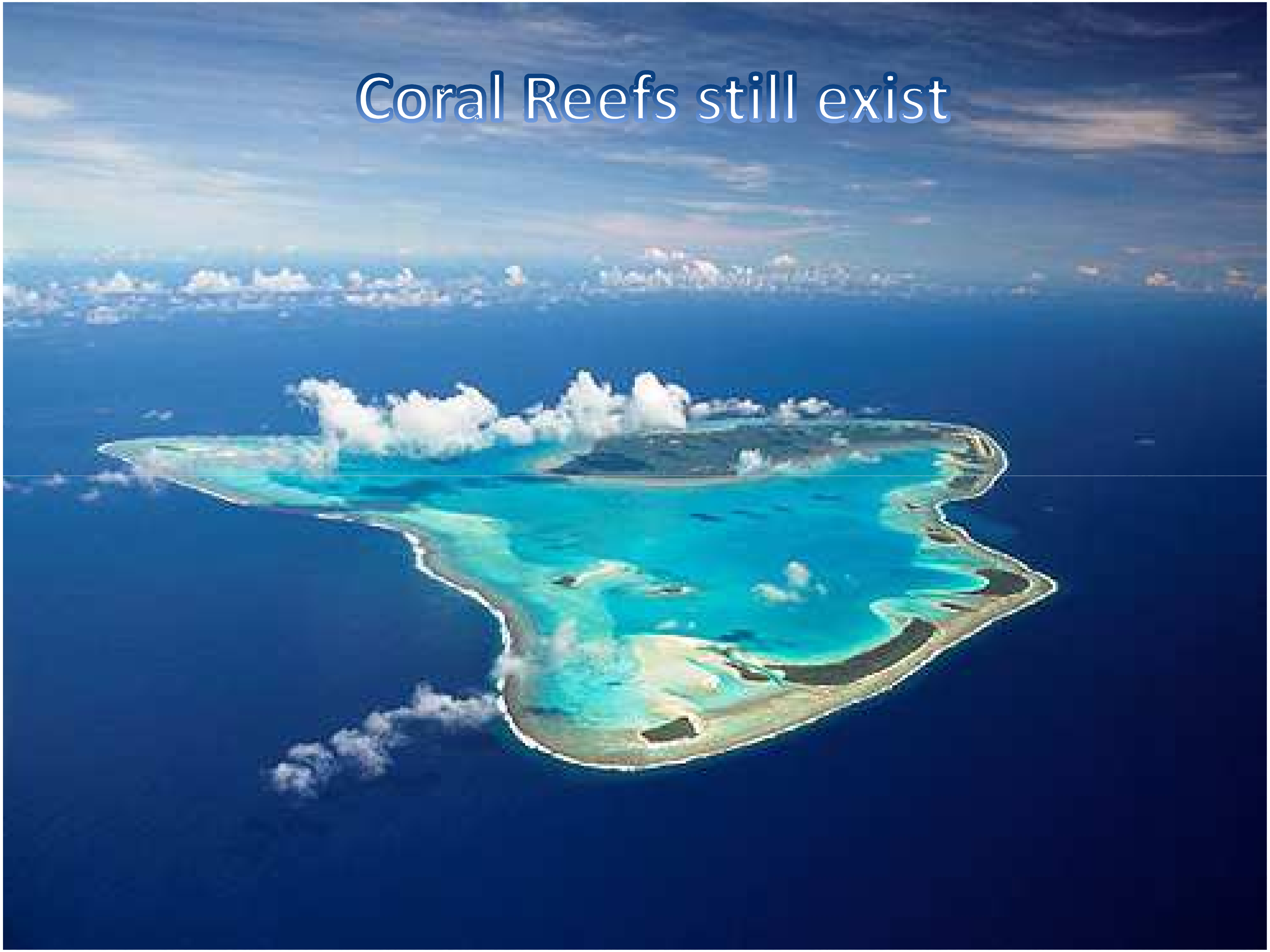
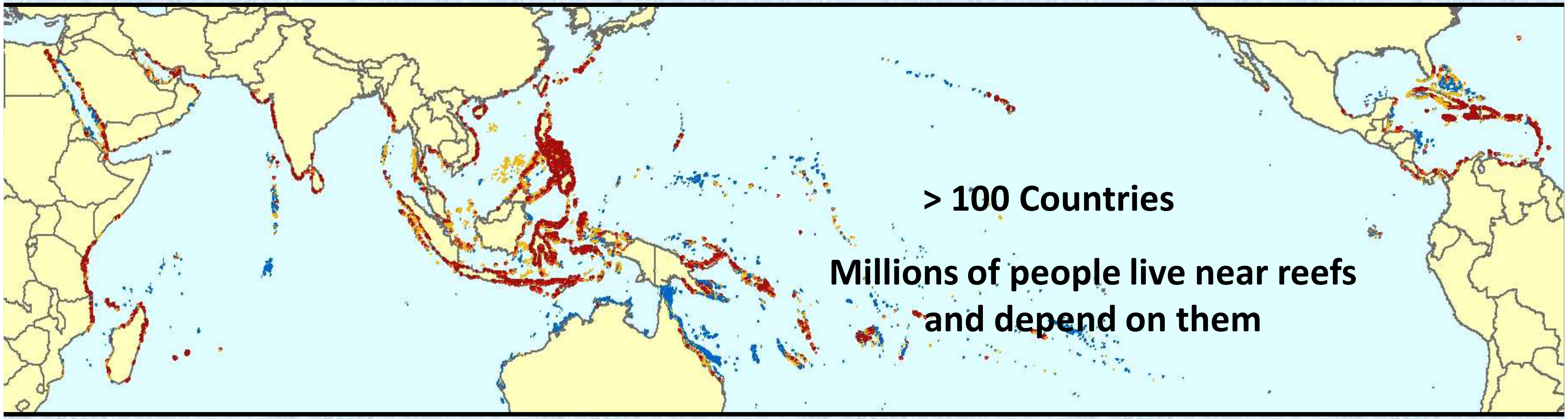
Investigating large scale patterns to try to understand local processes

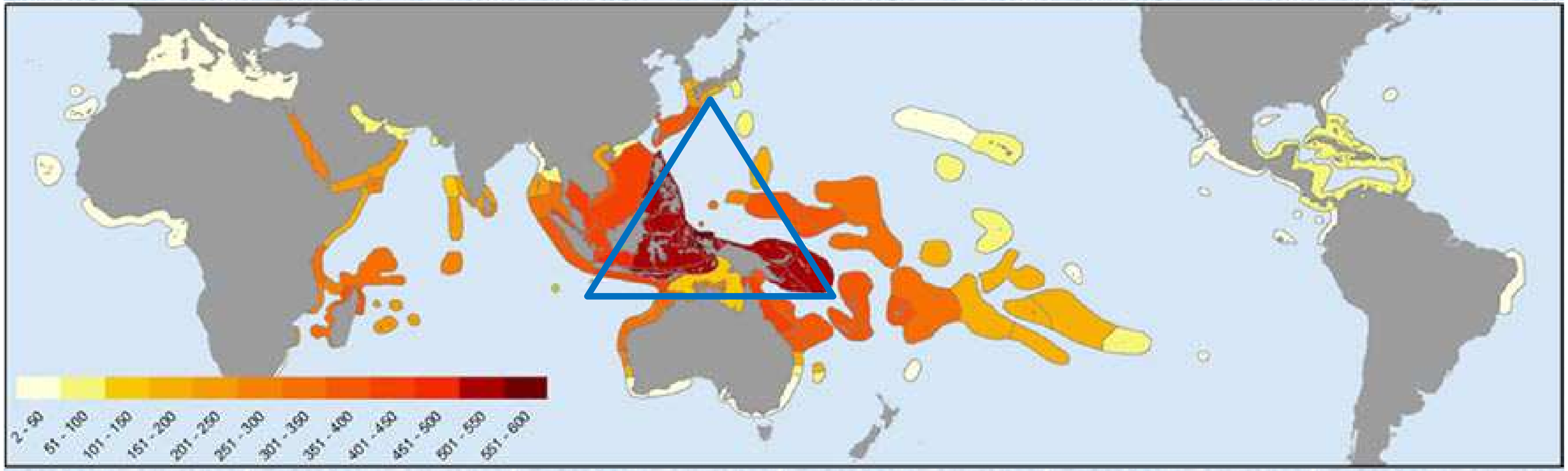
The exemple of Reef Fishes

The GASPAR Group
presented by Michel KULBICKI – IRD- UR 227 – CoReUs – Banyuls/mer - France

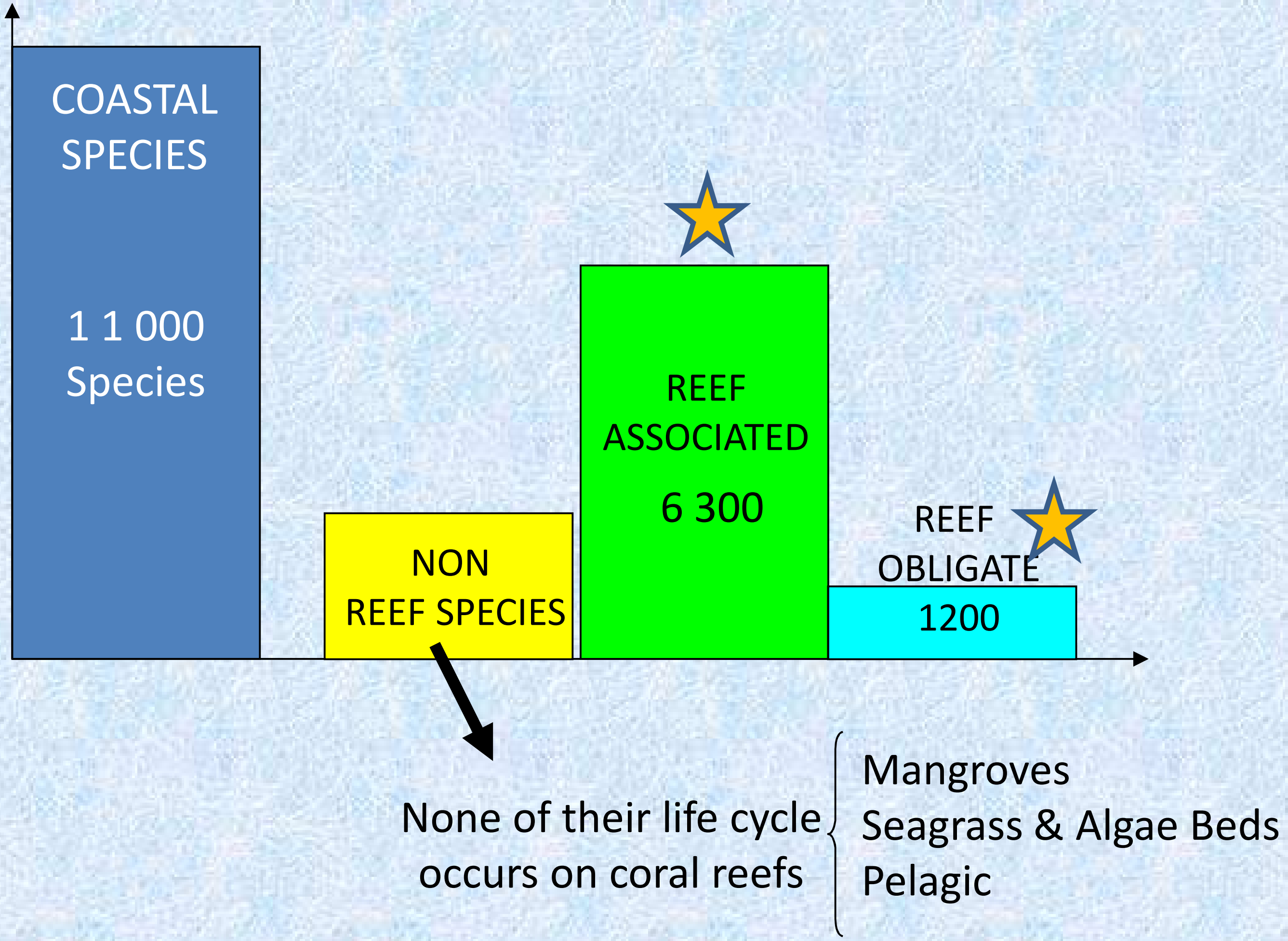

Coral Reefs still exist

Where are Coral Reefs ?

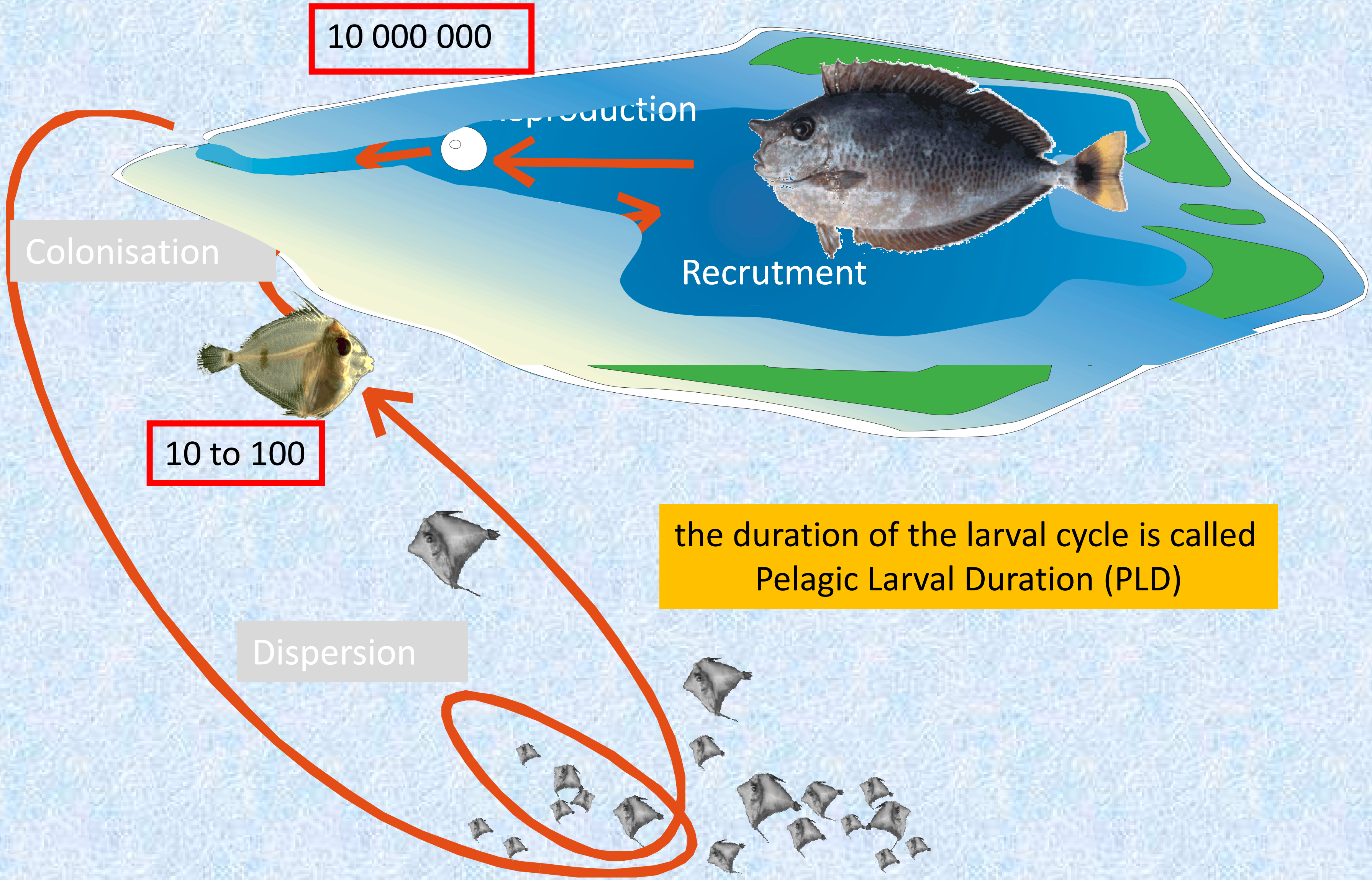




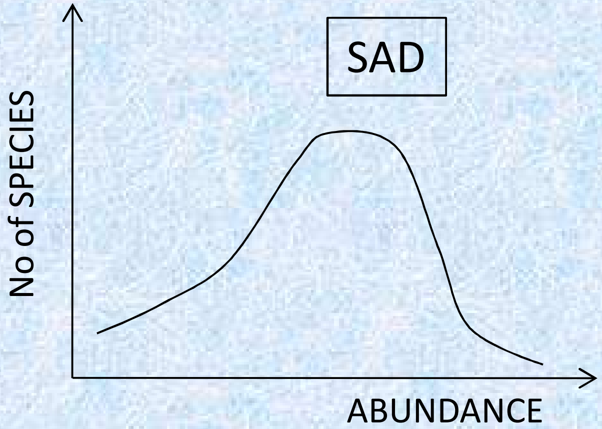
Reef Fishes – How many battalions ?

