

# Modeling reef fish biomass, recovery potential, and management priorities in the western Indian Ocean

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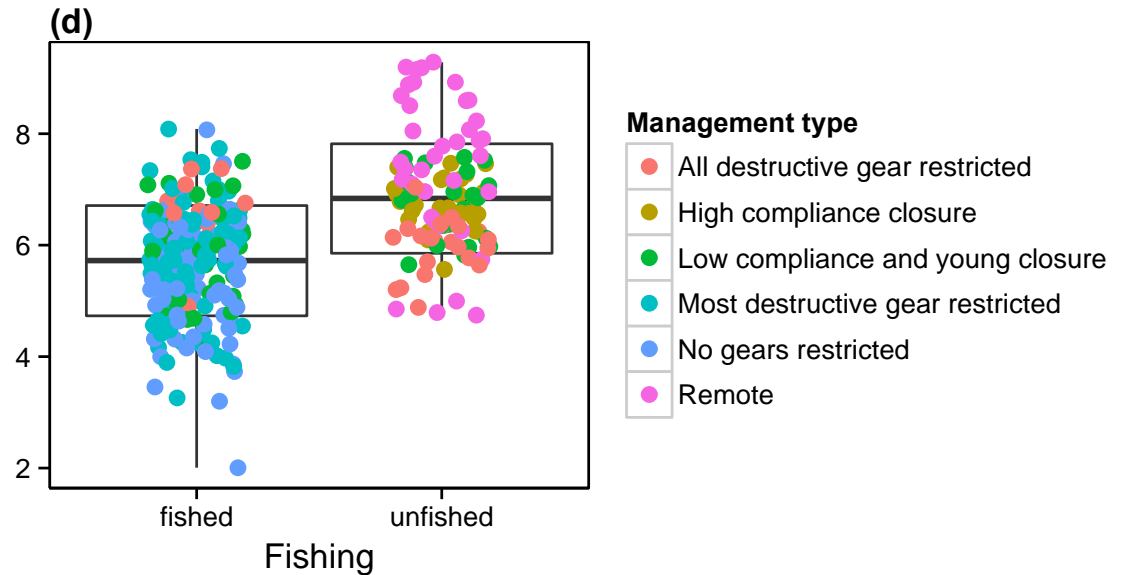
