Disentangling the effects of habitat and protection on coral reef fish communities in long-established marine reserves

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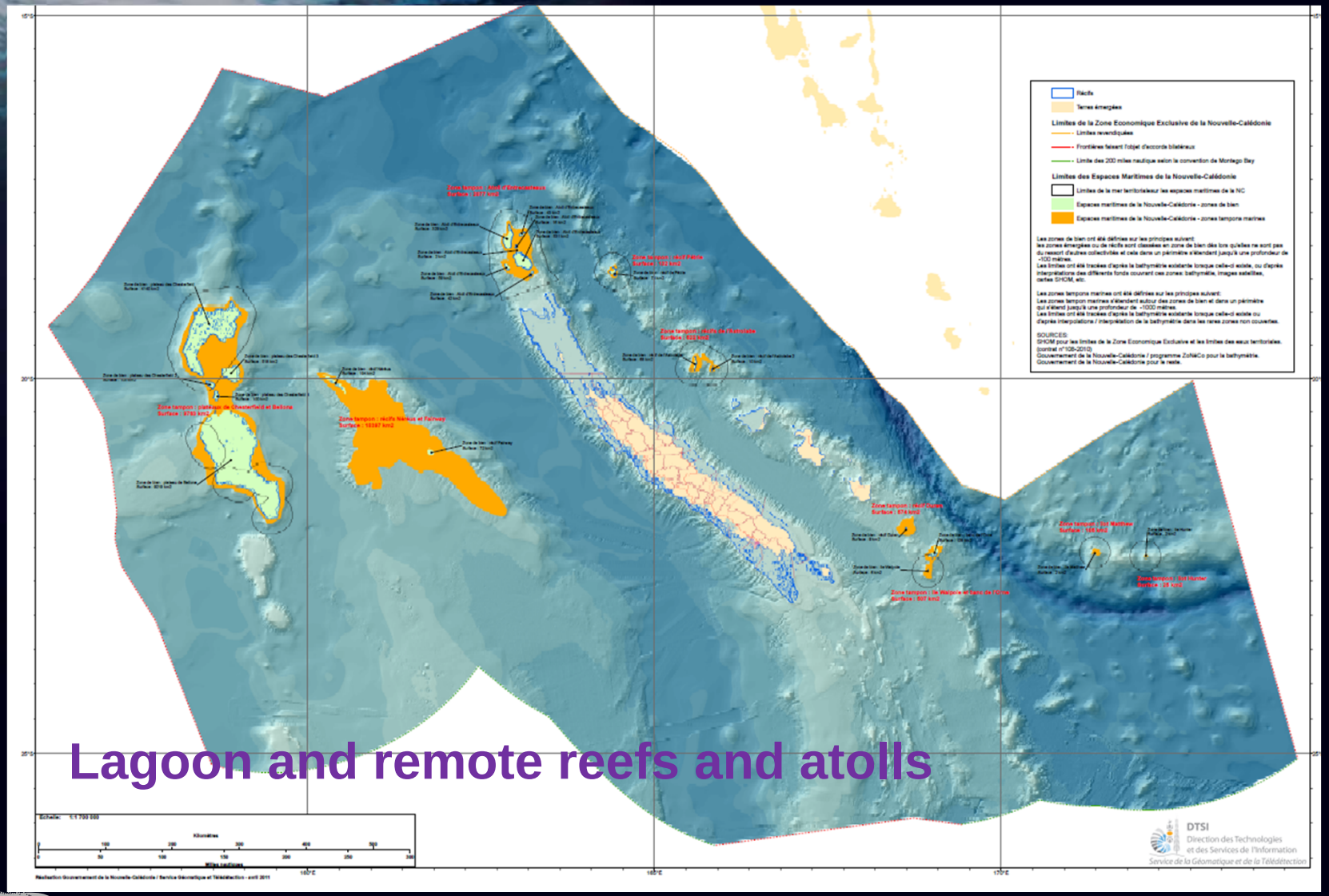
Conservation of shallow biodiversity

Introduction

Management of living resources



Lagoon and remote reefs and atolls

Conservation of coastal biodiversity
Management of living resources

- Marine Protected Areas and World Heritage sites
- Management plan
- Assessment of management effectiveness
- Diagnoses are based on quantitative indicators obtained from monitoring field data
- Diagnoses must assess whether management objectives are reached:
  - Conservation of biodiversity features
  - Sustainable exploitation of fished resources

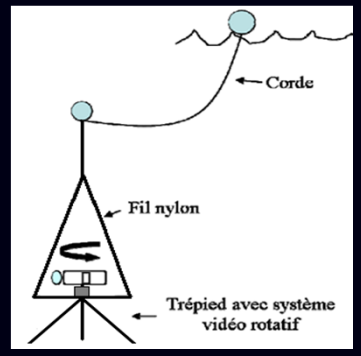
Coral reef ecosystems: Biodiversity features to assess

- Emblematic species such as marine mammals and turtles
- Fish communities:
  - Resources for fishing
  - Functional role in ecosystems
- Fish habitat : biotic and biotic cover and other environmental features
- Fish distribution is linked to habitat characteristics

➢ *Habitat must be taken into account when assessing spatial patterns of fish communities*

Autonomous unbaited underwater rotating video (STAVIRO)

- Sony HD camcorder
- rotates 60° every 30 s
- observation duration 12 min



- system records while set on sea bottom
- system dropped and retrieved from a small boat
- quick implementation
- 20-25 stations / day with 2 systems

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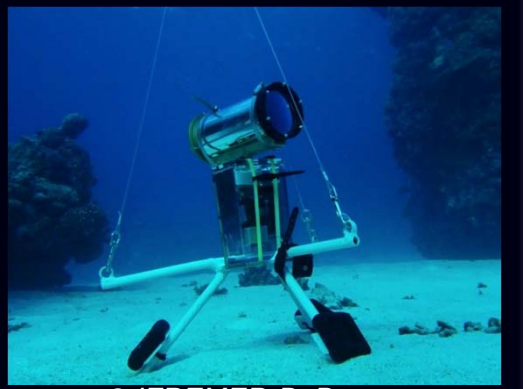