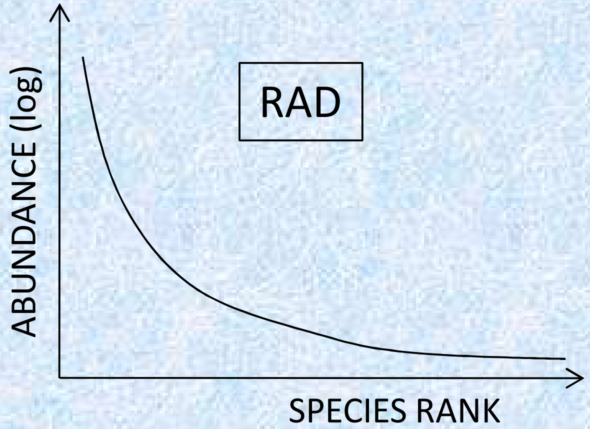


Life cycle of a reef fish



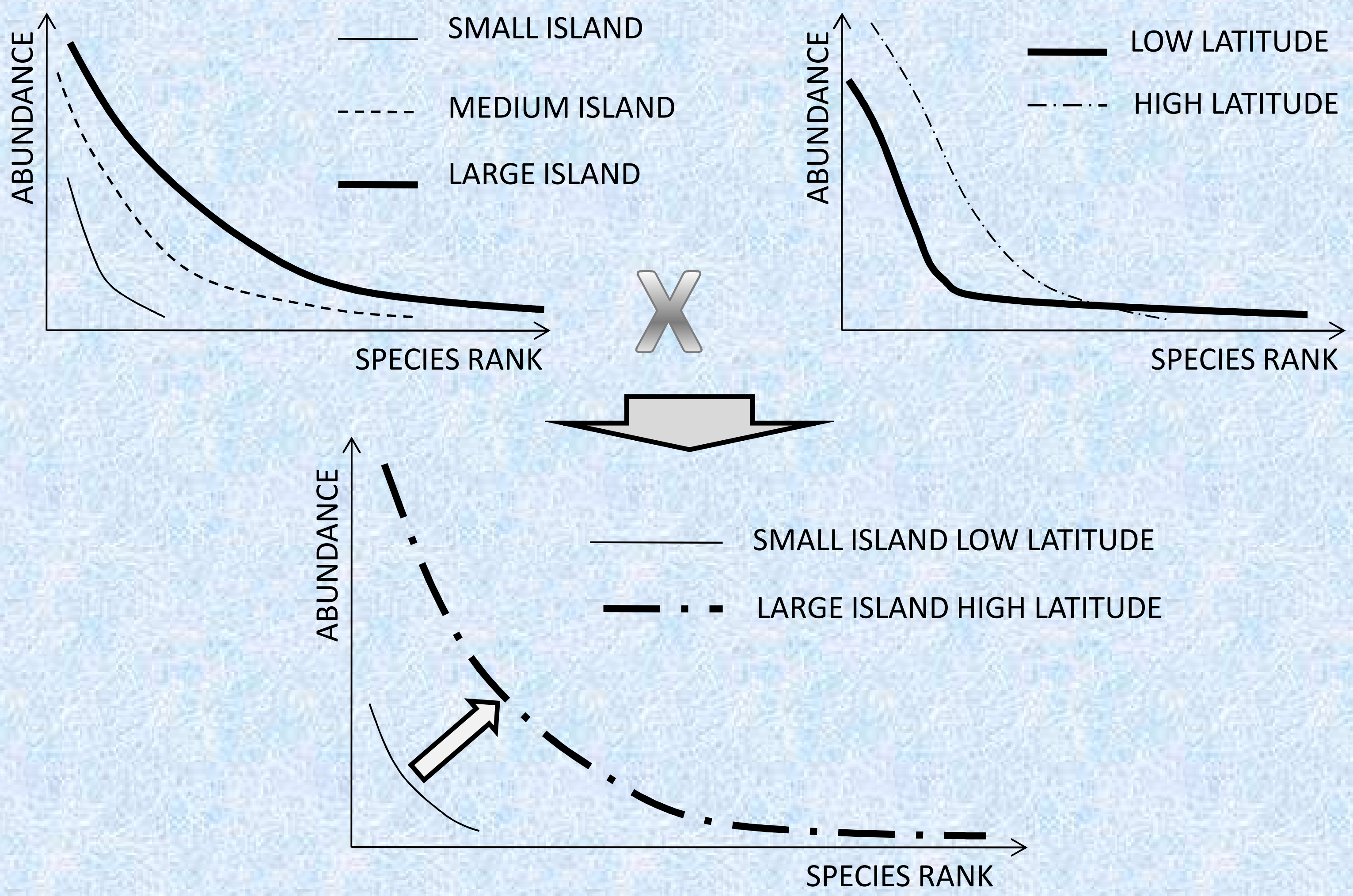
Why were we interested by Reef Fish global diversity ?

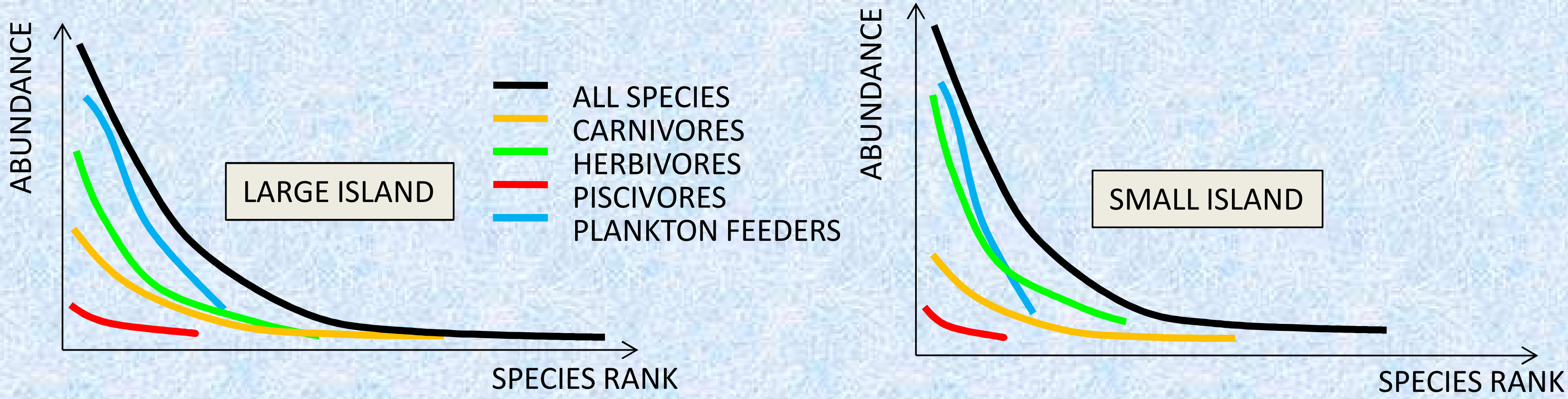




Explain local abundance according to both LOCAL & REGIONAL factors

Include intrinsic factors (Life-history traits)


SMALL ISLAND
MEDIUM ISLAND
LARGE ISLAND
ABUNDANCE
SPECIES RANK
LOW LATITUDE
HIGH LATITUDE
ABUNDANCE
SPECIES RANK
X
ABUNDANCE
SMALL ISLAND LOW LATITUDE
LARGE ISLAND HIGH LATITUDE
SPECIES RANK



Knowing the Life History Traits of species

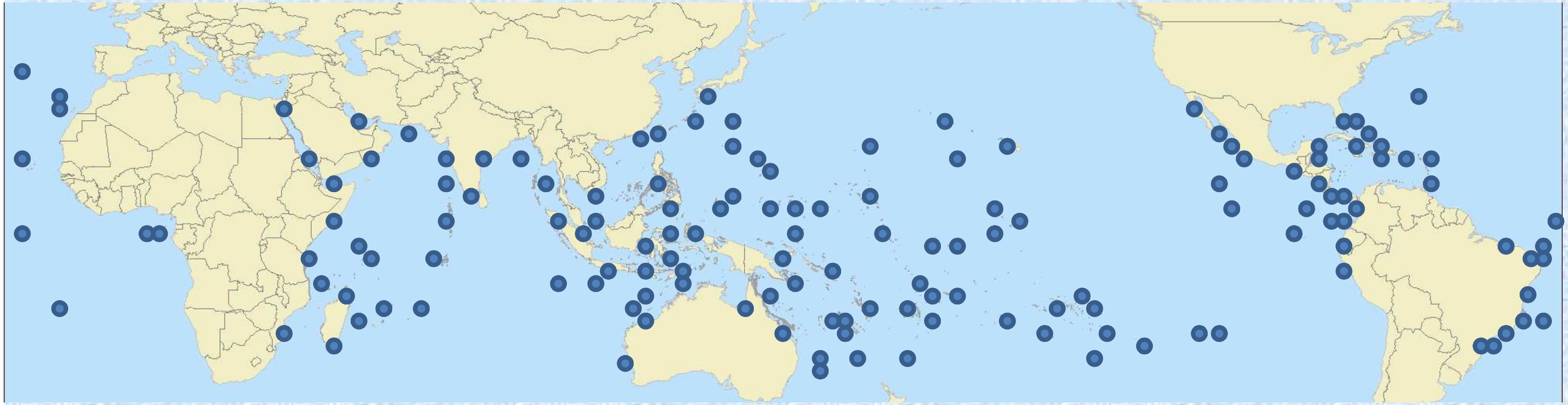
Finding out about assembly rules for species & traits

Access reliable abundance data

Access data on the physical, biogeochemical and human factors

3 year program GASPAR

Checklists (165) – 6300 teleost species



LHT: Diet, Size, Schooling, Home Range, Level in the water

Other traits for some species (PLD; growth; depth range and so on)

Physical , biogeochemical & human related data

Island and coral reef size

Island isolation

Geomorphological diversity of coral reefs

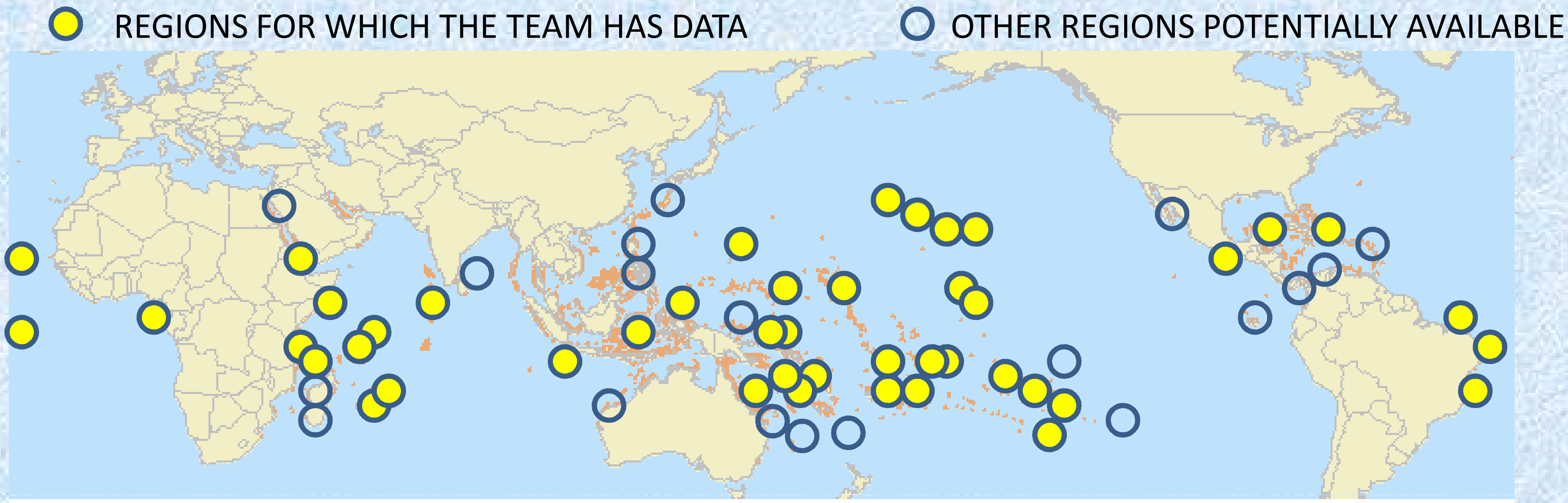
SST, salinity, chlorophyll and so on

Human density

MPAs : location, surface, status

Field Observations (UVC)

(1.5 million records + ~ 1 million additional)