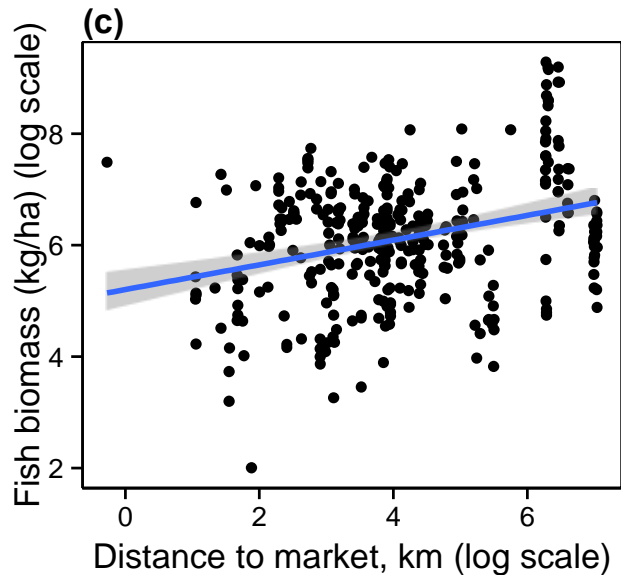
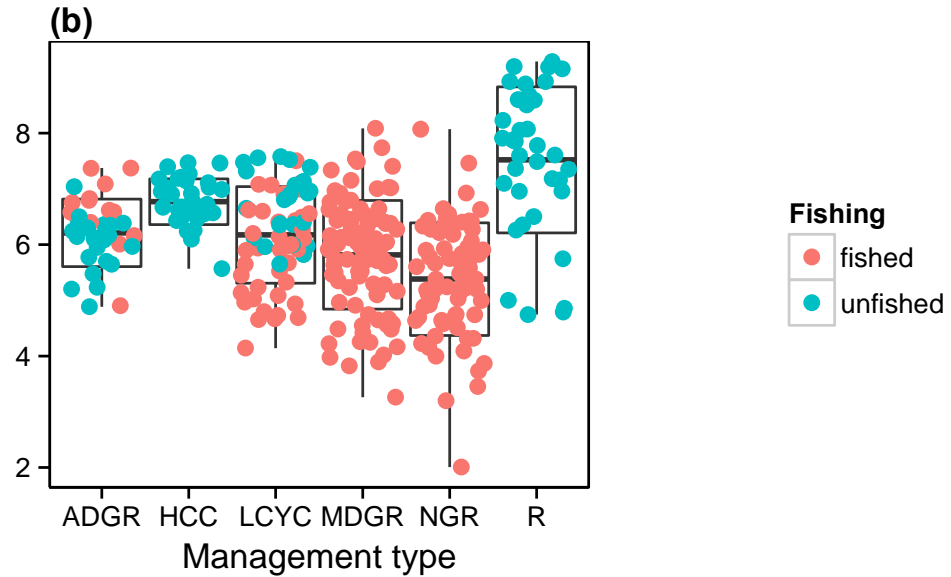
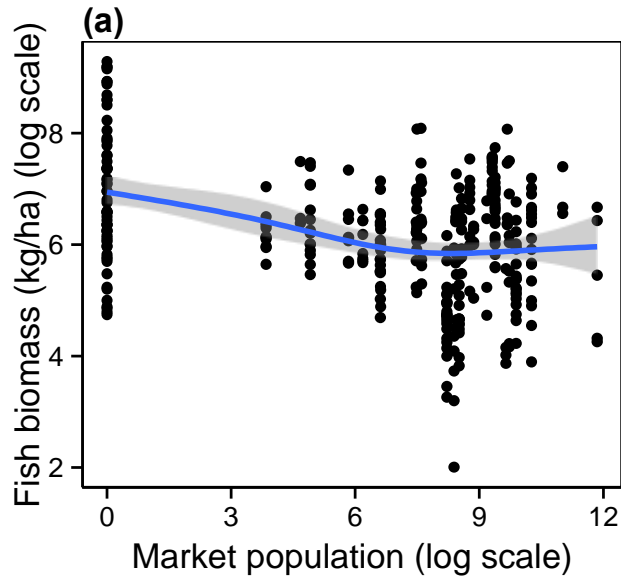
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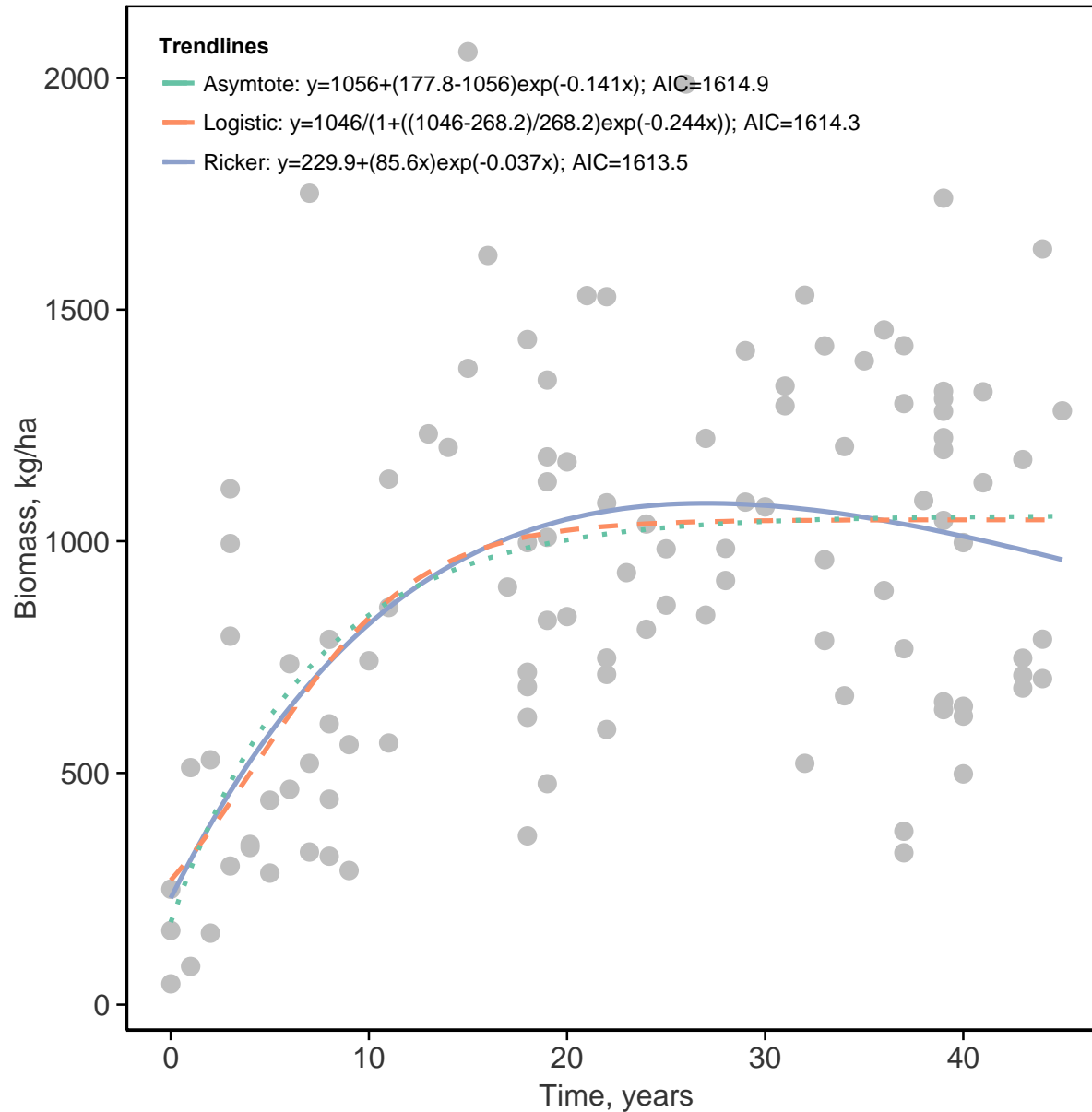
# Project outline