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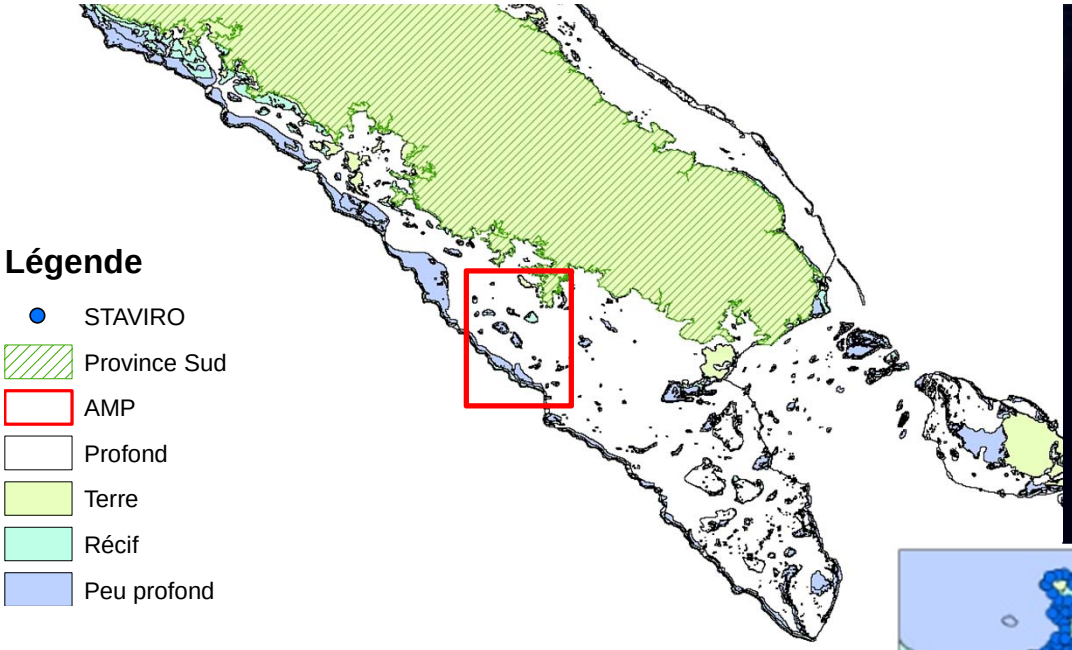
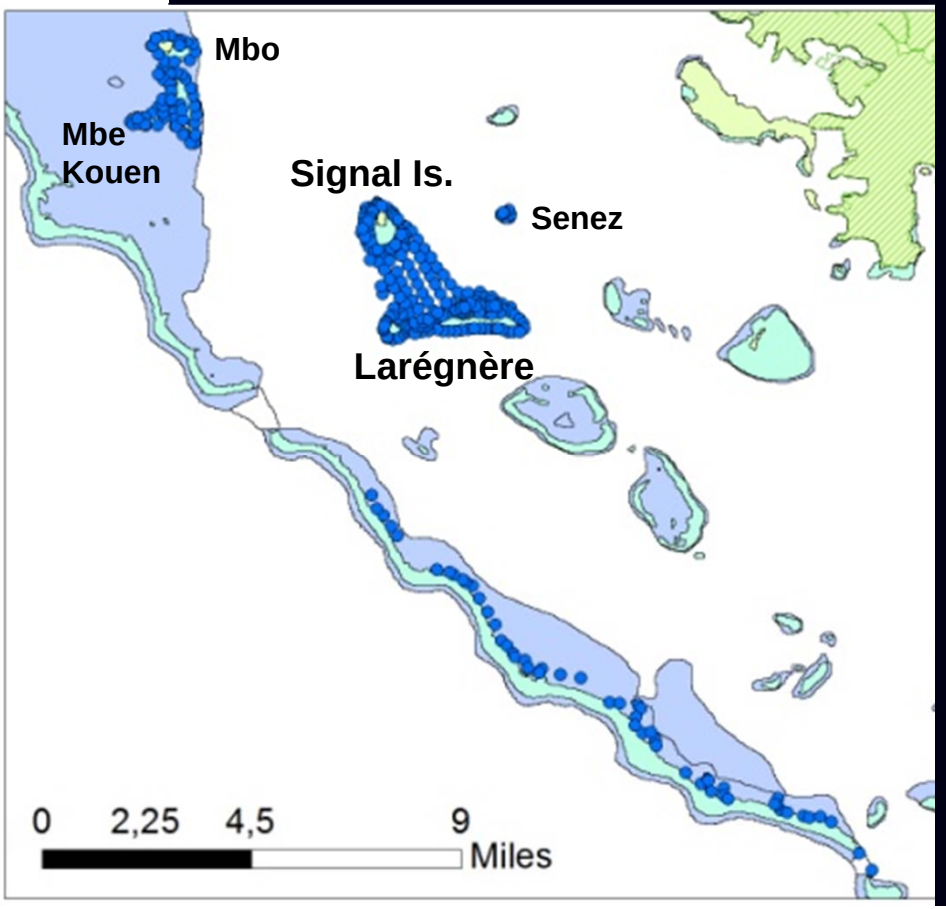
Pelletier et al. 2012. PLoS ONE 7(2): e30536

Study site and Data

2007-2008-2009-2010

565 valid stations on intermediate reefs and islets





- Signal (243 ha) and Larégnère (649 ha) islets have been no-take marine reserves since Jan. 1989
- Unprotected sites : Mbo, Senez, Mbe Kouen, Larégnère Reef

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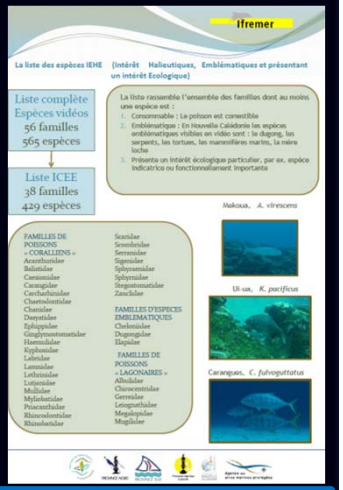
Image analysis

Data processing

- **Fish : Identification and counting:**
  - Species list (565 species)
  - Most precise taxonomic level
  - Computation of species occurrences, species richness and abundance density per species at each station
- **Habitat characterization:** Biotic and abiotic cover, topography, complexity, depth



Species list

- Families with at least one species that is edible, emblematic, or of ecological significance
- Lagoon species that can always be identified on video images: no cryptic, not too deep, adult size larger than 18cm