- 12 000 transects

Species composition

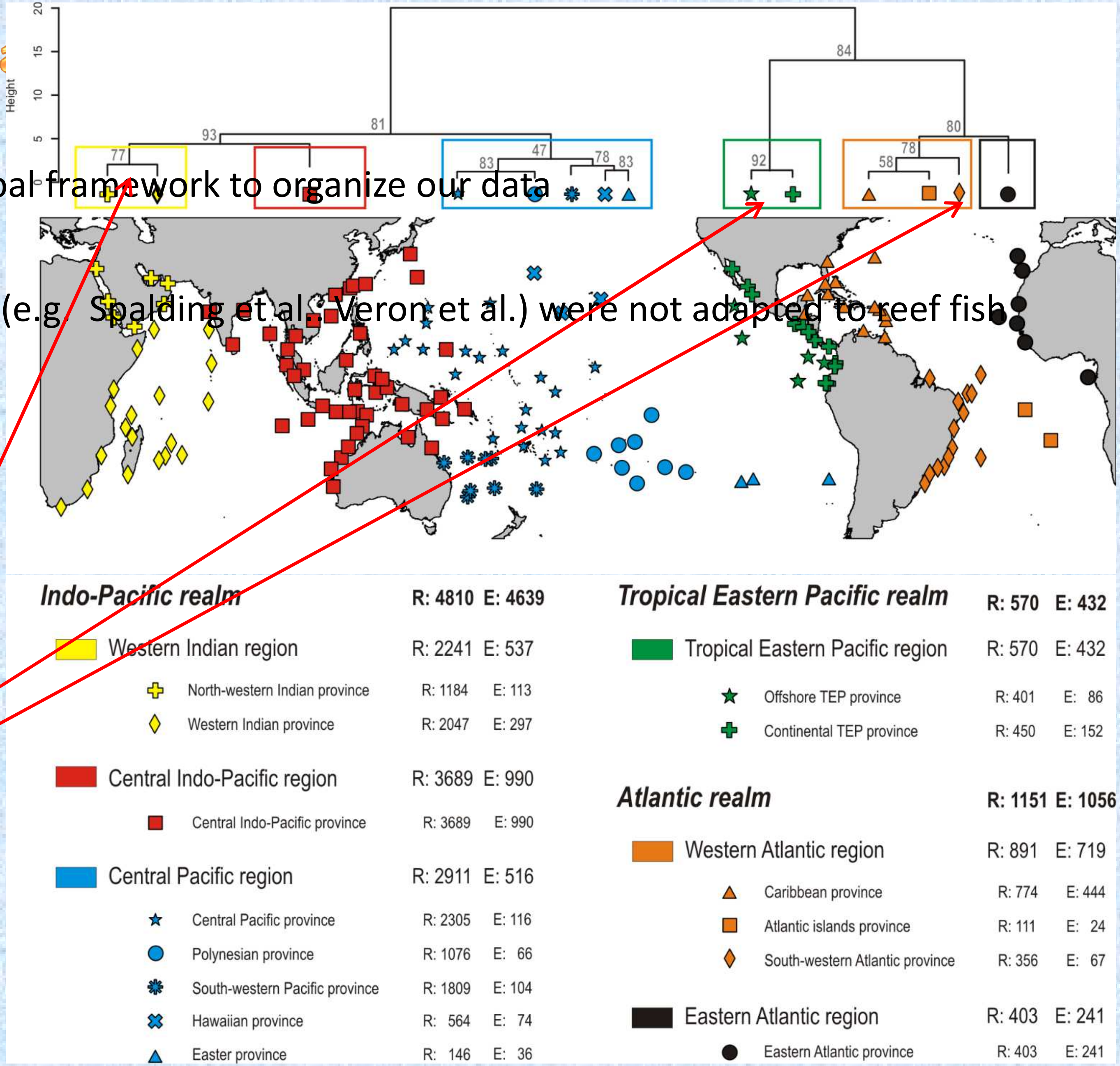
Abundance
Size distribution
} Biomass ; ~ Production

Benthic landscape

Biogeographica

Need for a global framework to organize our data

Existing limits (e.g. Spalding et al., Veron et al.) were not adapted to reef fish



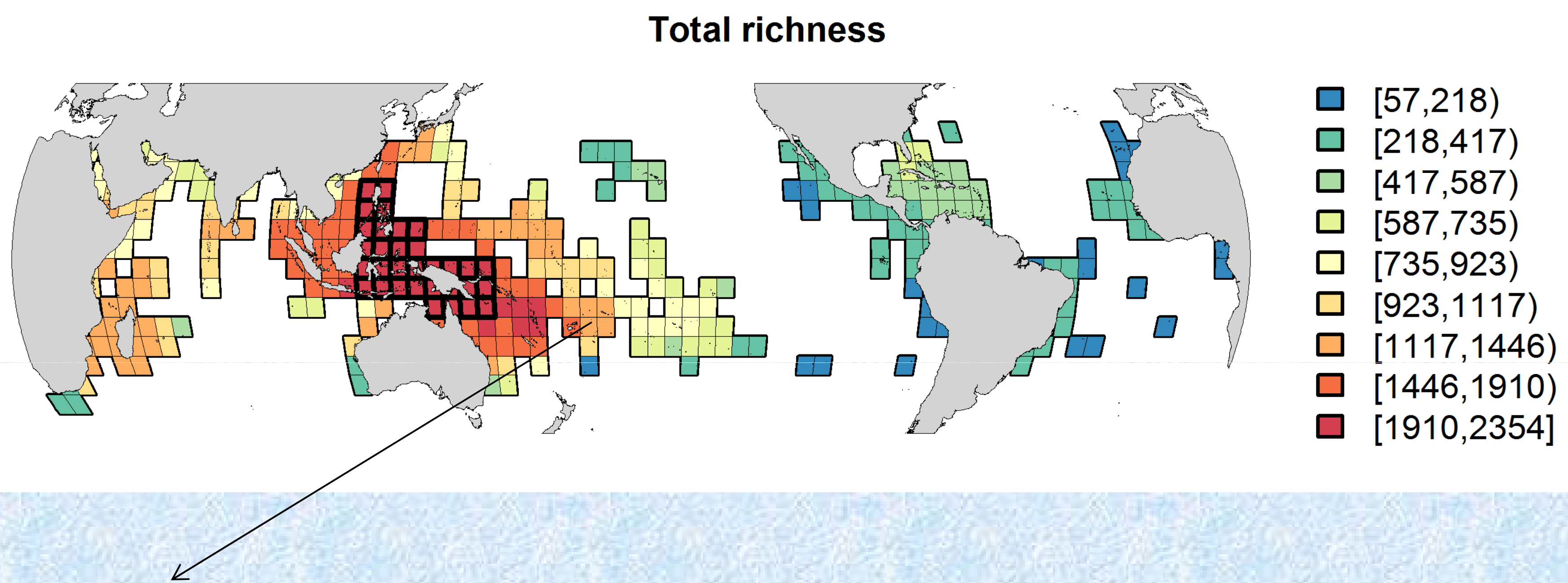
6300 species

Disimilarity

3 Realms
6 regions
14 provinces

Kulbicki et al. (2013) Global Biogeography of Reef Fishes: A Hierarchical Quantitative Delineation of Regions. Plos One 8(12)

Mouillot et al. . 2013 The challenge of delineating biogeographical regions: nestedness matters. Journal of Biogeography

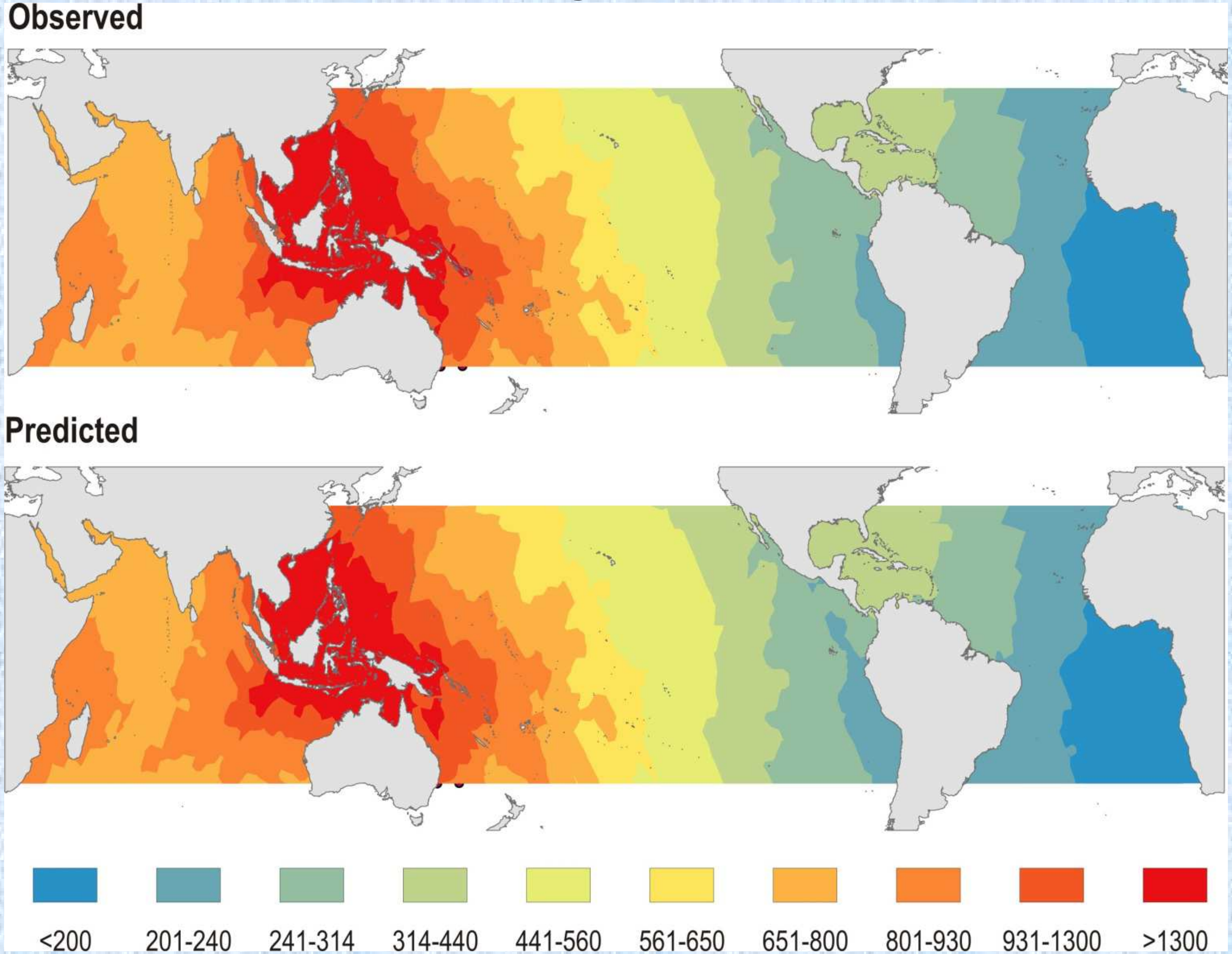


For each cell:

- Species composition
- Life-History Traits distribution
- Physical and biogeochemical factors
- Human associated data

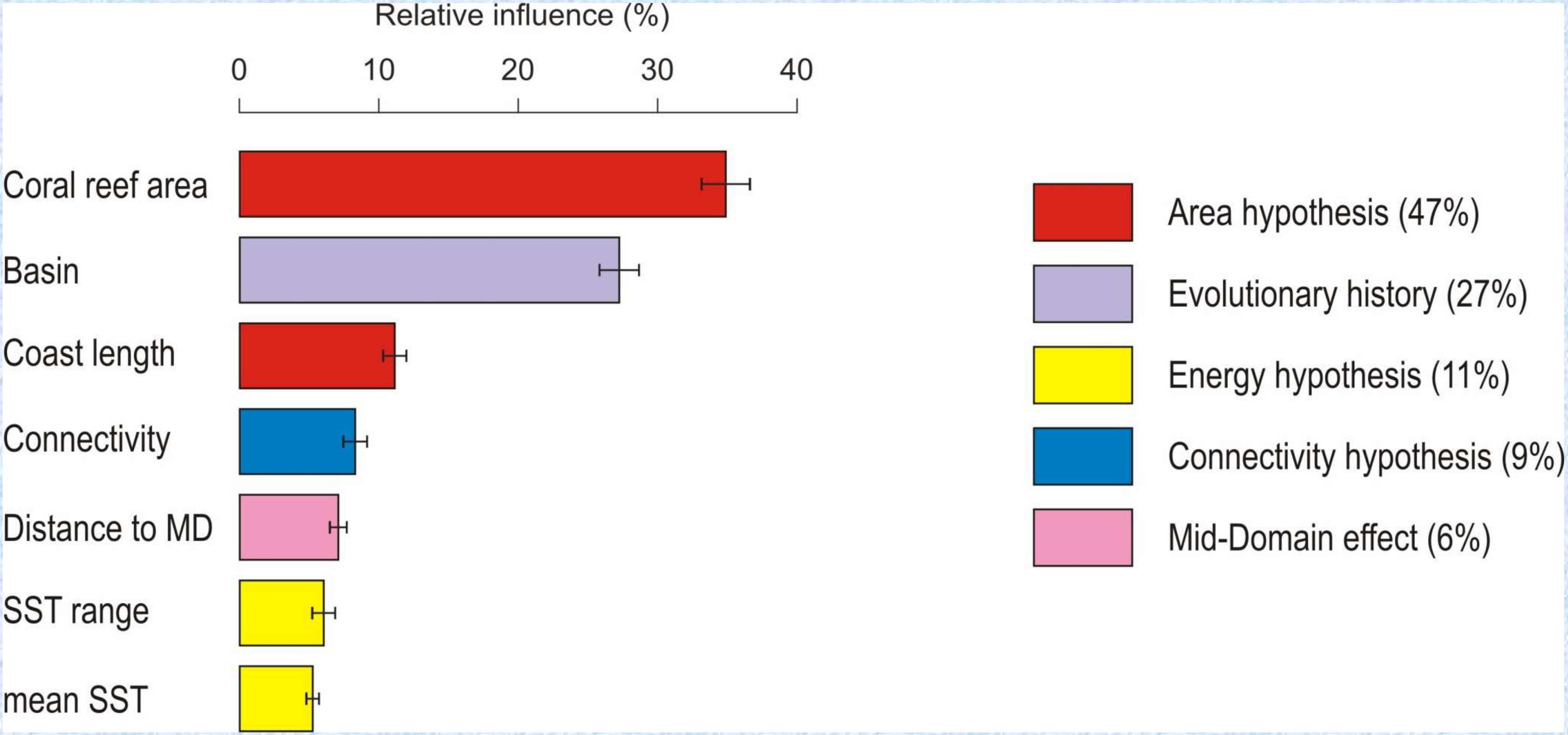
Global patterns and predictors of reef fish diversity

Few and easily accessible variables are enough to accurately predict the richness of reef-fishes at global scale



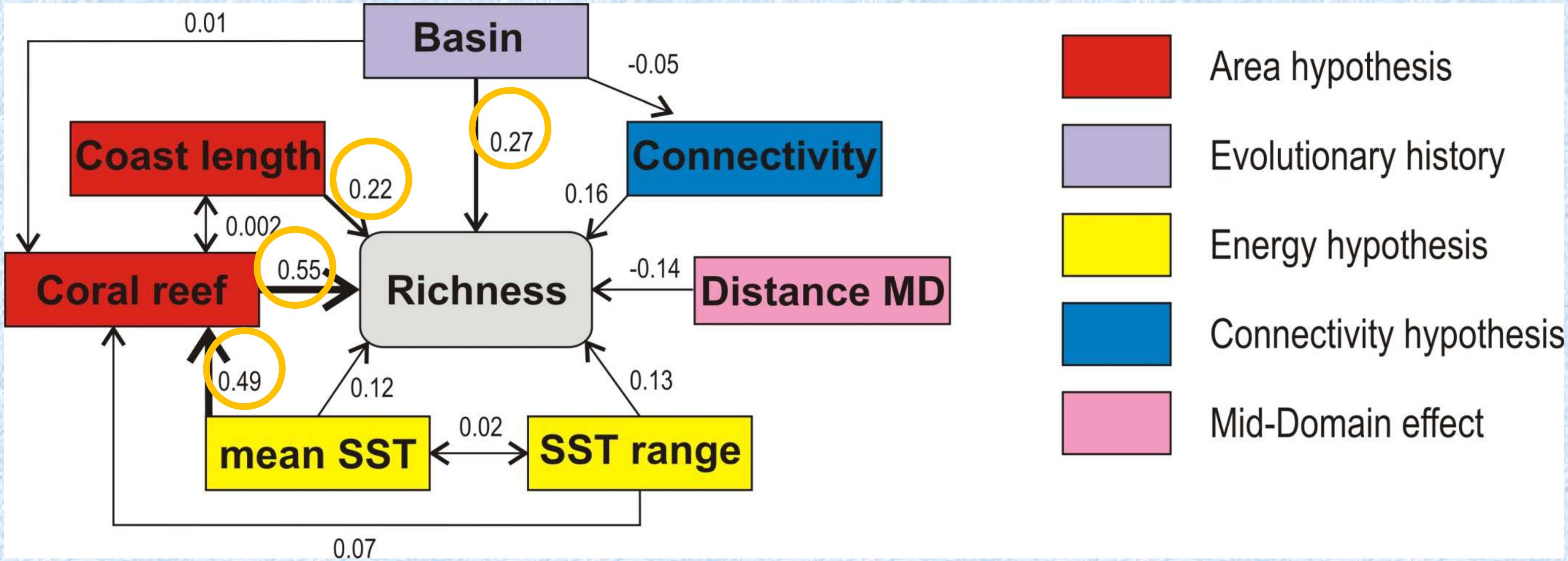
Parravicini et al. 2013 Global patterns and predictors of tropical reef fish species richness - Ecography 36: 001–009