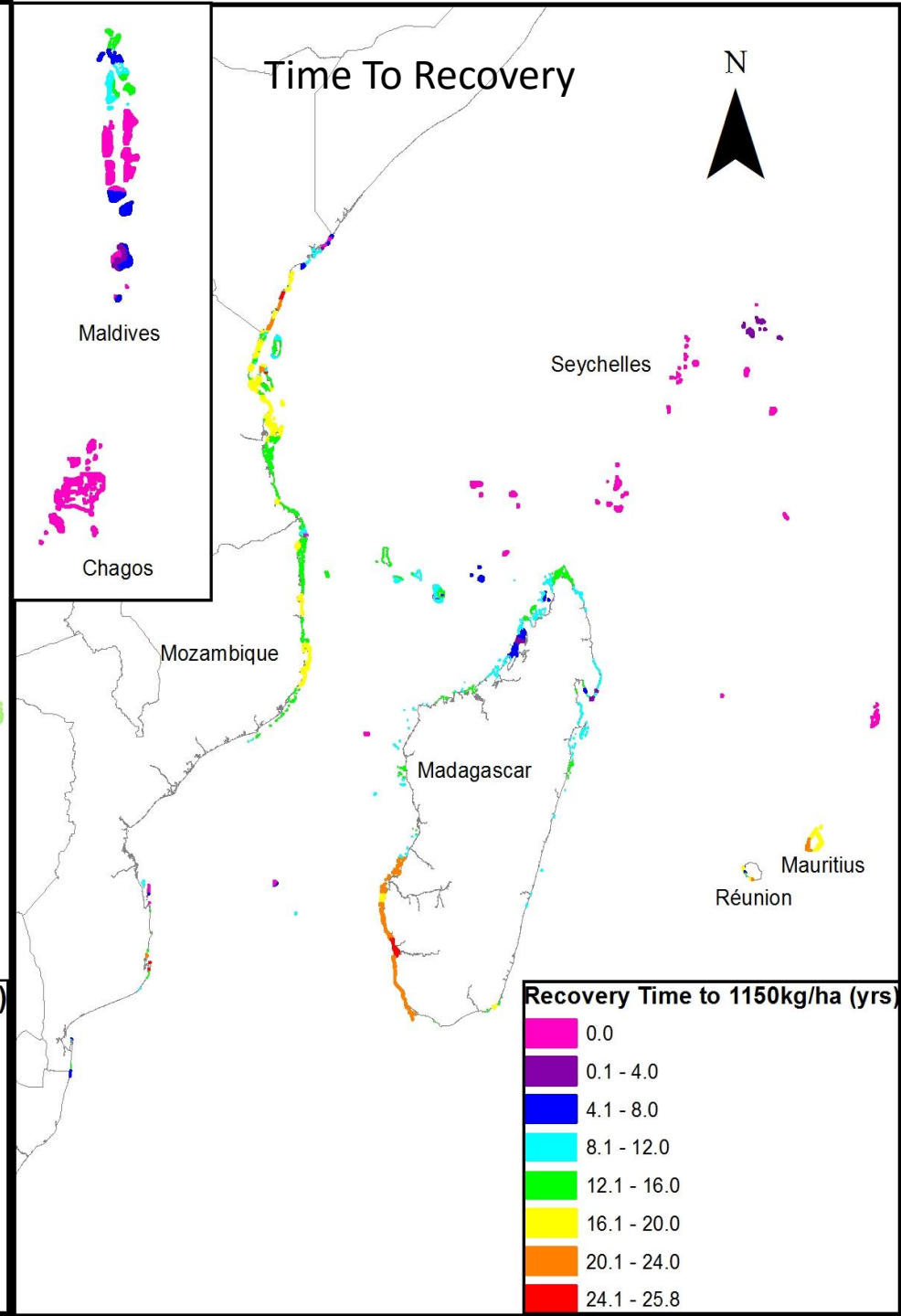
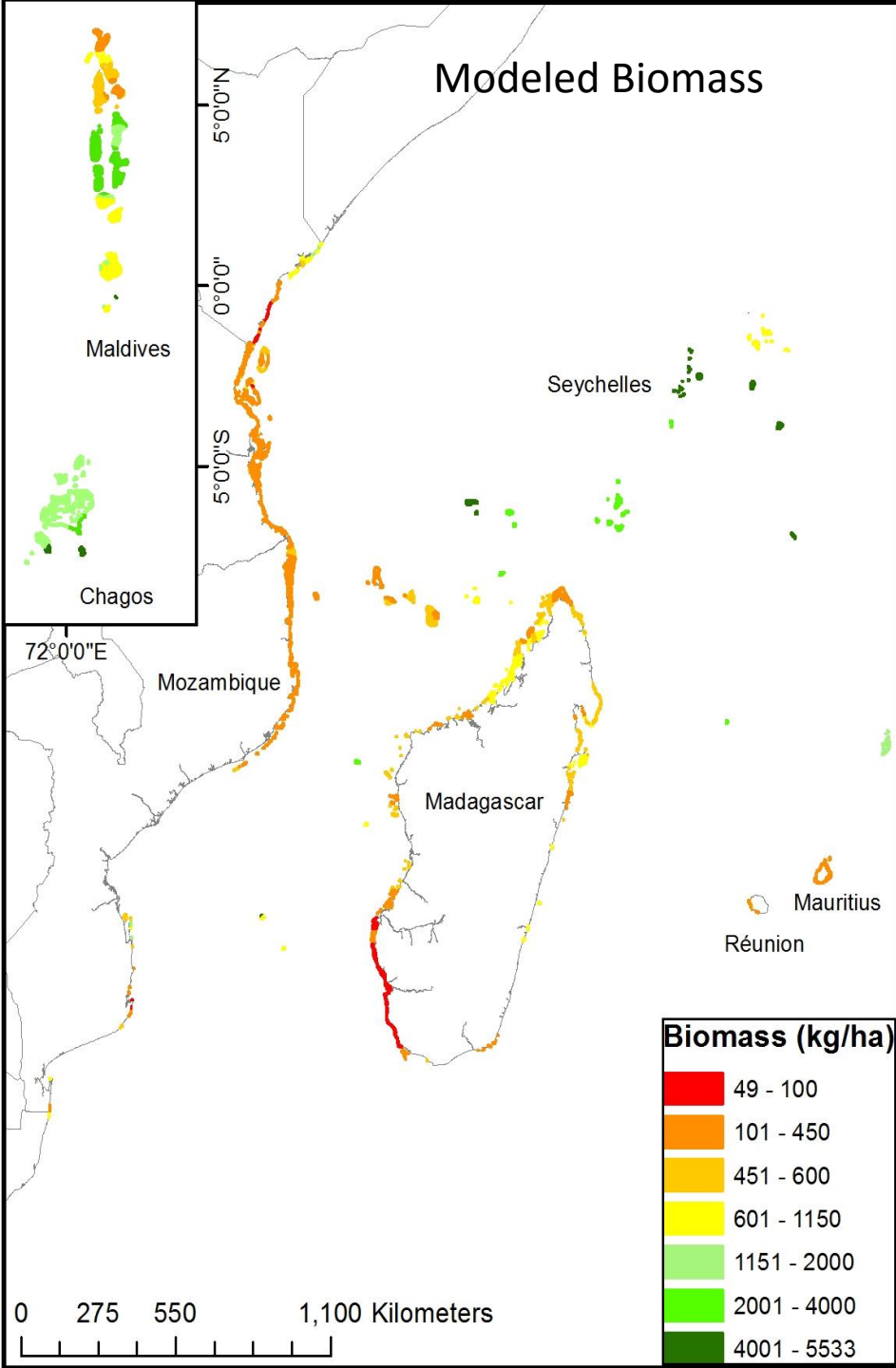
- Biomass modeling and mapping (11,678 - 2.5x2.5 km square grid planning units having coral reefs in the WIO including Maldives and Chagos)
- Time to recovery modeling based on space-for-time substitution in 16 regional fisheries closures
- Spatial prioritization based on choosing sites based on the cost of biomass recovery in years
  - Systematic (Marxan) minimize cost to insure protection of high biomass reefs (also a proxy for diversity)
  - Biomass depletion (community closure) model where priority is set to close most depleted reefs to promote sustainable fisheries