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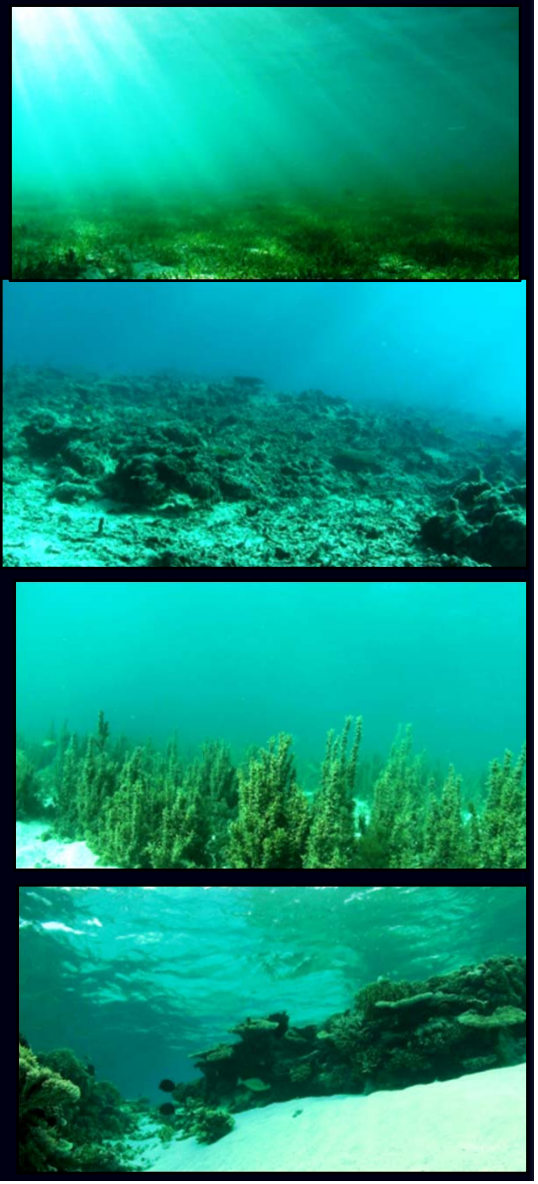
Habitat typology

Data analysis

- Reduction of habitat data to a single variable accounting for all habitat descriptors
- Principal component analysis
- Hierarchical clustering based on Ward criterion
- Achieved on a larget data set involving contrasted sites in New Caledonia (1450 stations)



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Fish data

Data analysis

❑ Spatial patterns of univariate indicators

- **Protection status : inside reserve versus outside reserve**
- **Habitat effect : use of habitat typology as an explanatory factor**
- **General Linear Models + multiple comparisons**
- **Indicators considered : overall density, species richness, density of target species (per gear), density per trophic group**

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Fish data

Data analysis

❑ Multivariate analysis of fish assemblage

- Protection status and Habitat factors
- Density per species, density per family
- Two-way permutational multivariate analysis of variance (PERMANOVA)
- Square-root transformation of data
- Carried out on Bray-Curtis similarity matrix
- Canonical Analysis of Principal Coordinates (CAP)

PERMANOVA: McArdle and Anderson 2001

CAP: Anderson & Willis 2003

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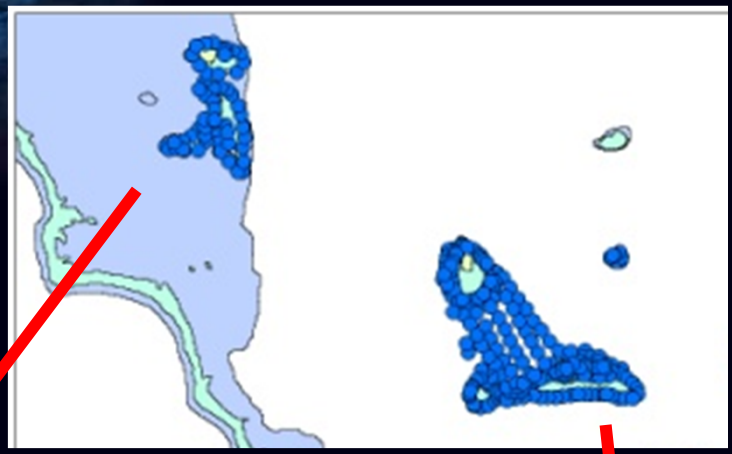
Habitat typology

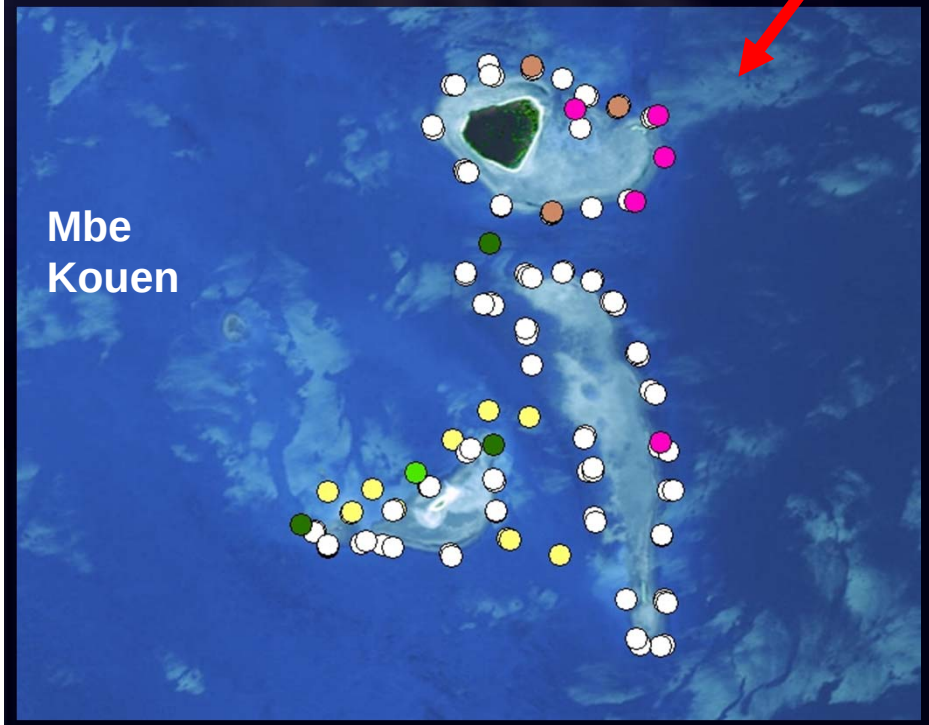
Habitat Cluster (% of stations)	Sand (%)	Rubble (%)	Hard Coral (%)	Boulder (%)	Rock (%)	Slab (%)	Depth (m)	Topography	Complexity	Living coral (%)	Seagrass (%)	Macroalgae (%)
Seagrass (20%)	**94.6**	3.1	1.5	0.1	0.2	0.4	8.0	1.2	2.7	0.9	**62.5**	6.2
Macroalgae (12%)	**90.7**	7.3	1.3	0.1	0.4	0.2	9.0	1.3	1.9	0.9	11.6	**53.7**
Sand (32%)	**85.6**	6.9	5.3	0.5	0.6	1.2	8.8	1.2	1.3	4.0	5.4	5.4
Live coral (6%)	17.5	11.8	**60.2**	0.8	1.5	9.0	4.2	**2.2**	**3.0**	**44.2**	0.0	2.3
Boulders and rocks (2%)	27.1	15.8	19.5	**20.0**	14.4	8.9	6.9	2.1	2.7	13.4	0.4	1.5
Debris (28%)	27.8	**34.3**	18.5	1.7	3.3	**15.7**	5.3	1.5	2.2	10.2	0.5	2.4