Coral reef area was the most inflential variable, followed by evolutionary history, energy, connectivity and the mid-domain effect



More about interactions.... direct and indirect effects

Results of a Structural Equation Model (SEM) which allows to disentangle direct effects from indirect ones by combining several equations within the same model



The role of life-history traits

Several of the previous hypotheses imply an important role for:

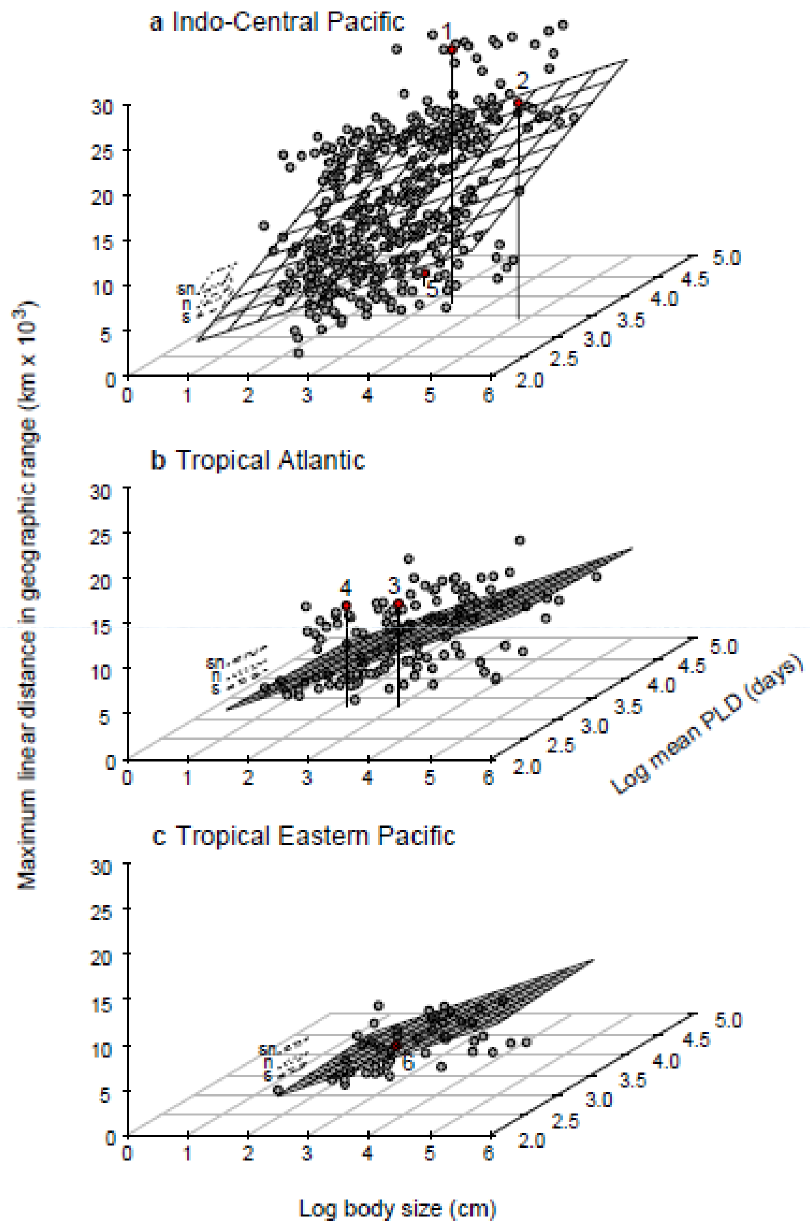
1- dispersal capacities

2- colonizing capacities

These capacities were known to be linked to

SIZE
PLD
GEOG RANGE (AOO)

We analyzed the relationships between these parameters taking biogeographical realms into account



Luiz et al. . 2013 Adult and larval traits as determinants of geographic range size among tropical reef fishes- PNAS 110 (41):16498–16502

Two major strategy types for Dispersion + Colonisation

Strategy I

Massive but rare egg batches

Long PLD

Adults: Habitat Generalists

Adults : Diet Generalists

Species Large– Solitary – Above bottom

Strategy adapted to colonising isolated islands

Strategy 2

Small but frequent egg batches

Short PLD

Adults : Habitat Specialists

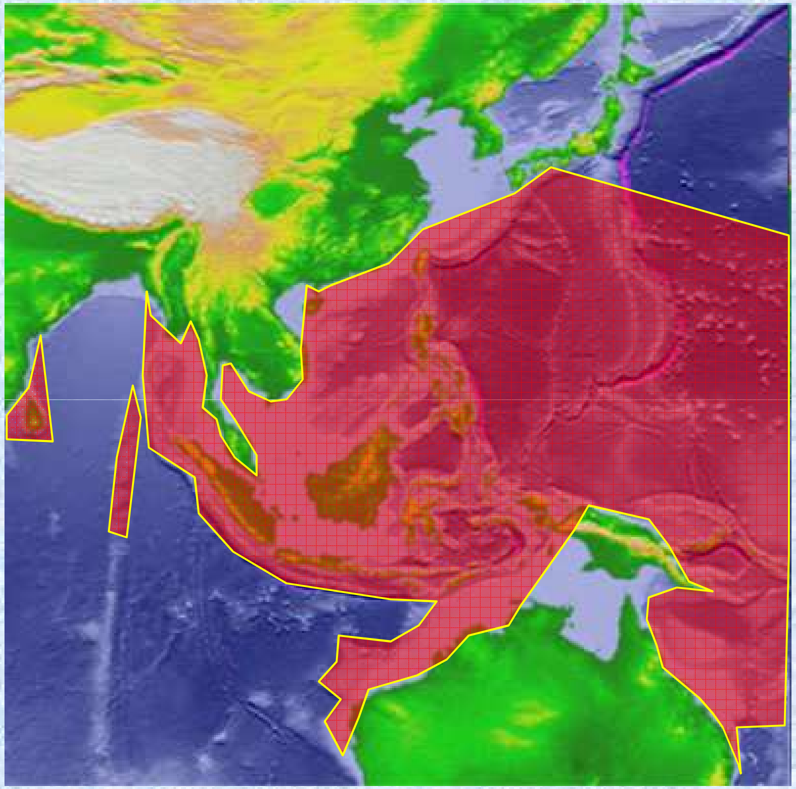
Adults : Diet Specialists

Species Small – Gregarious – Bottom dwelling

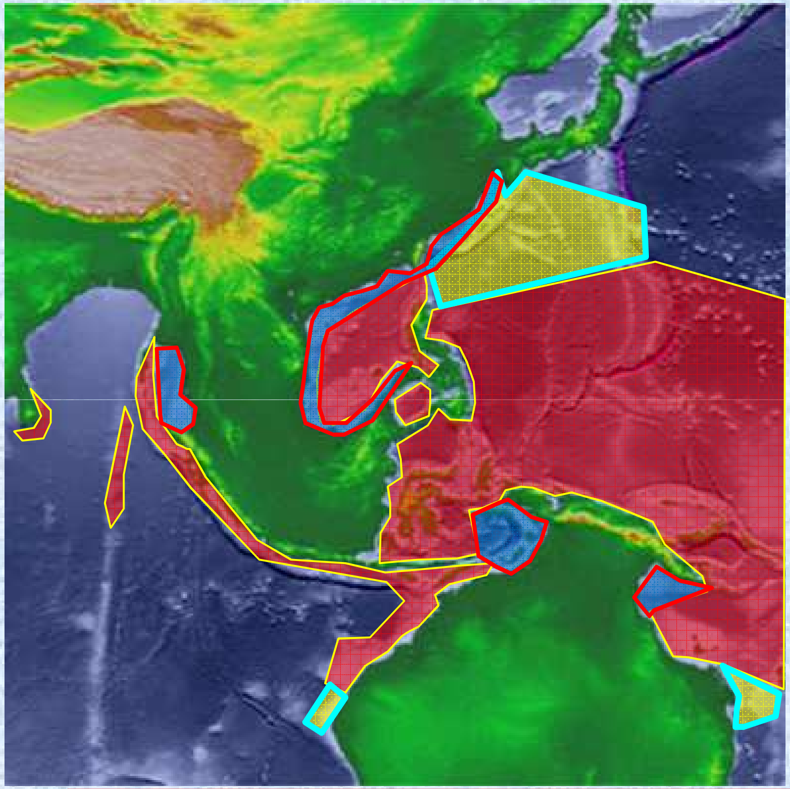
Strategy adapted to colonising in a stepping stone way

The role of evolutionary history

During ice-age periods coral reefs « shrink », sea level goes down



Today



Lowest Sea Level during the quaternary

conditions favorable to coral reefs

too cold

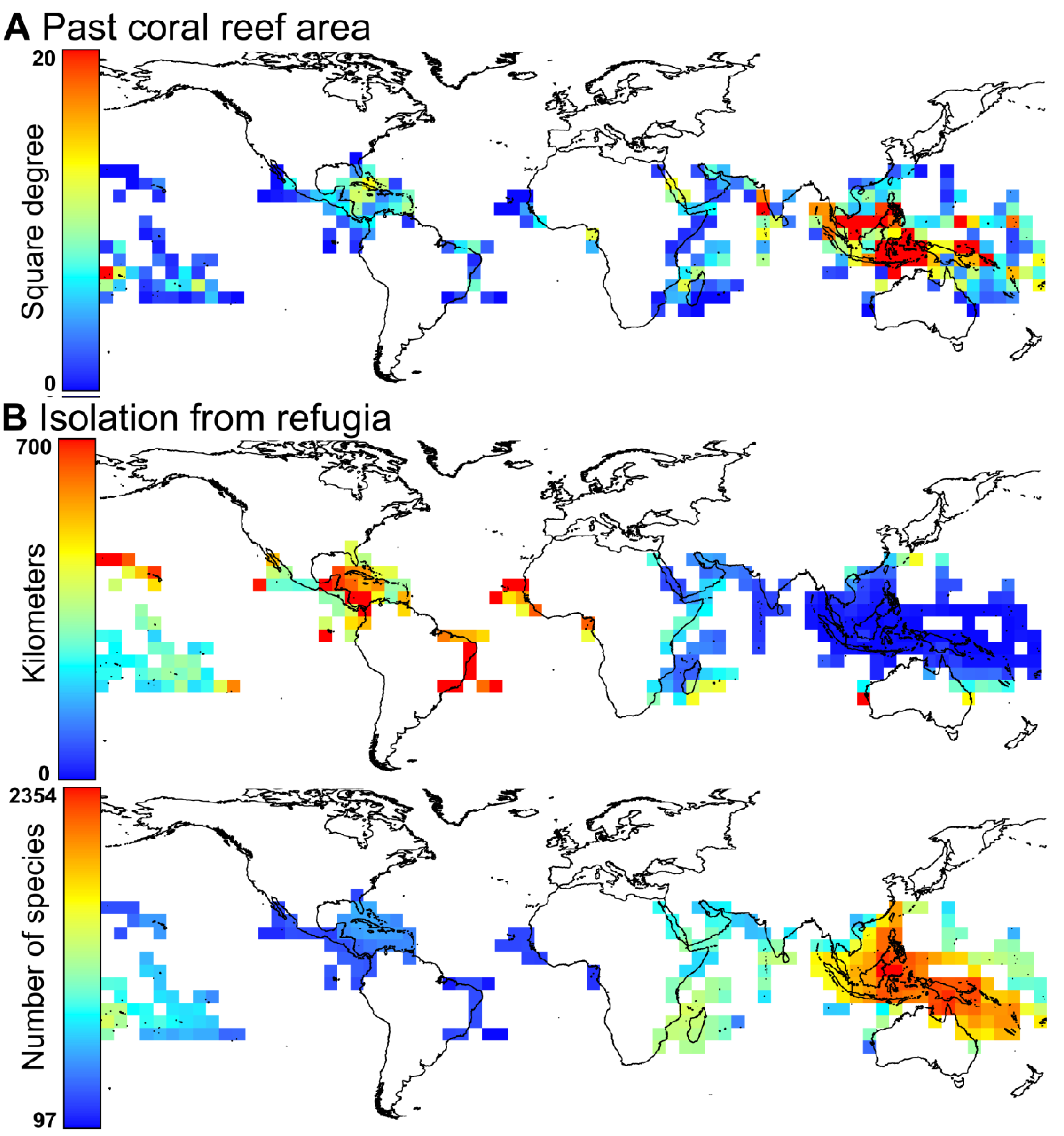
unfavorable salinity

Pellissier et al.2014 Quaternary coral reef refugia preserved fish diversity. Science. 344(6187): 1016-1019 -

Frequency of refugia (there were many changes during the last 3 MY – 1 value each 1000 years)