Relationships between fish biomass, fisheries management categories, and fishing impact proxies were used to model the spatial distribution of fish biomass. The equations derived from the empirical data from 337 sites in 9 countries below were used to fill in the spatial planning units



# Best fit equations for closure age vs fishable biomass in high compliance closures of the region based on 111 site x times in 16 high compliance closures





Modeled biomass (kg/ha) expressed as a percentage of the total reef area for each location or country

<b>Country</b>	<b>&lt;300 kg/ha</b>	<b>300-450 kg/ha</b>	<b>450-600 kg/ha</b>	<b>600-1150 kg/ha</b>	<b>&gt;1150 kg/ha</b>
Bassas da India	0.00	0.00	0.00	48.76	51.24
British Indian Ocean Territory	0.00	0.00	0.00	0.00	100.00
Comoro Islands	1.72	48.85	49.43	0.00	0.00
Glorioso Islands	0.00	0.00	0.00	72.64	27.36
Ile Europa	0.00	0.00	0.00	100.00	0.00
Ile Tromelin	0.00	0.00	0.00	0.00	100.00
Juan de Nova Island	0.00	0.00	0.00	0.00	100.00
Kenya	32.38	5.36	5.69	49.59	6.98
Madagascar	39.82	16.40	23.73	20.05	0.00
Maldives	0.00	11.15	16.41	24.78	47.66
Mauritius	48.90	0.00	0.00	0.00	51.10
Mayotte	0.00	16.80	74.93	5.66	2.62
Mozambique	35.99	50.44	11.88	0.31	1.37
Reunion	53.54	22.34	15.13	8.99	0.00
Seychelles	0.00	0.00	0.00	4.17	95.83
South Africa	0.00	0.00	0.00	100.00	0.00
Tanzania	41.50	43.61	13.32	1.57	0.00
<b>Entire Region</b>	<b>22.28</b>	<b>19.52</b>	<b>13.65</b>	<b>12.35</b>	<b>32.21</b>

Mean ( $\pm$ SD) time to recovery values in years for suggested biomass thresholds for each country.. 450 is considered mean sustainability, 600 is high sustainability and 1150 kg/ha is conservation thresholds.

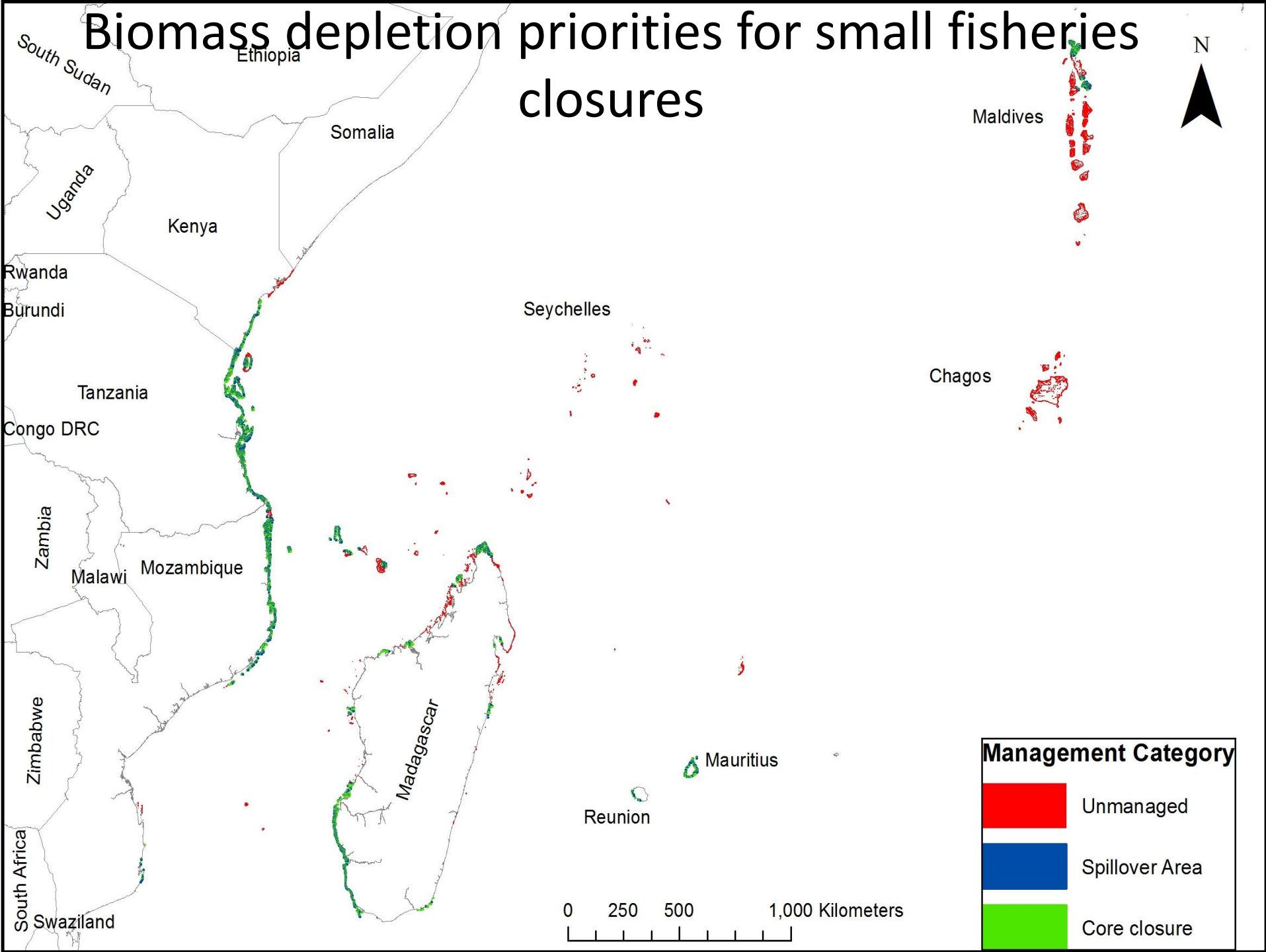
<b>Country</b>	<b>450 kg/ha (SD)</b>	<b>600 kg/ha (SD)</b>	<b>1150 kg/ha (SD)</b>
Bassas da India	0 (0)	0 (0)	3.6 (3.94)
British Indian Ocean Territory	0 (0)	0 (0)	0 (0)
Comoro Islands	1.9 (1.87)	4.53 (2.22)	12.75 (1.53)
Glorioso Islands	0 (0)	0 (0)	4.29 (3.1)
Ile Europa	0 (0)	0 (0)	8.35 (0.02)
Ile Tromelin	0 (0)	0 (0)	0 (0)
Juan de Nova Island	0 (0)	0 (0)	0 (0)
Kenya	3.47 (3.58)	4.52 (4.5)	13.5 (7.19)
Madagascar	2.36 (3.37)	4.46 (3.71)	13.55 (5.7)
Maldives	0.25 (0.9)	1.18 (2.08)	4.64 (5.28)
Mauritius	4.1 (3.62)	5.17 (4.57)	11.13 (9.83)
Mayotte	0.04 (0.13)	2.75 (1.78)	10.92 (2.45)
Mozambique	4.08 (2.14)	6.6 (1.9)	14.62 (3.1)
Reunion	4.38 (3.14)	6.48 (3.35)	15.5 (4.48)
Seychelles	0 (0)	0 (0)	0.16 (0.43)
South Africa	0 (0)	0 (0)	6.73 (0.74)
Tanzania	3.92 (2.52)	6.7 (1.84)	15.07 (2.43)
<b>Entire Region</b>	<b>1.44 (1.25)</b>	<b>2.49 (1.53)</b>	<b>7.93 (2.95)</b>