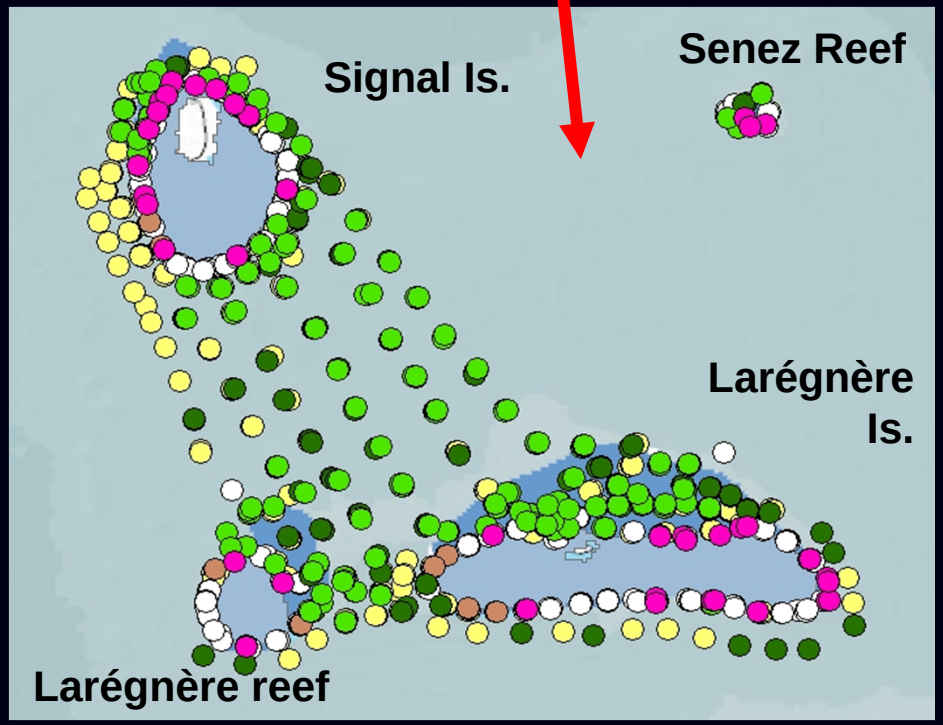
Habitat typology

Results

Seagrass
Macroalgae
Sand
Live coral
Boulders and rocks
Debris







Univariate analysis of fish data

Results

Metric	Status only	Status + Habitat
Overall density	NS	NS
Species richness	NS	NS
Density of spearfished species	NS	larger in RE ($p<0.013$)
Density of line target species	NS	NS
Density of net target species	NS	larger in sea grass ($p<0.054$)
Density of carnivores	NS	larger in RE ($p<1.7.10^{-5}$) in sea grass and macroalgae
Density of herbivores	larger in RE ($p<0.012$)	status*habitat interaction ($p<2.6.10^{-7}$)
Density of piscivores	NS	larger in RE on coral habitat ($p<0.0004$)
Density of plankton feeders	NS	larger HR ($p<0.016$)
Presence of marine turtles	NS	NS

