is survey area | Coral reefs   * Grigg (1994) * Roberts (1995) | |
| **Macroalgal cover**  MA is area covered by macroalgae; A is survey area | Coral reefs   * McClanahan and Arthur (2001) * Dulvy et al. (2002) | |
| **Ratio: Coral to Macroalgal cover**  HC is area covered by hard coral; MA is area covered by macroalgae | Coral reefs   * Huntington et al. (2010) * McClanahan et al. (2011) | |
| **Structural complexity**  Or  LD is distance covered when a chain or tape is pulled taught across the benthos; SD is the linear distance between the start and end of the chain or tape when it is draped over the contours of the benthos | Coral reefs   * Roberts (1995) * Dulvy et al. (2002) | |
| **Urchin density**  N is biomass or abundance of urchins; A is survey area | Coral reefs   * Watson and Ormond (1994) * McClanahan et al. (1999) | |
| **Urchin predation index**  U is the survival rate of urchins; T is the time over which the survival of urchins is estimated | Coral reefs   * McClanahan et al. (1999) * McClanahan et al. (2011) | |

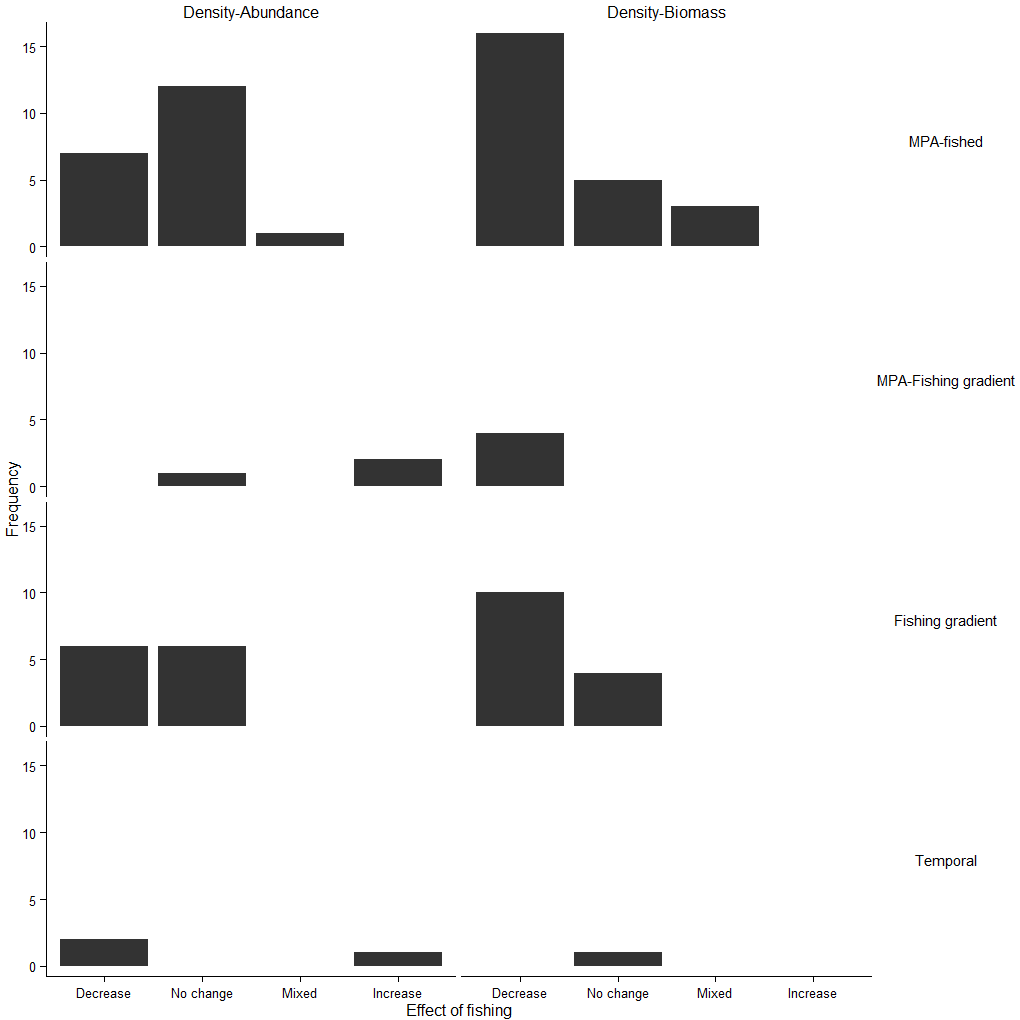
**Figure S1.** Number of publications reporting the effect of fishing on indicators estimated at the community level, for studies looking at either A) local or B) regional scales. X-axis represents change in indicator value in response to an increase in fishing pressure, either along a fishing gradient or from no-take to fished areas. Only those indicators presented more than 5 times in the literature are shown.



**B**

**A**

**Figure S2.** Number of publications reporting the effect of fishing on indicators estimated at the community level, for a range of fishing gradients: A) MPA versus fished; B) MPA versus a fishing gradient; C) a fishing gradient; and D) a gradient in fishing over time. X-axis represents change in indicator value in response to an increase in fishing pressure. Only those indicators presented more than 5 times within different fishing gradients in the literature are shown.



**D**

**C**

**B**

**A**

**References**

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