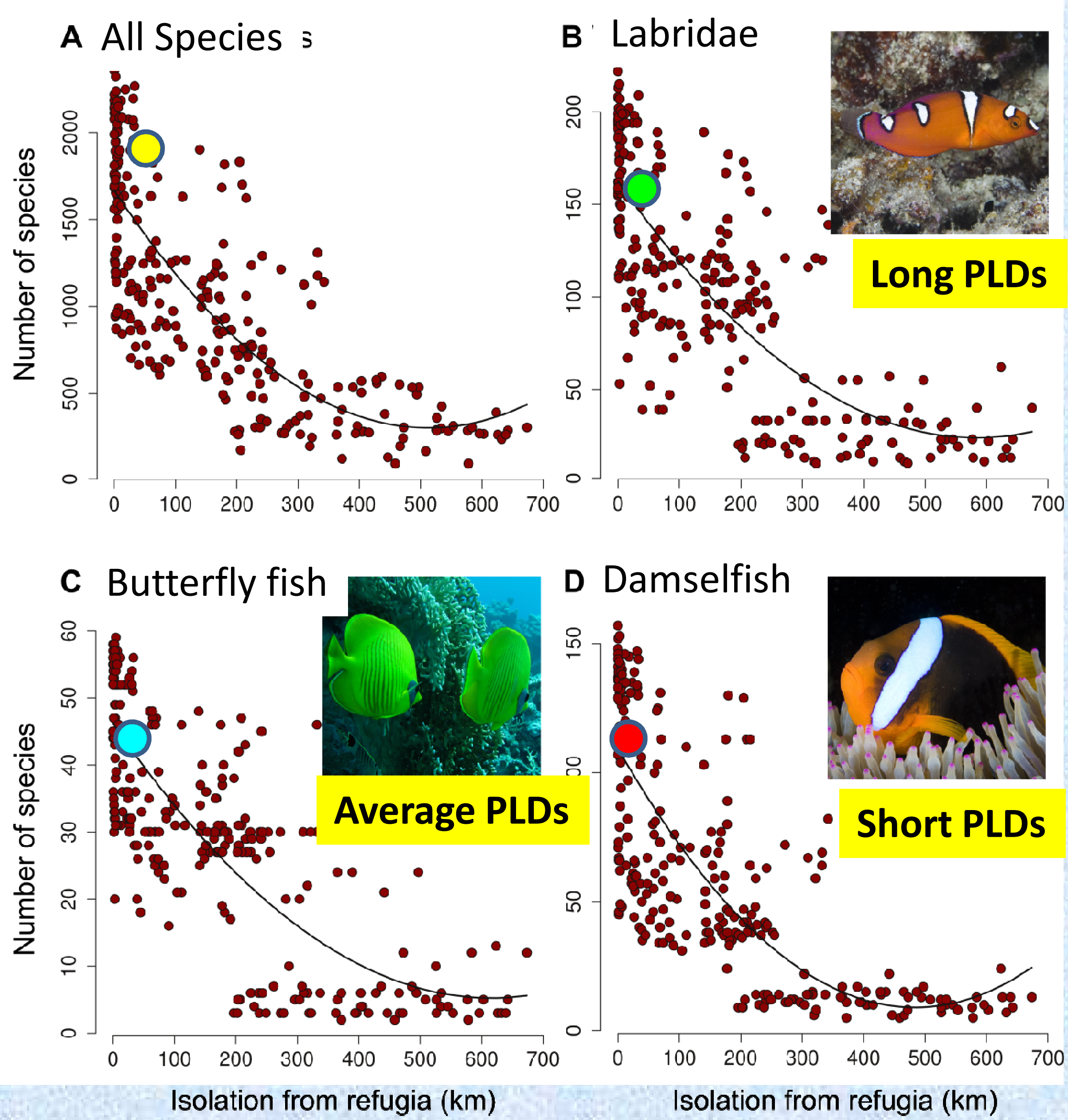
Distance of each cell to the nearest refugia. Average over 3 MY

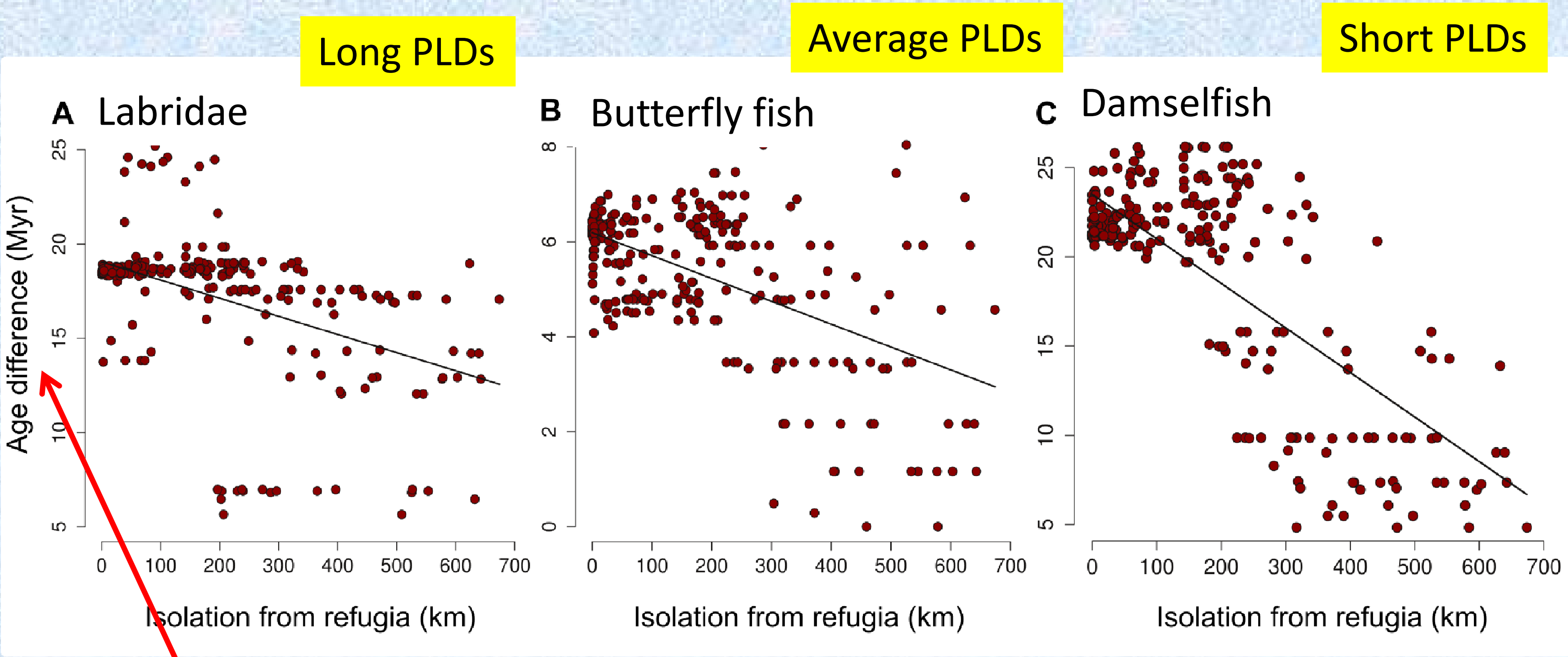
Today's distribution of reef fish



Species richness decreases with distance to refugia. This distance explains~ 60% of the spatial distribution of today's reef fish

Colonizing capacity is essential to explain the present day diversity distribution





Measure of the dispersion of species ages (différence between the 95th and the 5th percentile for each site) **within each geographical cell**

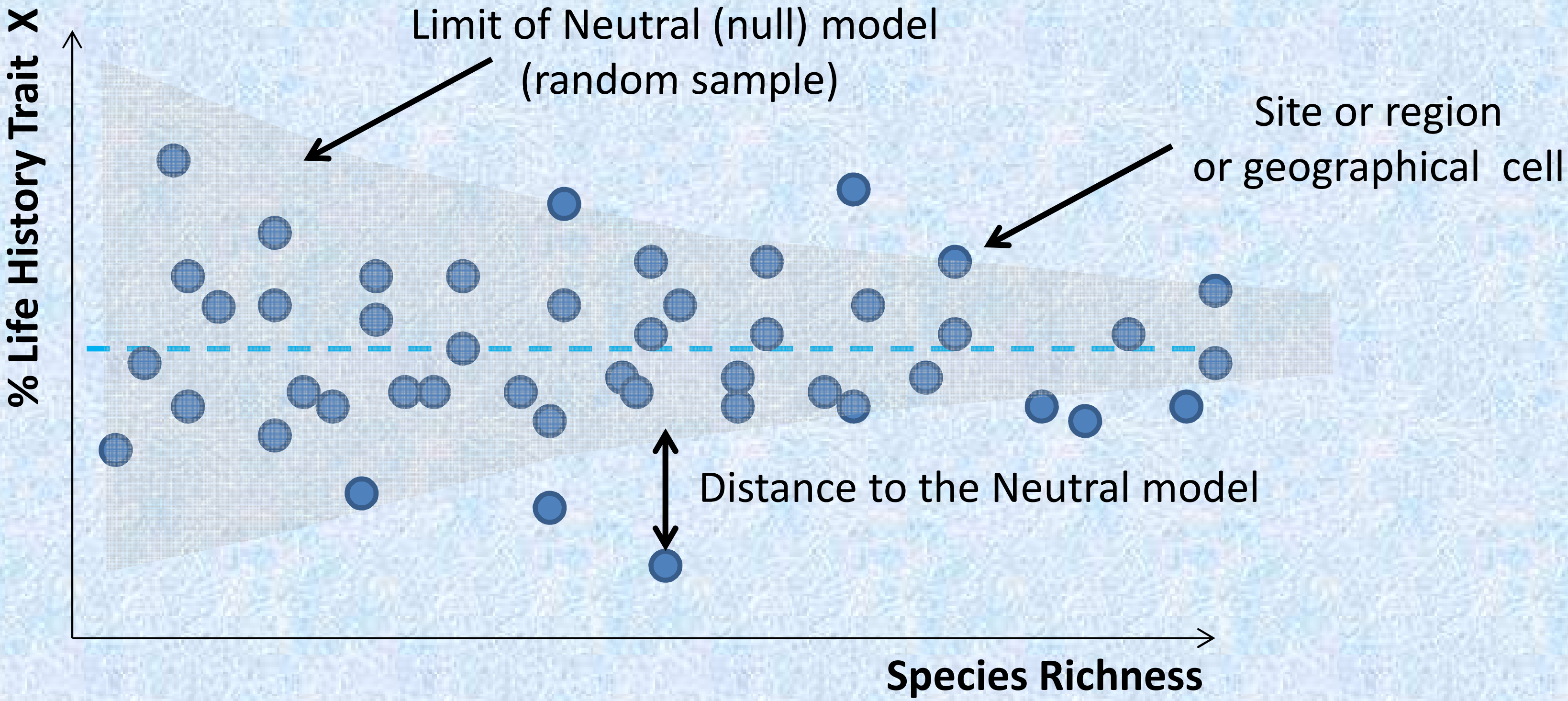
The further away from refugia and more ages tend to be similar

The slope is proportional to average PLD

From Species to Traits

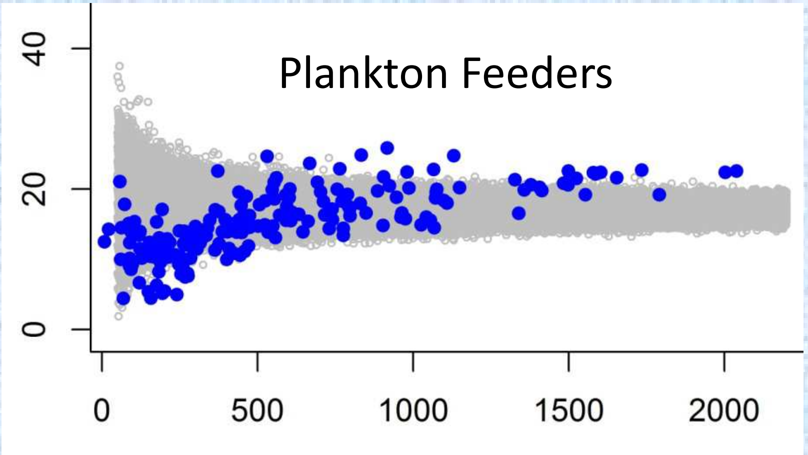
Hypothesis: all reef fish assemblages function along the same principles and therefore should have the same structure on any reef in the world

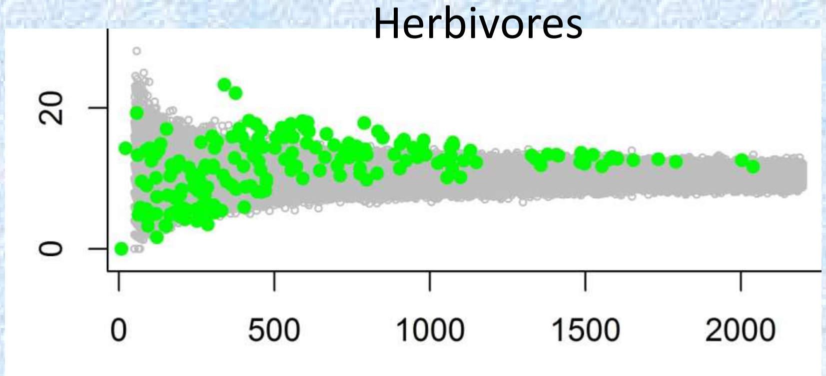
The proportion (% of all local species) of a group – e.g. herbivores – is the same everywhere