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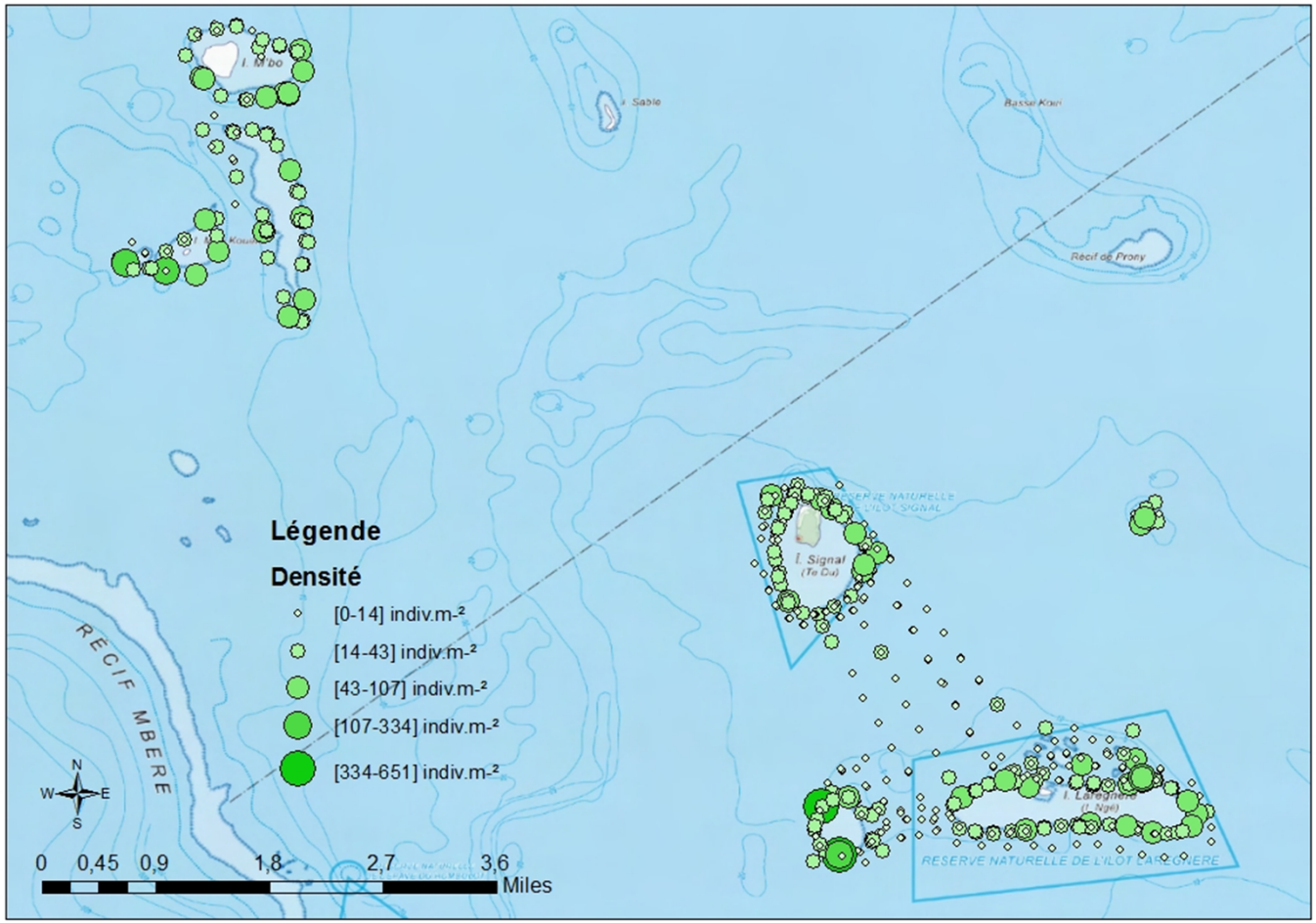
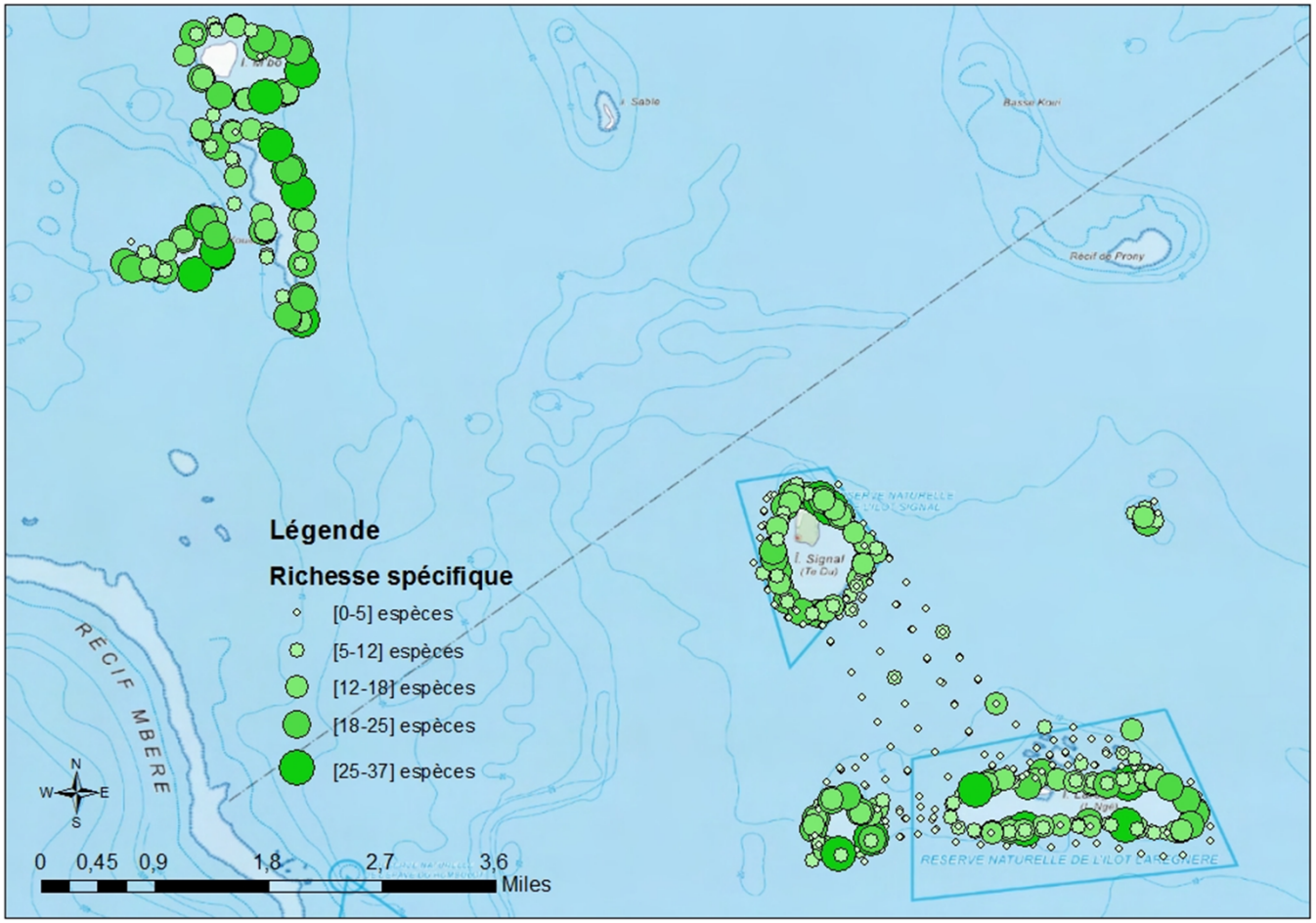
Species richness



Overall abundance density



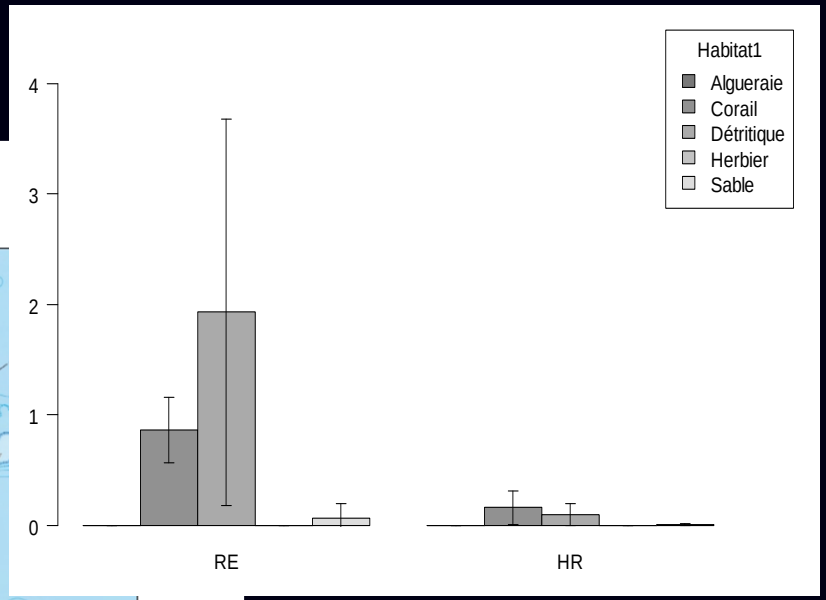
Response of target species to protection