# Community vs national/international closure spatial model approaches

- Community approach – prioritize protection of degraded areas
  - Select core areas of low biomass, surrounded by “spillover” areas
- National/International approach – prioritize for pristine areas
  - Use Marxan to prioritize for reef area while minimizing Time-to-recovery.
  - Meet targets for 20% of area as conservation, and 50% as sustainable fishing
  - Collaboration to achieve targets between all WIO nations vs no collaboration

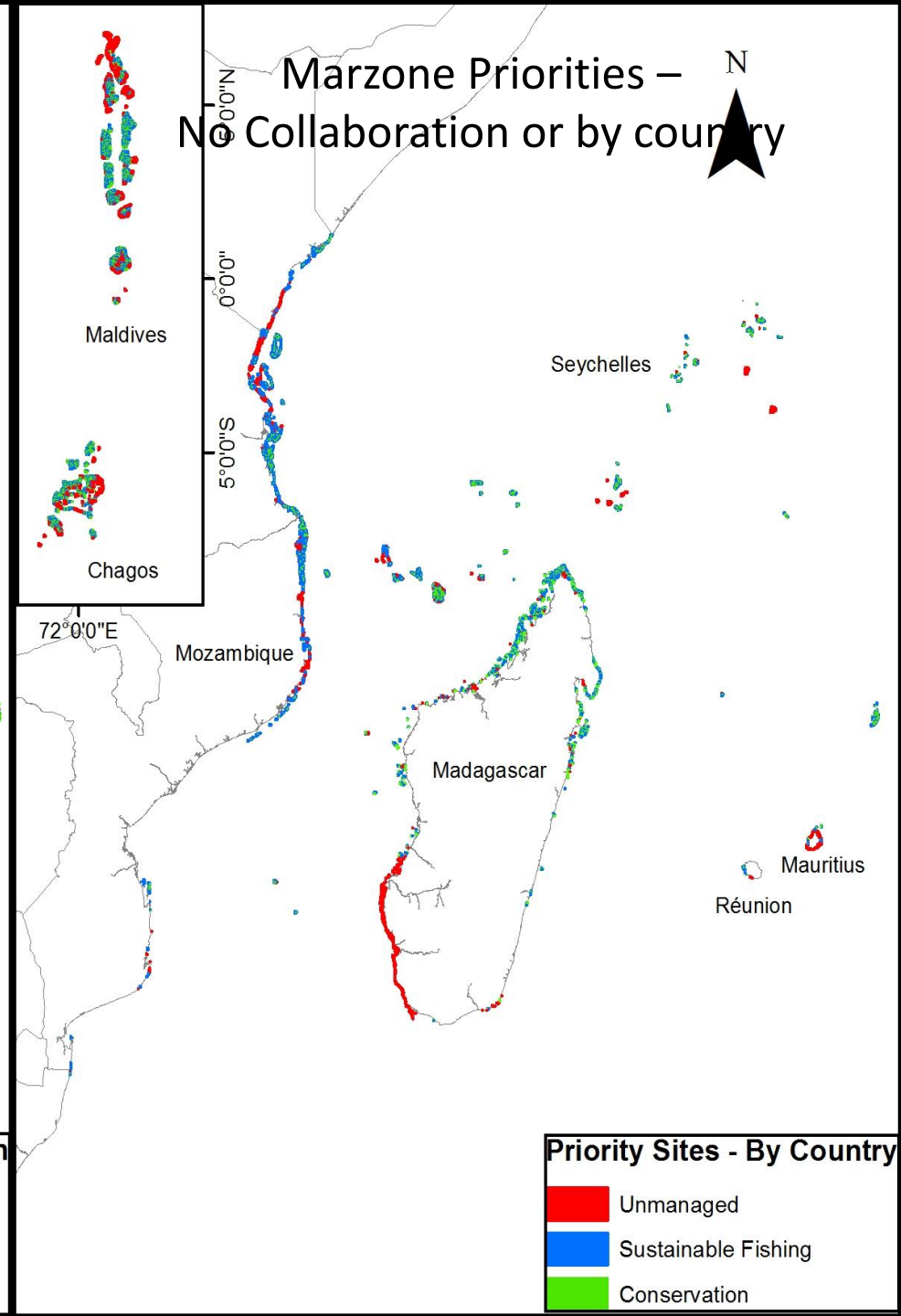
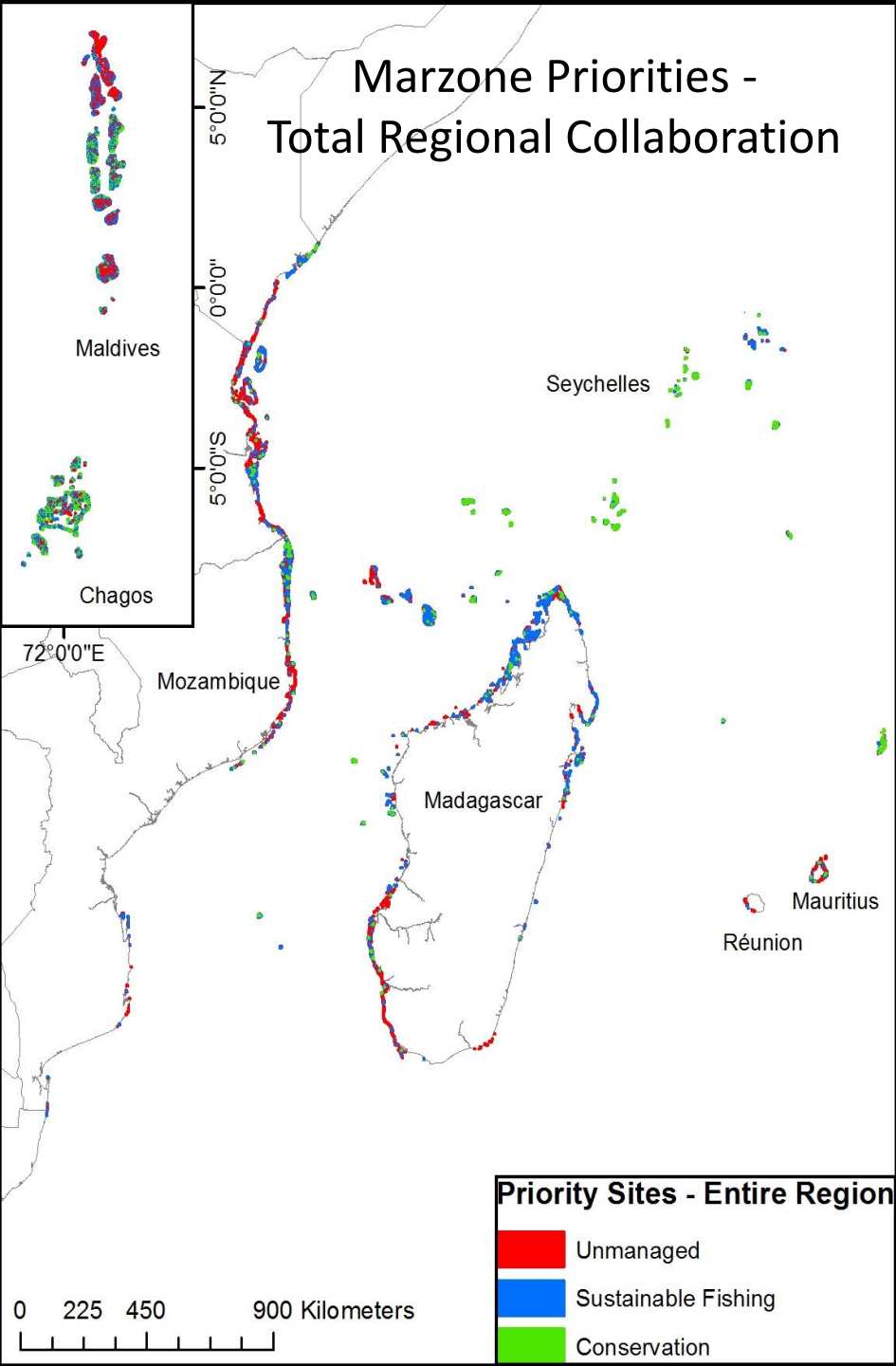


# Biomass depletion priorities for small fisheries closures



Amount of reef (as a percentage of the total in each country) selected in each management type using the biomass depletion prioritization scenario.