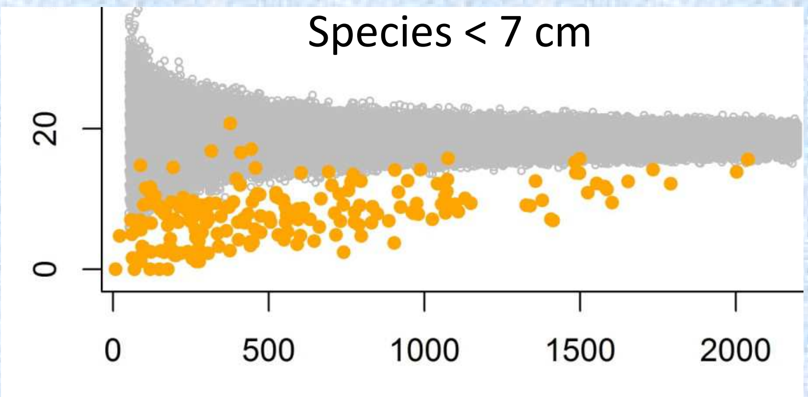
Unpublished work – submission end 2014

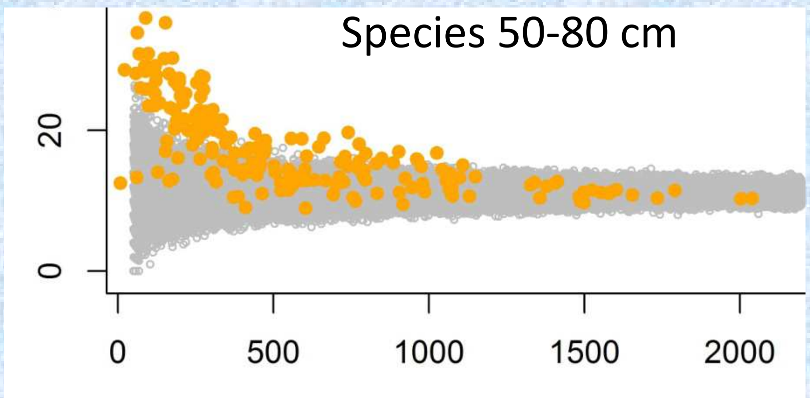
Some example from the Indo Pacific



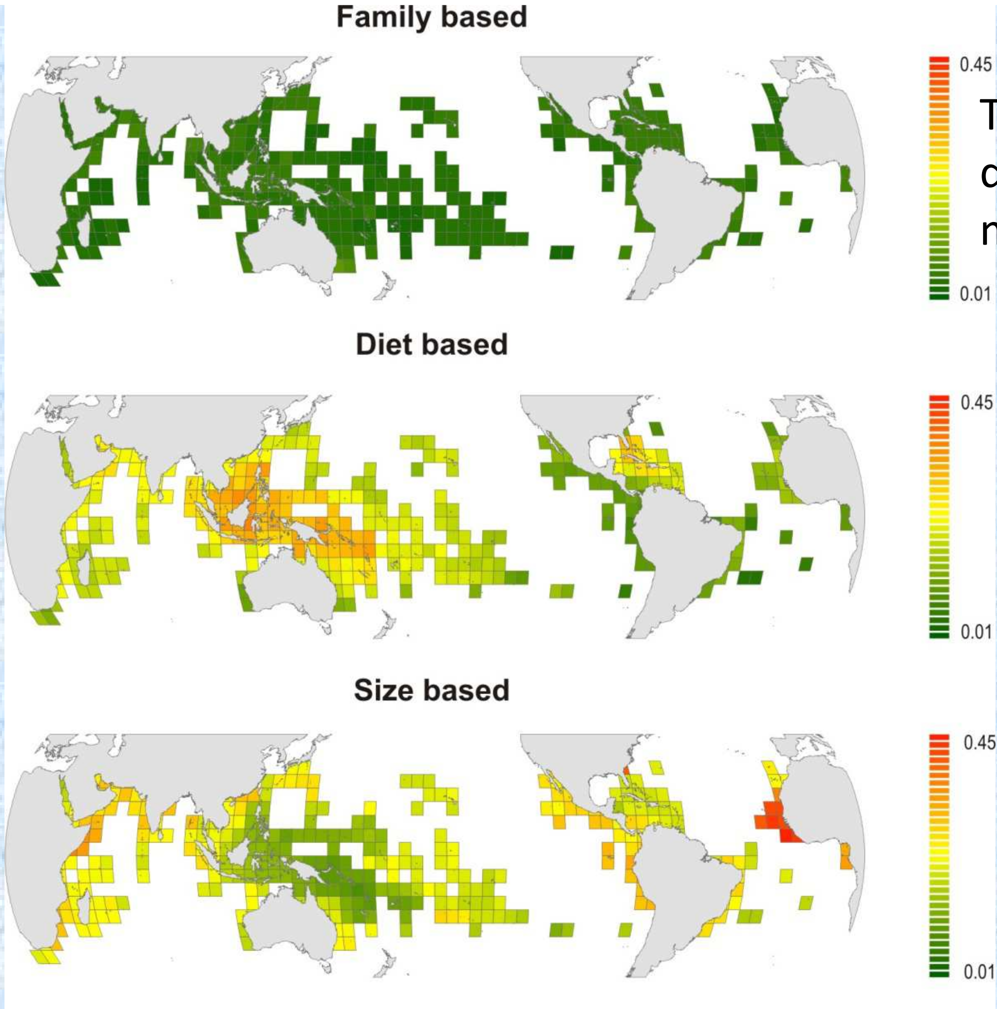


Number of Species / Site





Number of Species / Site

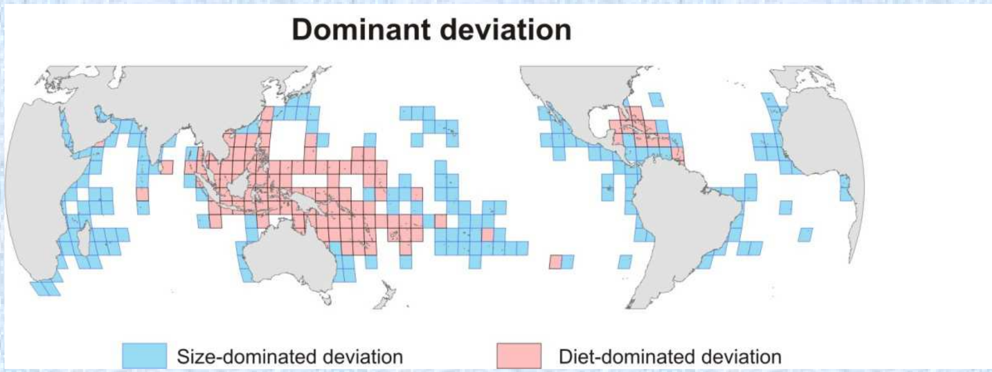


The global deviation (sum of all deviation from Neutral) was measured for each cell

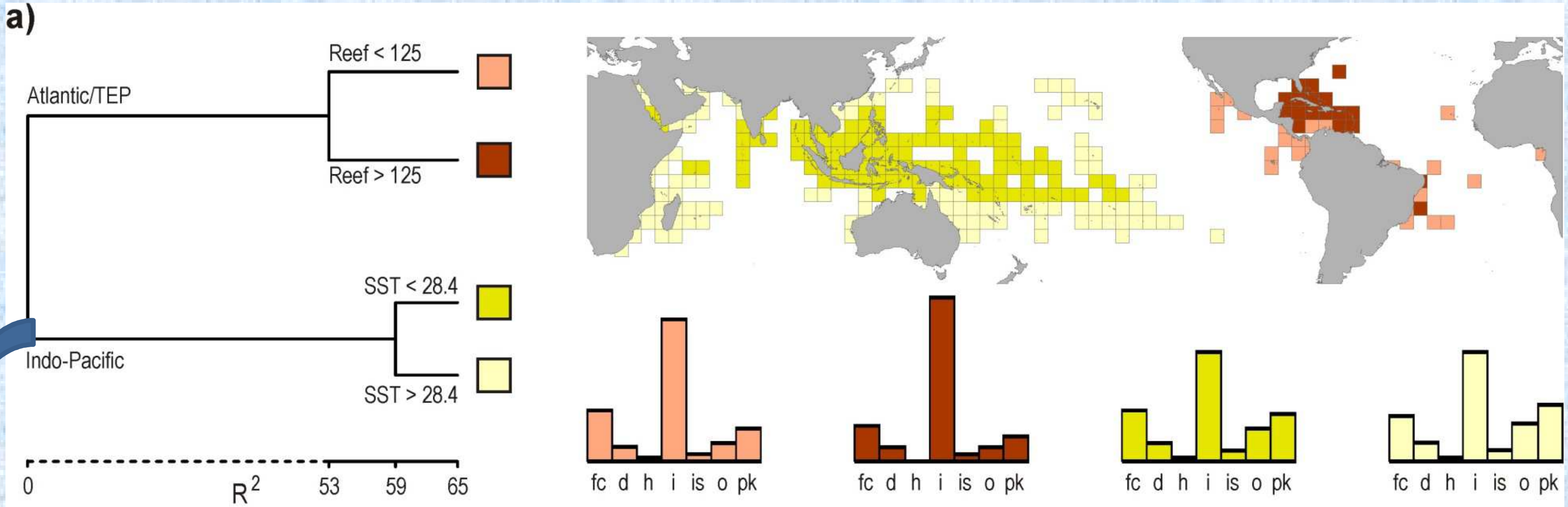
The deviation is nearly constant for families → very stable % of each family within a realm

Trophic structure is the furthest from the Neutral model in regions with high div ersity

Size Structure is the furthest from the Neutral model in isolated and peripheral regions



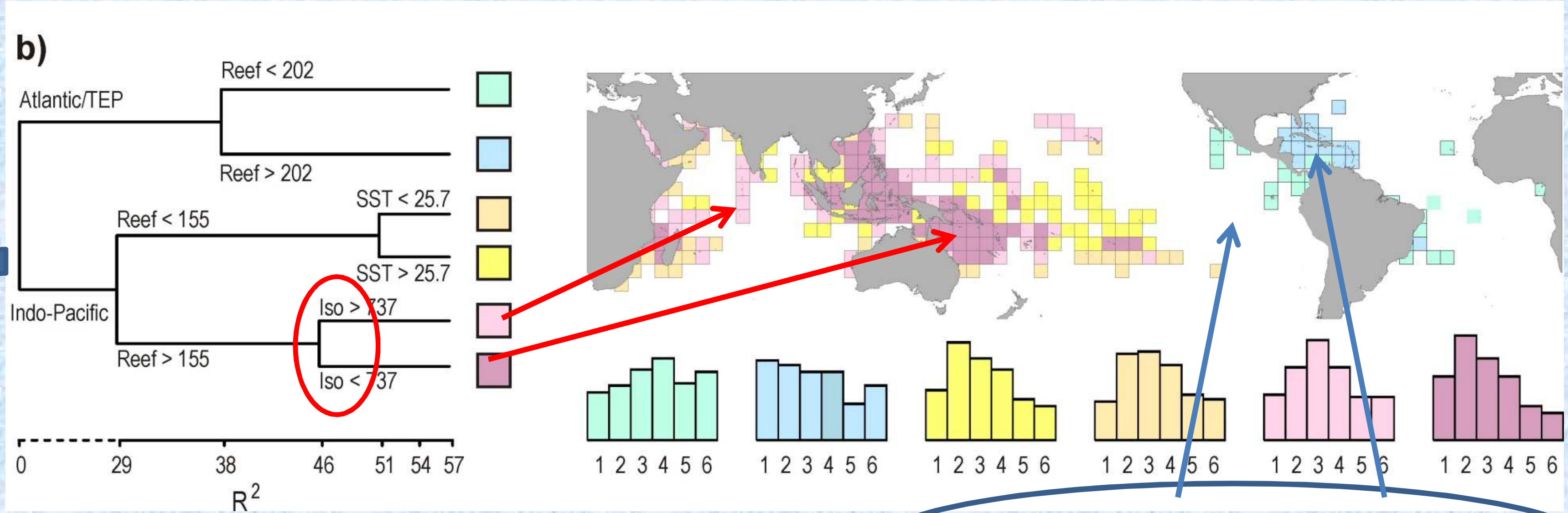
Trophic and Size Structures have geographically distinct distributions



FC: Piscivores D: Detritus Feeders H: Herbivores I: Carnivores

IS : Sessile carnivores O: Omnivores PK: Plankton Feeders

No significant effect of island size or isolation, therefore of physical connectivity, on trophic structures



1: < 7cm ; **2**: 8-15 cm: **3**: 15-30 cm; **4**: 30-50 cm; **5**: 50-80 cm; **6**: > 80 cm

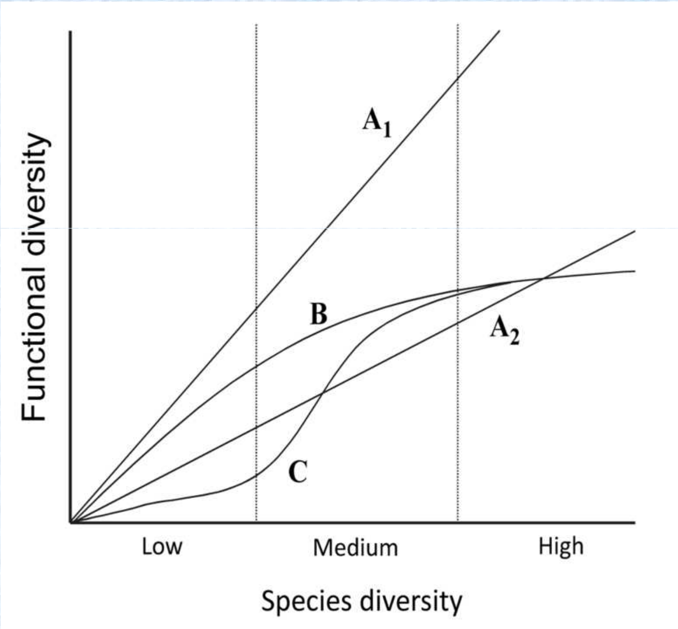
« Isolation » : combinaison of distance and size of the nearest islands, therefore a proxy of physical connectivity

Physical connectivity plays a significant role in the size structure of reef fish assemblages in the Indo-Pacific

From Species to Function

Why are we interested in functions ?

Do functions have the same distribution as species ?



from Michaeli & Halpern 2005

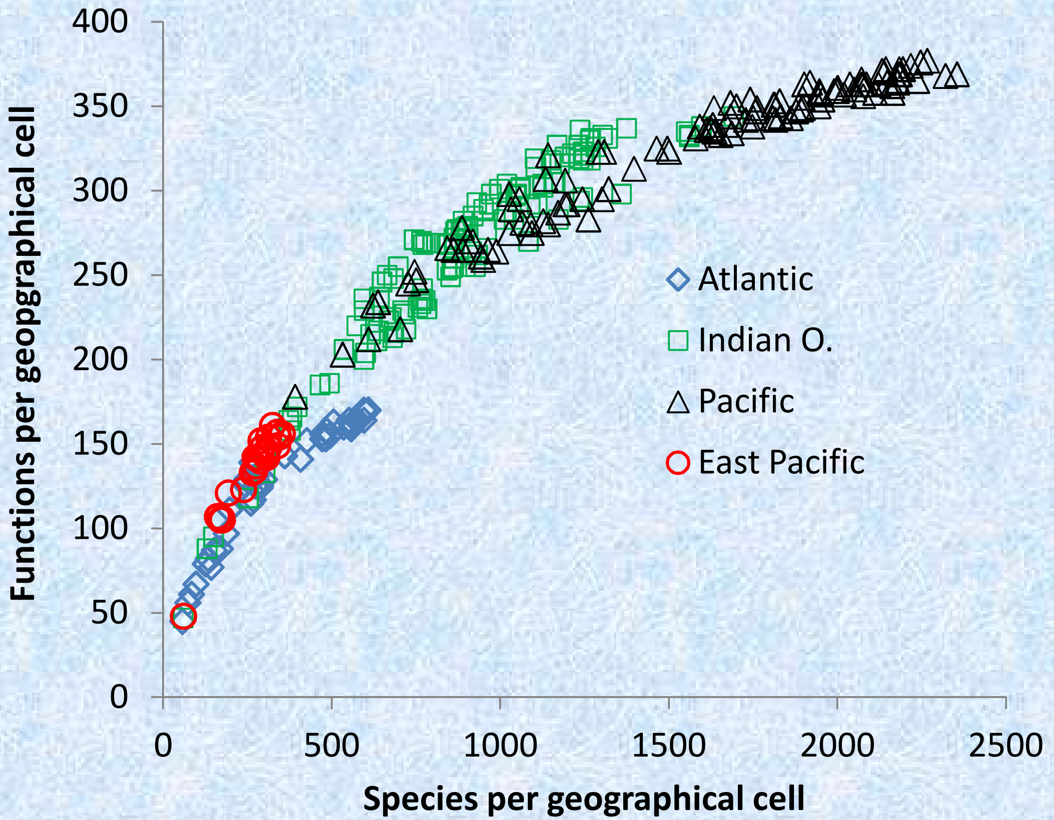
A1: 1 species ←→ 1 function

B: increasing redundancy as species richness increases

C: ecological threshold beyond which functions are more diversified

Mouillot et al. 2014 Functional over-redundancy and high functional vulnerability in global fish faunas of tropical reefs. PNAS

Kulbicki et al. in press Patterns and processes linked to body size. C.Mora ed. "Ecology of fishes on coral reefs". Oxford Univ. Press