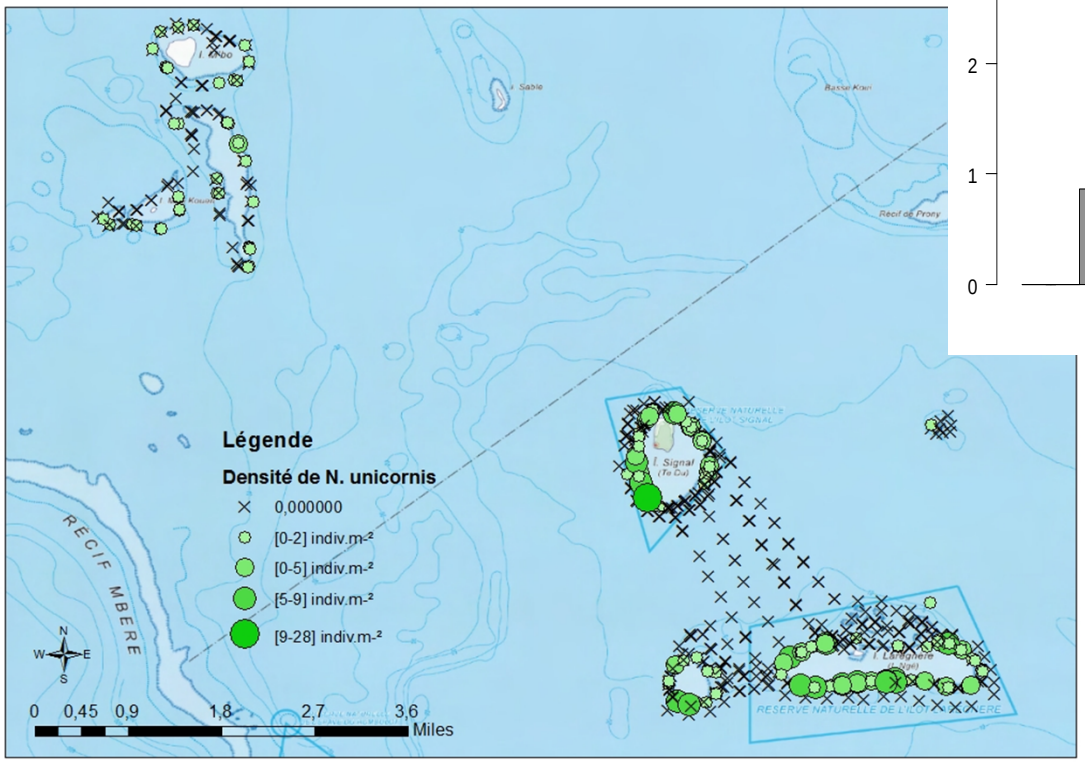
Species	Fishing gear	Protection	Habitat effect	Observed in
Bluespine unicornfish (*Naso unicornis*)	Spear fishing & Nets	*** (p<9e-6)	*** (p<2.2e-16)	Live coral and debris habitats
Coral trout (*Plectropomus leopardus*)	Spear fishing	NS	Sea grass: RE>OR but NS	Live coral and debris habitats
Spangled emperor (*Lethrinus nebulosus*)	Line fishing	NS	Live coral: RE>OR (p<0,055)	Sea grass and sandy habitat