<b>Country</b>	<b>Core closure (%)</b>	<b>Spillover (%)</b>	<b>Biomass &gt;450</b>
Bassas da India	0	0	100
British Indian Ocean Territory	0	0	100
Comoro Islands	22.2	30.7	47.2
Glorioso Islands	0	0	100
Ile Europa	0	0	100
Ile Tromelin	0	0	100
Juan de Nova Island	0	0	100
Kenya	16.2	25.1	58.7
Madagascar	27.8	29.1	43.2
Maldives	5.32	6.5	88.2
Mauritius	22.6	26.3	51.1
Mayotte	5.5	13.7	80.8
Mozambique	40.4	46.5	13.1
Reunion	32.9	59.9	7.2
Seychelles	0	0	100
South Africa	0	0	100
Tanzania	39.1	48.7	12.2
<b>Regional average</b>	12.5	16.9	70.7



# Comparing times to recovery (years) for the three prioritization approaches

Country	Marxan - Total Collaboration		Marxan - No Collaboration		Biomass Depletion Prioritisation	
	450 kg/ha (SD)	1150 kg/ha (SD)	450 kg/ha (SD)	1150 kg/ha (SD)	450 kg/ha (SD)	1150 kg/ha (SD)
Bassas da India	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
British Indian Ocean Territory	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Comoro Islands	N/A	N/A	1.45 (1.7)	12.41 (1.46)	3.55 (0.91)	14.11 (0.59)
Glorioso Islands	0 (0)	1.95 (2.99)	0 (0)	0.56 (1.85)	0 (0)	0 (0)
Ile Europa	N/A	N/A	0 (0)	8.36 (0.03)	0 (0)	0 (0)
Ile Tromelin	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Juan de Nova Island	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Kenya	0 (0)	1.1 (2.92)	0.49 (1.71)	5.39 (5.98)	6.96 (1.14)	19.77 (3.31)
Madagascar	1.84 (3.47)	11.56 (7.28)	1.4 (2.79)	11.2 (5.54)	5.43 (3.07)	18.57 (4.56)
Maldives	0 (0)	0.01 (0.25)	0 (0)	0 (0.02)	2.52 (1.58)	13.64 (0.75)
Mauritius	0 (0)	0 (0)	0 (0)	0 (0)	7.30 (0.11)	19.82 (0.35)
Mayotte	0 (0)	0 (0)	0 (0)	9.34 (3.99)	0.26 (0.29)	12.71 (0.14)
Mozambique	0.2 (0.56)	3.78 (5.94)	2.38 (2.24)	12.03 (4.88)	4.62 (1.64)	15.39 (1.71)
Reunion	N/A	N/A	4.42 (3.83)	15.51 (4.35)	5.43 (2.46)	17.12 (2.81)
Seychelles	0 (0)	0 (0.04)	0 (0)	0 (0)	0 (0)	0 (0)
South Africa	N/A	N/A	0 (0)	6.55 ( )	0 (0)	0 (0)
Tanzania	3.51 (2.61)	14.26 (2.18)	2.82 (2.46)	14.1 (1.92)	4.49 (2.2)	15.59 (2.15)
<b>Regional average</b>	<b>0.43 (0.51)</b>	<b>2.51 (1.66)</b>	<b>0.76 (0.92)</b>	<b>5.62 (1.88)</b>	<b>2.39 (0.79)</b>	<b>8.63 (0.96)</b>

# Conclusions

- Reef fish biomass can be modeled by management systems and human pressure with ~60% accuracy
- Recovery of biomass takes ~20-25 years
- The mean time to recovery for the whole region to the conservation threshold is  $7.9 \pm 3.0$  (+ SD)  $2.5 \pm 1.5$  years for high sustainability and  $1.4 \pm 1.3$  for the low sustainability thresholds.
- Recovery time varied considerably with Kenya's southwest Madagascar fringing reefs and portions of Mauritius and Reunion requiring 16 to 26 years where as Tanzania, Mozambique, northern Madagascar and most inhabited islands required moderate times of 4 to 16 years. These are the main areas where the biomass depletion recovery strategy prioritizes action.
- Most of the remote islands, such as Chagos and Seychelles, are already above the suggested threshold biomass levels and regional collaboration will chose these locations but eliminate places like Mauritius and Reunion that have low biomass
- The no-collaboration national model insures more coverage in the region and more redundancy.
- A dual approach that combines the national and the biomass-depleted or community closure model is recommended for future action