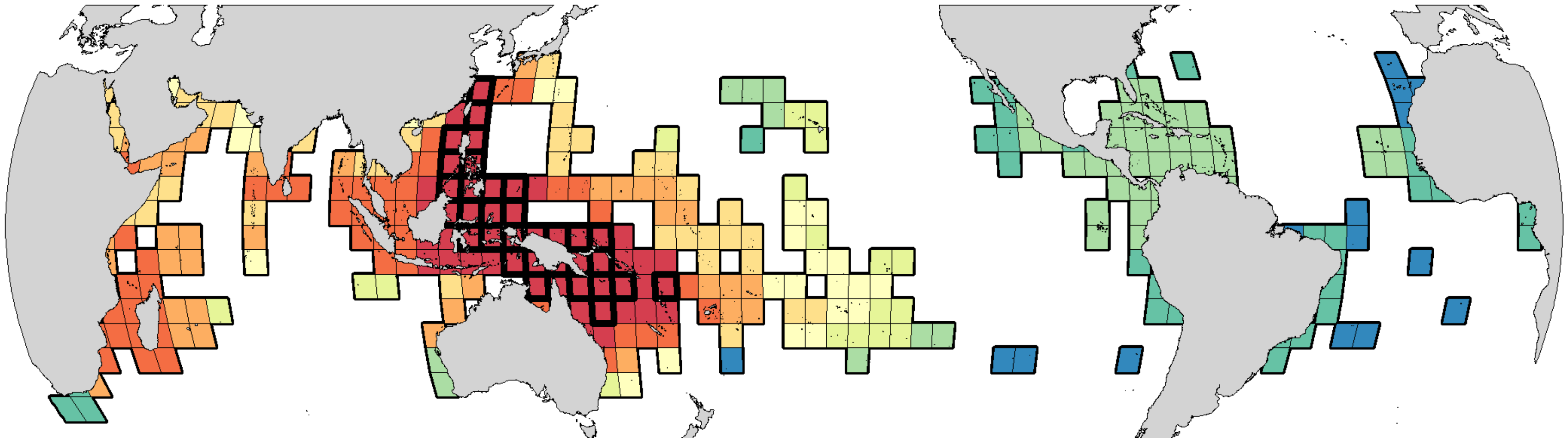


Relation B from previous slide, at large scale, for all realms

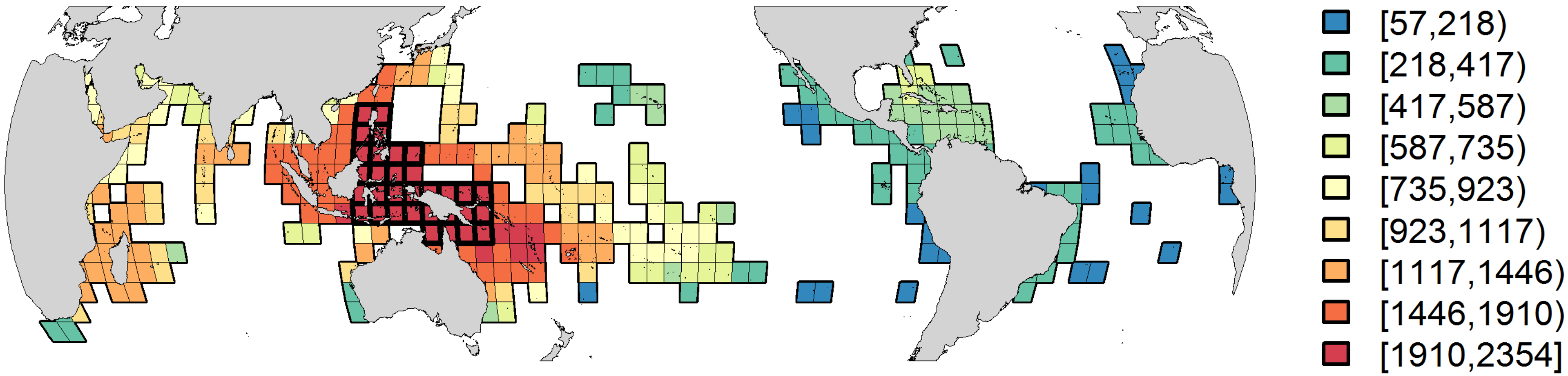
Same is true at a local scale

Guillemot et al. (2011) Functional Redundancy Patterns Reveal Non-Random Assembly Rules in a Species-Rich Marine Assemblage. PLoS ONE 6(10): e26735.

Functional richness



Total richness



No major mismatch

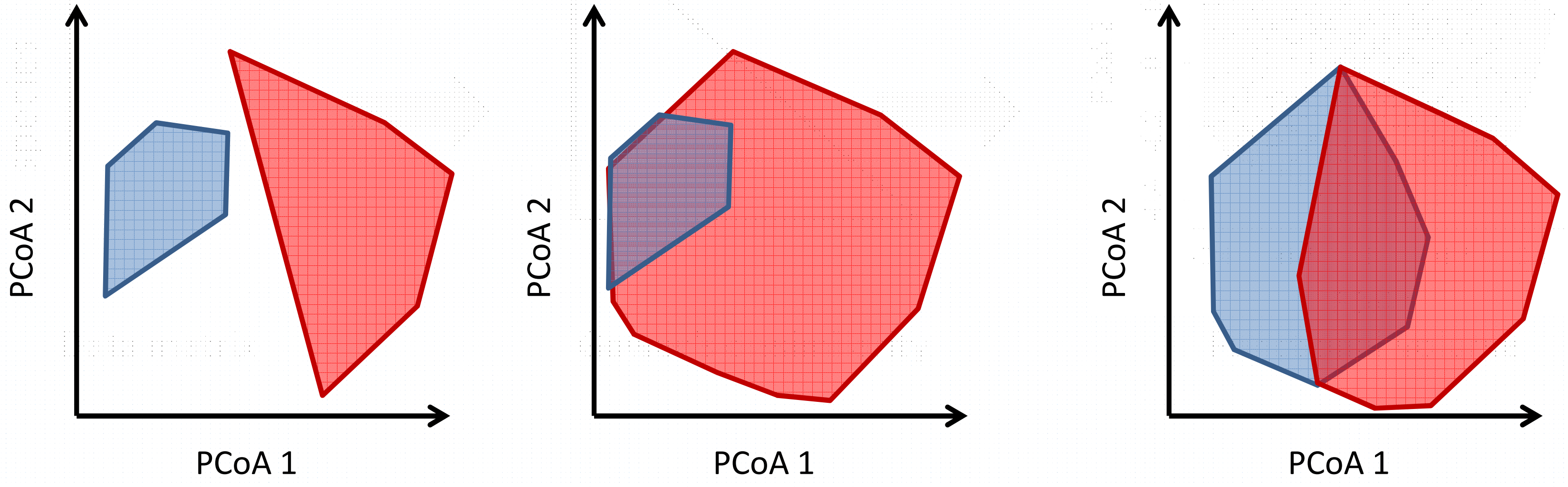
Functional Volumes

with N Life-History traits → multispace volume
e.g. an assemblage with H, Pis & Carn. has a larger FV than an assembalge with only H

Hypotheses

Poor region (e.g. Eastern Atlantic)

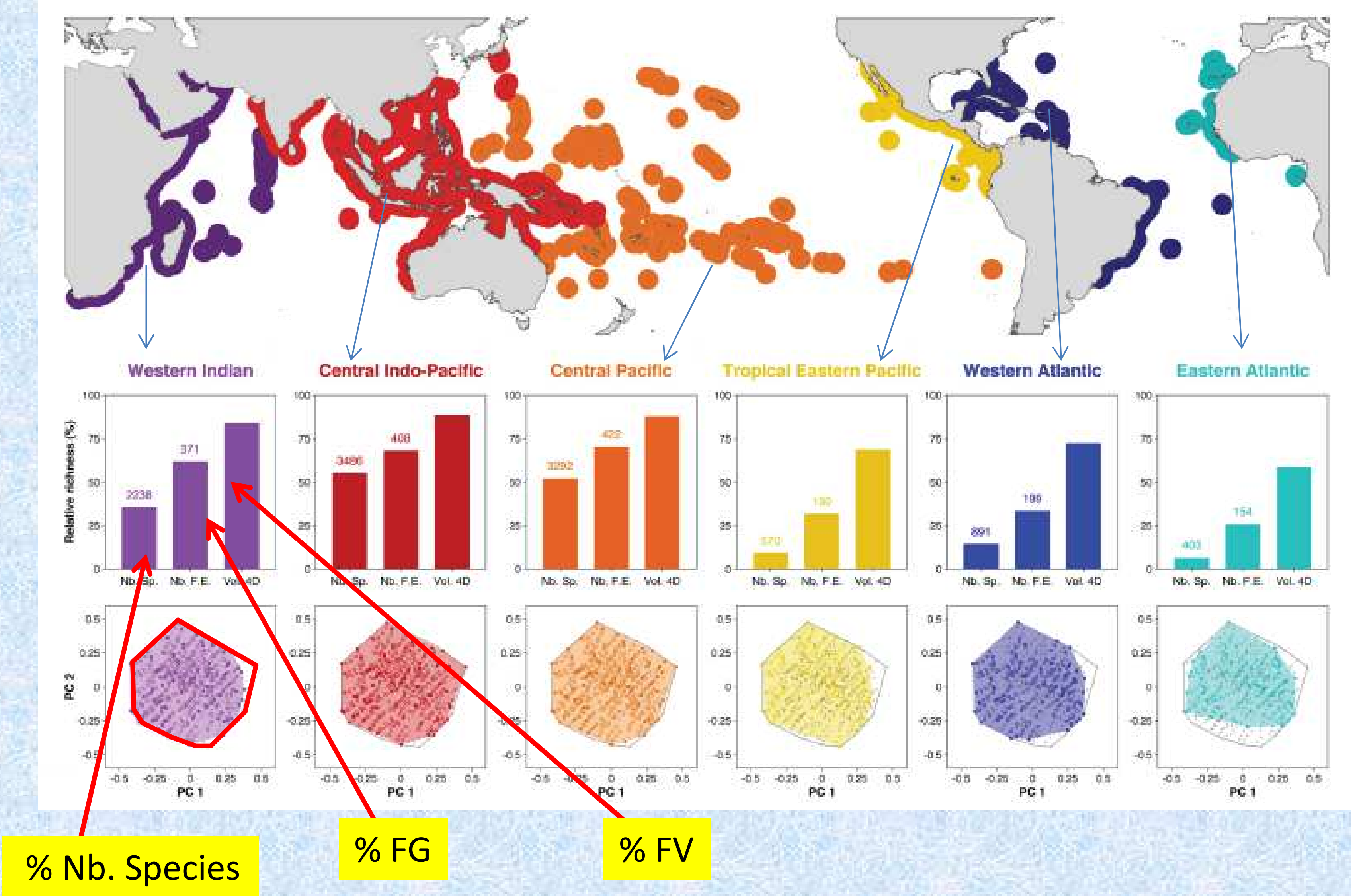
Rich region (e.g. Central Indo-Pacific)



Different Functional richness | Different Functional richness | Similar Functional richness

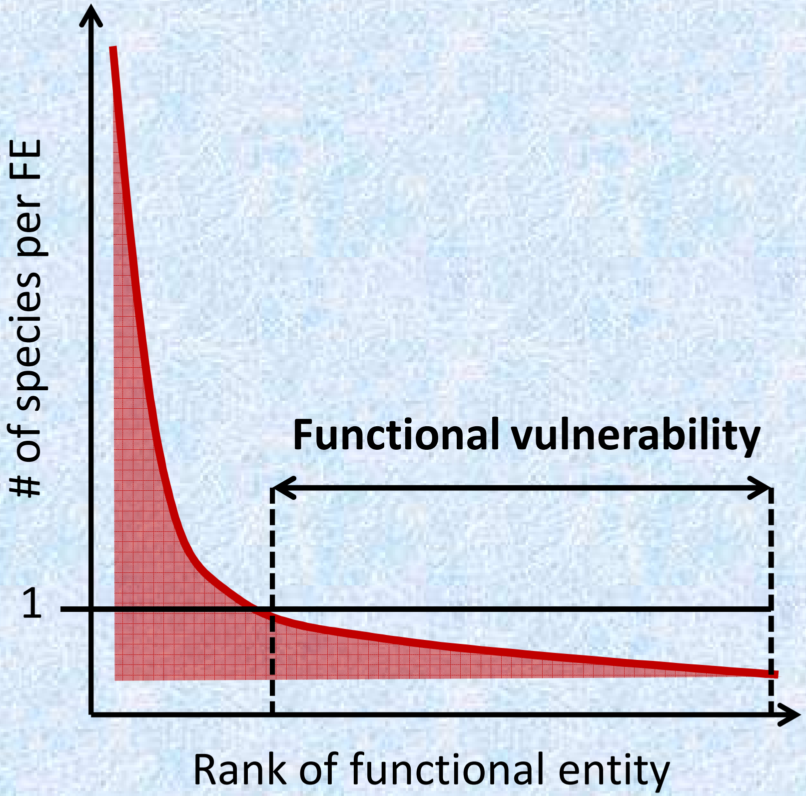
Different Functional structure | Nested Functional structure | Overlapping Functional structure

Despite large differences in species richness, all biogeographical regions share the same functional space

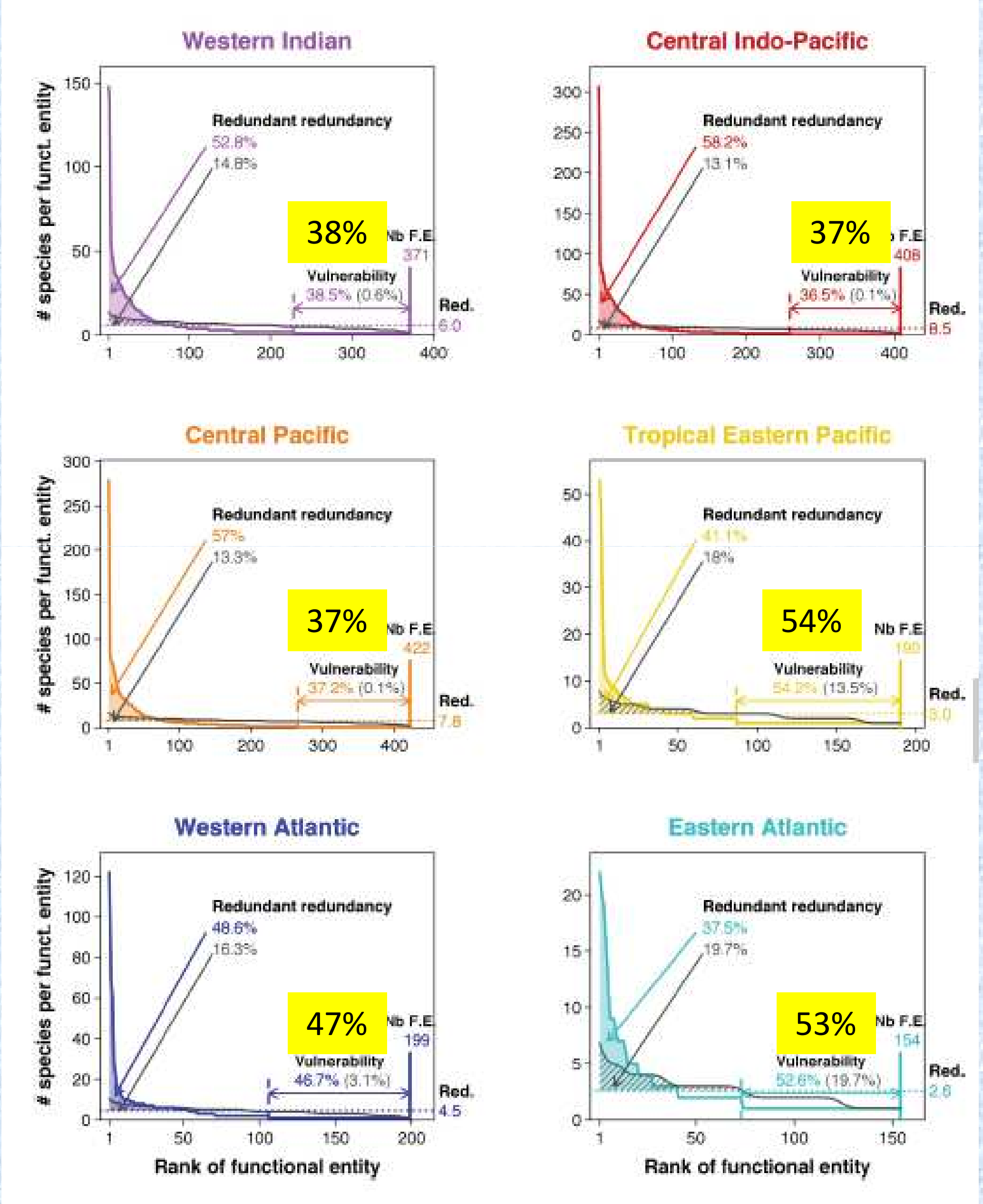


Vulnerability : Species versus Functions

Species richness packing within functional entities reveals high functional vulnerability of reef fish assemblages