Univariate analysis of fish data

Response of target species to protection

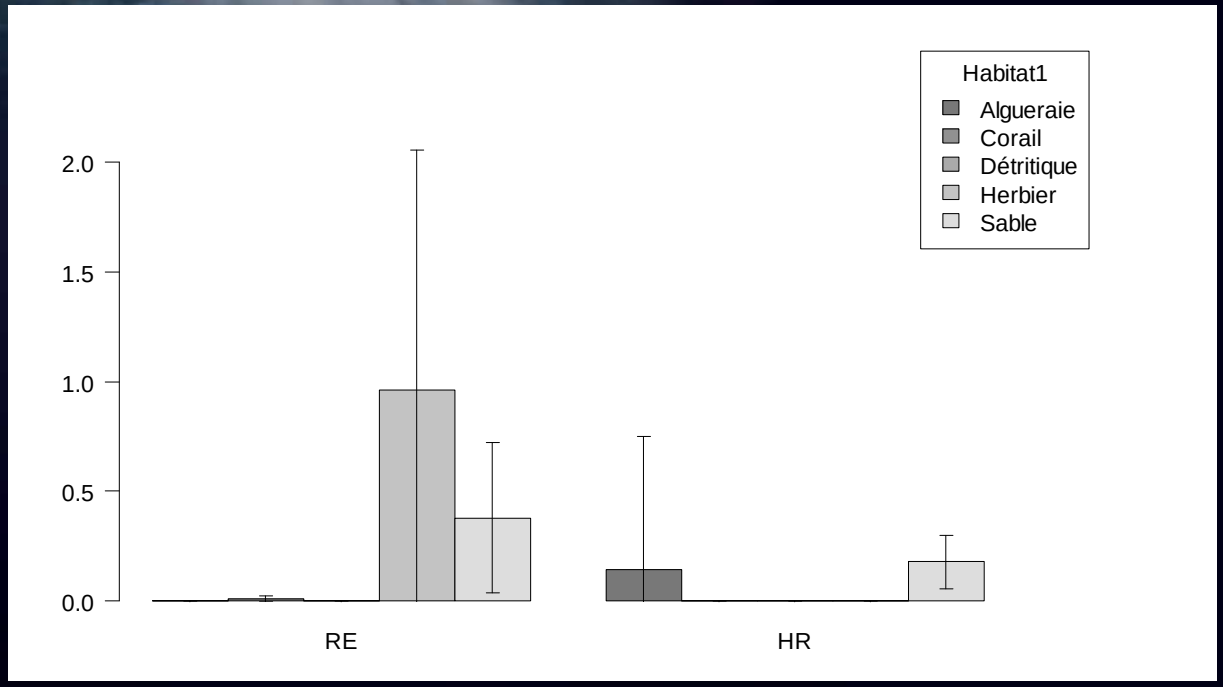
Results





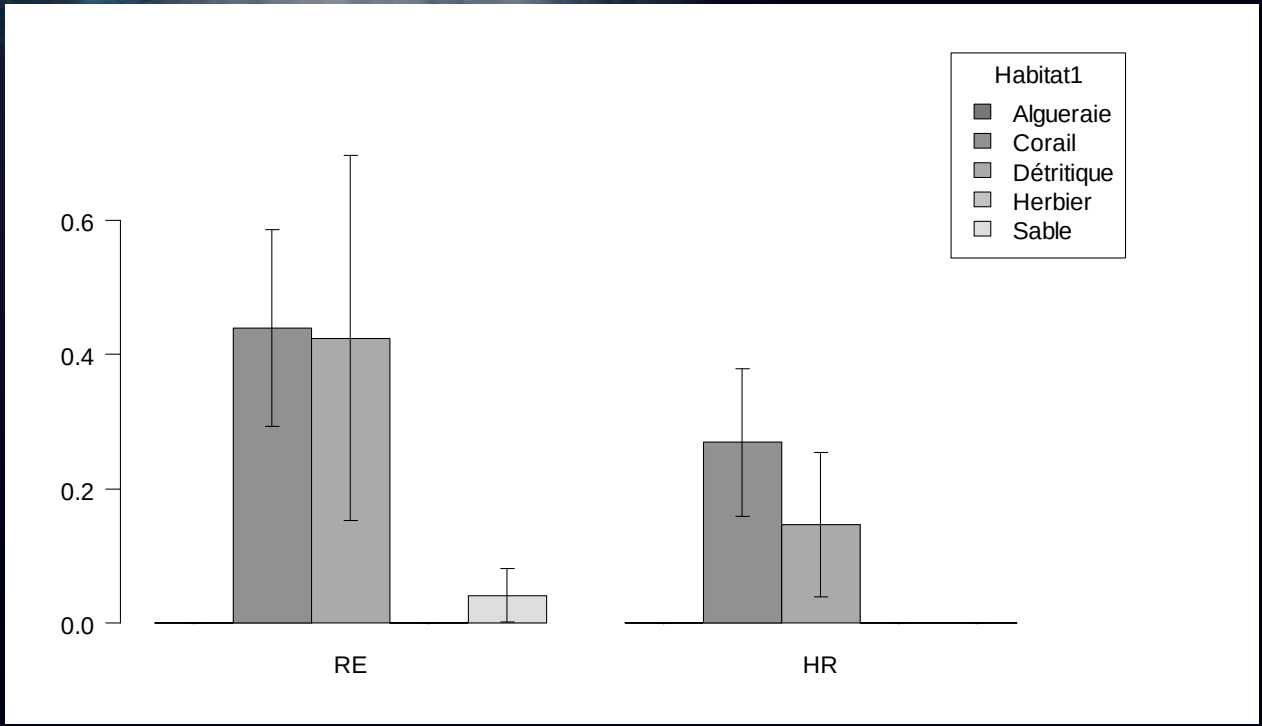
Density of blue spine unicorn fish

Response of target species to protection



Density of spangled emperor

Response of target species to protection



Density of coral trout

Multivariate analysis of fish assemblage (abundance density) : PERMANOVA

Results

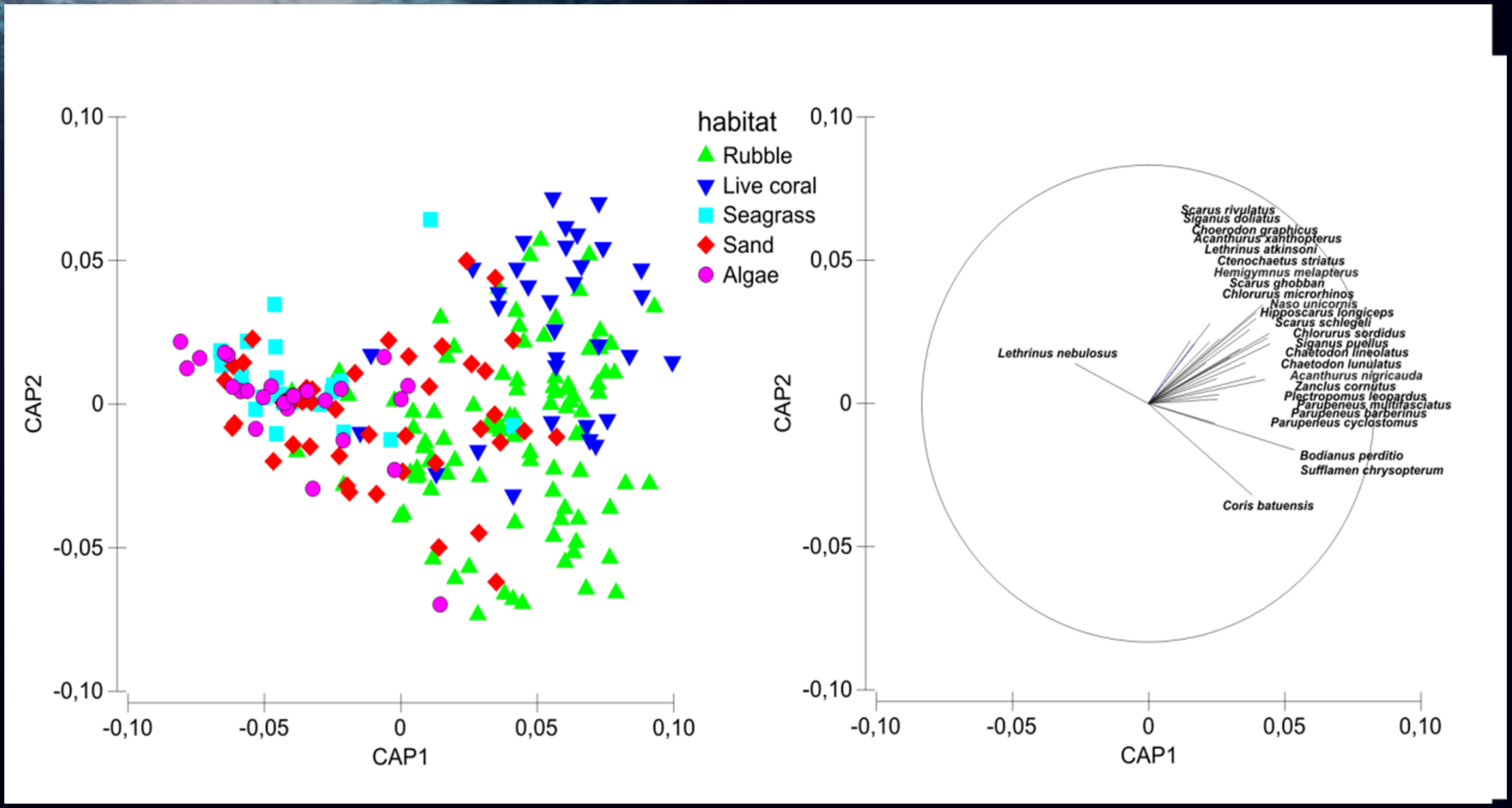
Level of taxonomic aggregation	Factors included in PERMANOVA	df	Pseudo-F	p(perm)
Species assemblage	status	1	3,7019	**0,0012**
	habitat	4	24,811	**0,0001**
	statusxhabitat	4	1,8998	**0,0022**
Family composition	status	1	2,6583	**0,0378**
	habitat	4	47,113	**0,0001**
	statusxhabitat	4	1,6446	0,0635
Trophic structure	status	1	2,5939	0,0613
	habitat	4	55,331	**0,0001**
	statusxhabitat	4	1,5861	0,1079

Multivariate analysis per habitat

Results

Metric	Factor included		df	Pseudo-F	p(perm)
Species assemblage	Status	Coral	1	2,1198	**0,0011**
		Seagrass	1	1,1925	0,2515
		Algae	1	0,39796	0,9717
		Sand	1	1,5891	0,0973
		Debris	1	7,8614	**0,0001**
Family composition	Status	coral	1	2,4209	**0,0114**
		seagrass	1	1,5812	0,1453
		algae	1	0,29259	0,907
		sand	1	0,86676	0,455
		debris	1	5,8416	**0,0001**
Trophic structure	Status	coral	1	2,0511	0,0708
		seagrass	1	0,5048	0,6612
		algae	1	3,59E-02	0,9853
		sand	1	0,86676	0,455
		debris	1	5,8416	**0,0001**

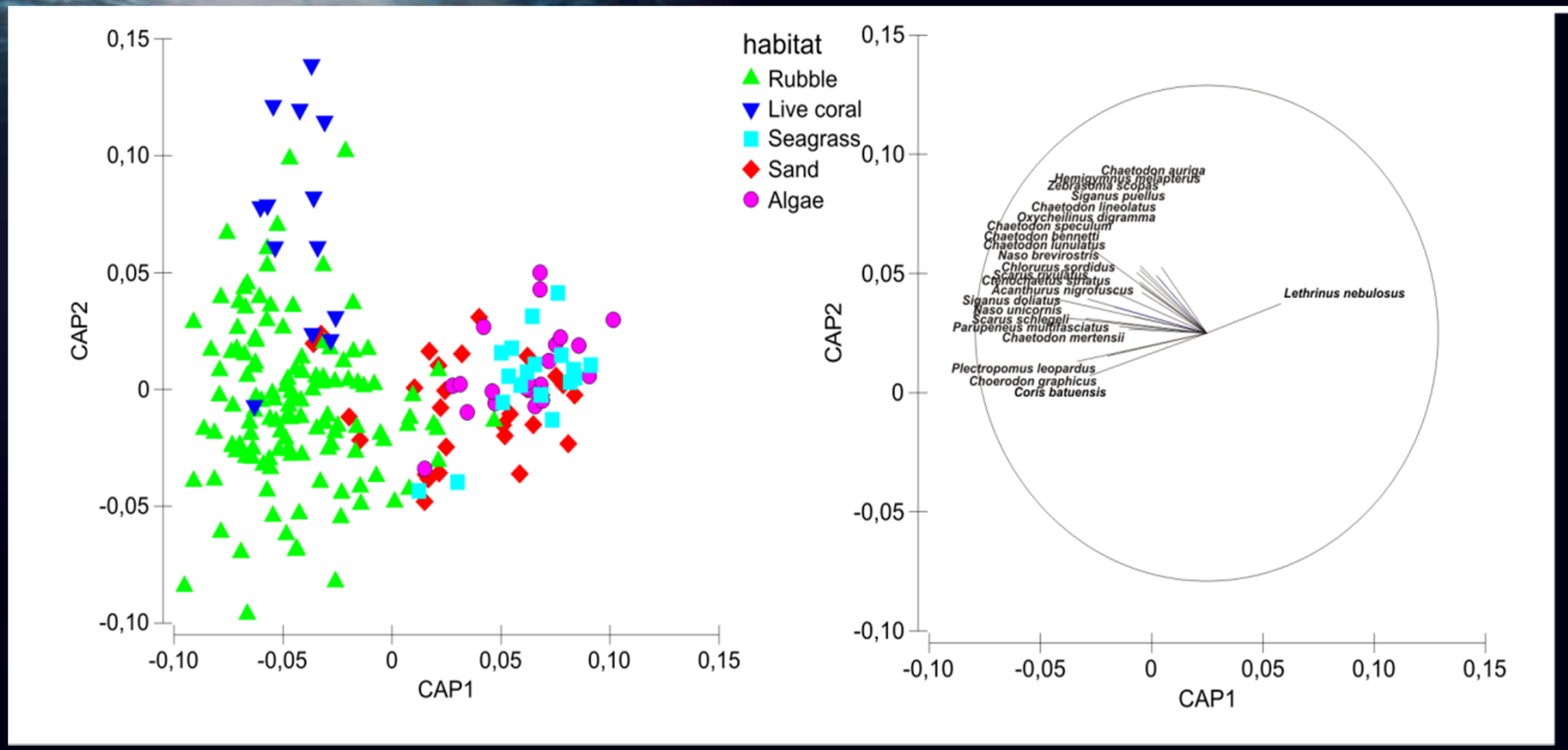
Multivariate analysis of fish assemblage
Canonical Analysis of Principal Coordinates



INSIDE RESERVE

Vectors : species with Spearman rank correlations > 0.3 with the two CAP axes

Multivariate analysis of fish assemblage
Canonical Analysis of Principal Coordinates



OUTSIDE RESERVE

Vectors : species with Spearman rank correlations > 0.3 with the two CAP axes

Main outcomes

❑ Univariate metrics

- More significant protection effects when habitat is taken into account, e.g. overall density, species richness, density of spear fished species
- Detection of protection effects in sea grass habitat for important target species

❑ At the assemblage level

- Protection effects observed at species, family and trophic group levels
- Protection effects more apparent in live coral and debris habitats
- Debris Habitat: Significant protection effects at all three taxonomic levels

Conclusion

- Habitat data are needed to investigate and assess the ecological effectiveness of protection measures
- Data in all lagoon habitats are needed
- Replication must be sufficient to test factors explaining spatial patterns
- Our video technique enables to

- Sample both fish and habitat at no extra cost
- Ensure a sufficient replication level for spatial replication and design involving all relevant lagoon habitats

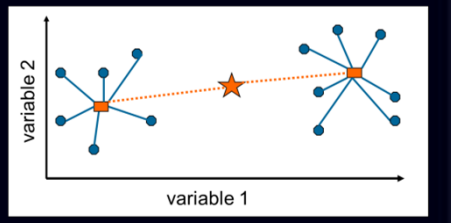
Perspectives

- Utilize this large data set for quantitative investigation of questions such as scaling-up to territory level, link with environmental variables, relationships between observed taxa, relationships with anthropogenic pressures observed in the lagoons
- Optimization of sampling design based on extensive data set
- Automate image analysis

PERMANOVA

- **Bray-Curtis similarity index between two vectors**

$$BC_{jk} = \frac{2\sum_{i=1}^{p} min(N_{ij}, N_{ik})}{\sum_{i=1}^{p}(N_{ij} + N_{ik})}$$



where Nij is the abundance density of species i at station j

- **Sum of squares decomposed from dissimilarity matrix**
- **Permutation tests for significance of SSQ**

CAP

Anderson & Willis 2003

- Constrained ordination based on any dissimilarity measure, here MDS
- Canonical correlation analysis

➢ ***To correlate original variables with the canonical axes***