Functional vulnerability: The percentage of functional entities with no redundancy, i.e. composed by only one species



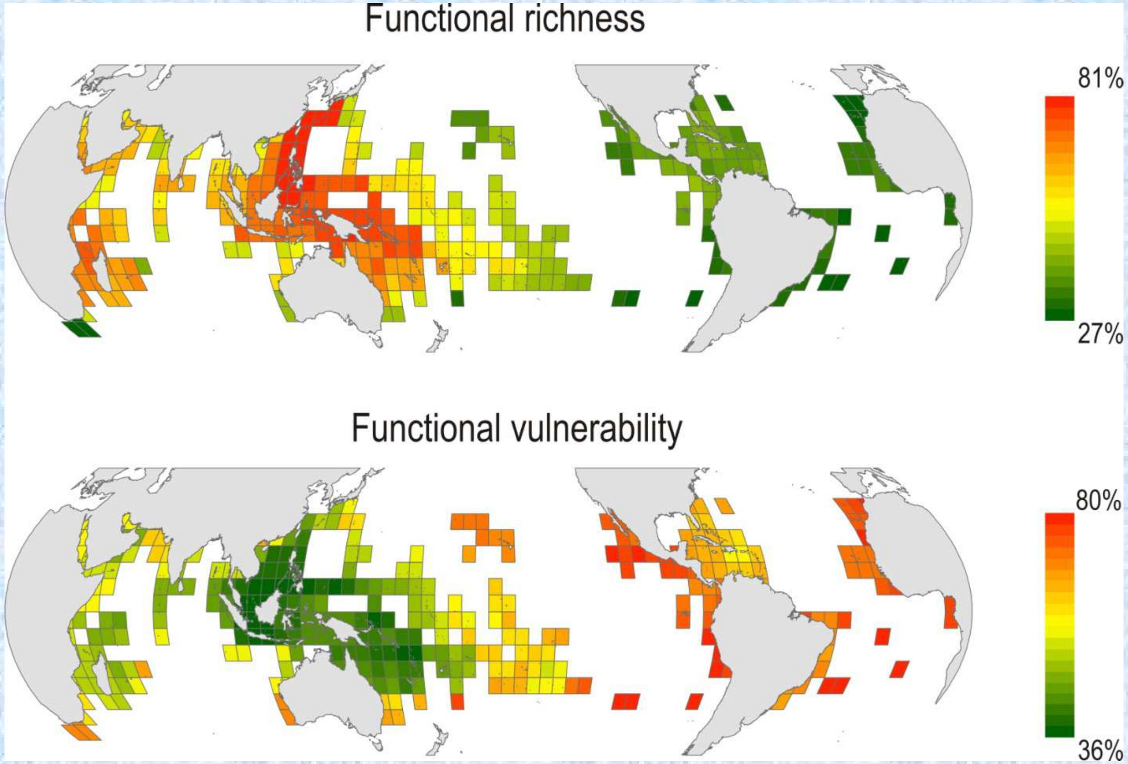
Species richness packing within functional entities reveal high functional vulnerability of reef fish assemblages

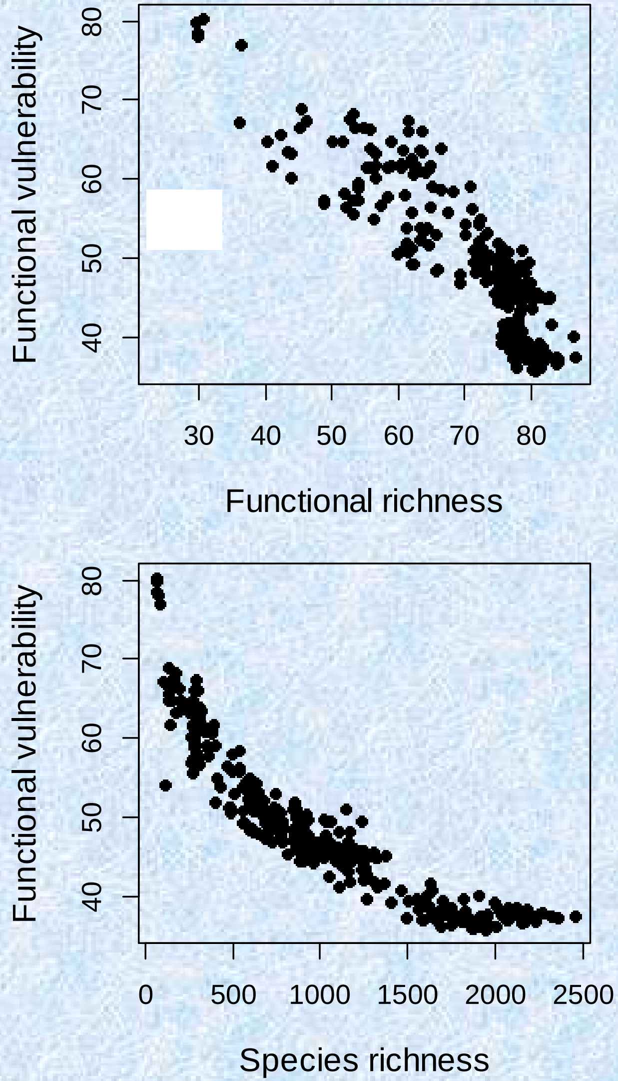
Even the richest regions shows an extremely high functional vulnerability (at least 36%)

The local extinction of those species may have dramatic effect on the functional structure of assemblages

Functional attributes and functional vulnerability, in particular, are important criteria to be taken into account for conservation

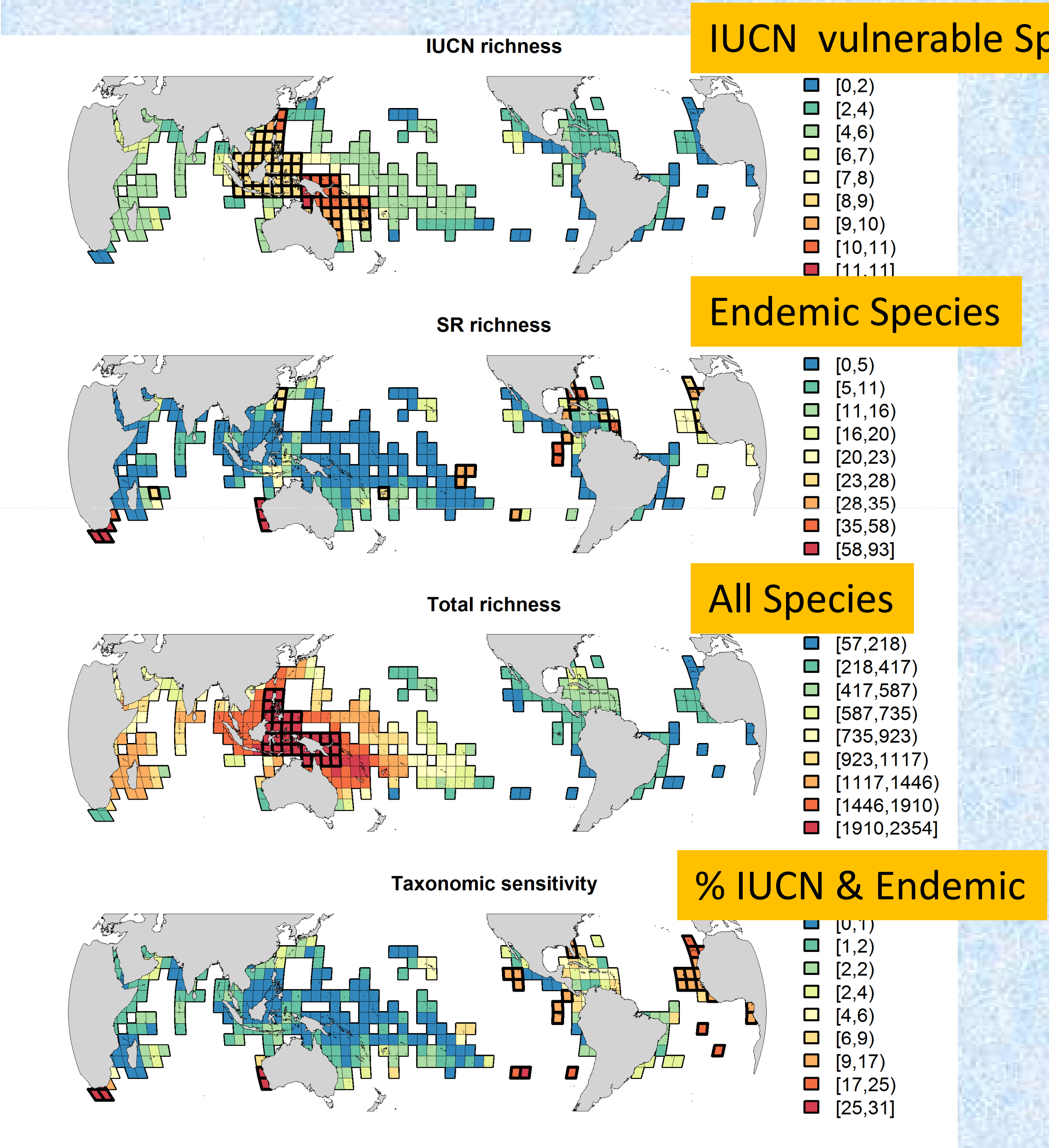
What is the functional vulnerability of local communities?





Parravicini et al.. 2014.The vulnerability framework indicates alternative global protection priorities for coral reef fishes. Ecol.Letters.

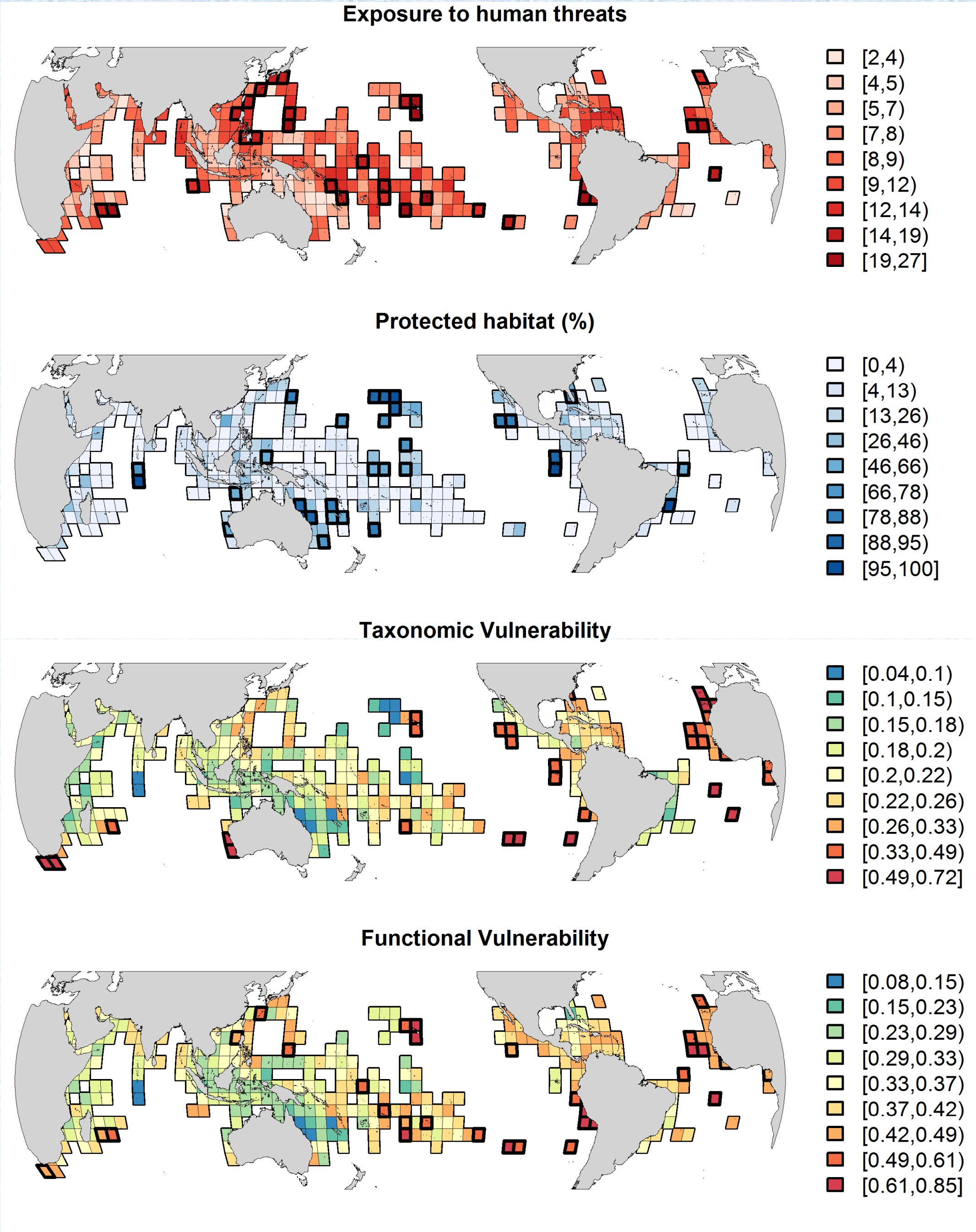
Matching Protection and Vulnerability on a global scale

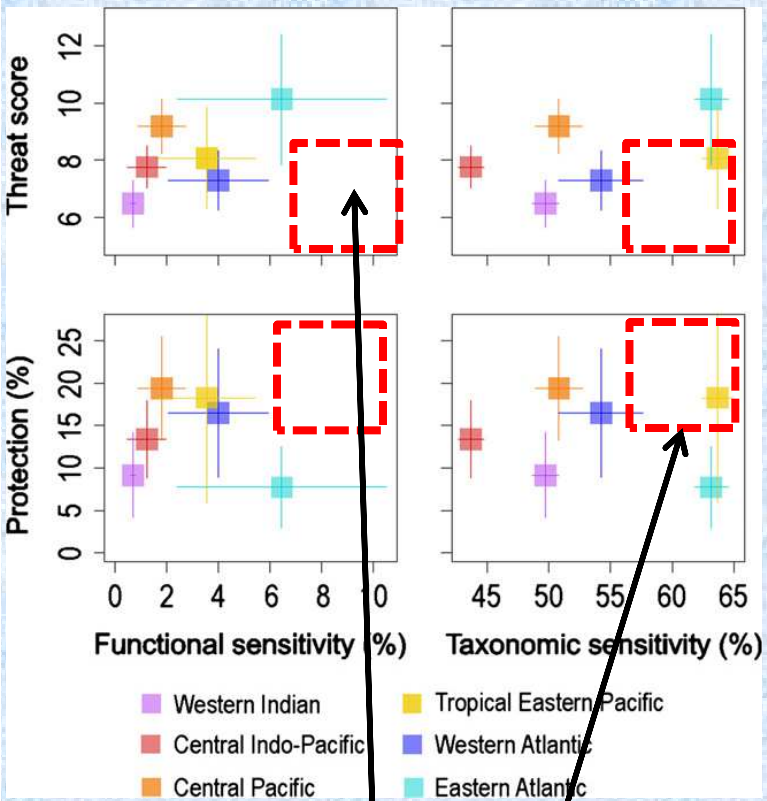


VULNERABILITY

=

f (SENSITIVITY; THREAT)





Mismatch between protection & vulnerability

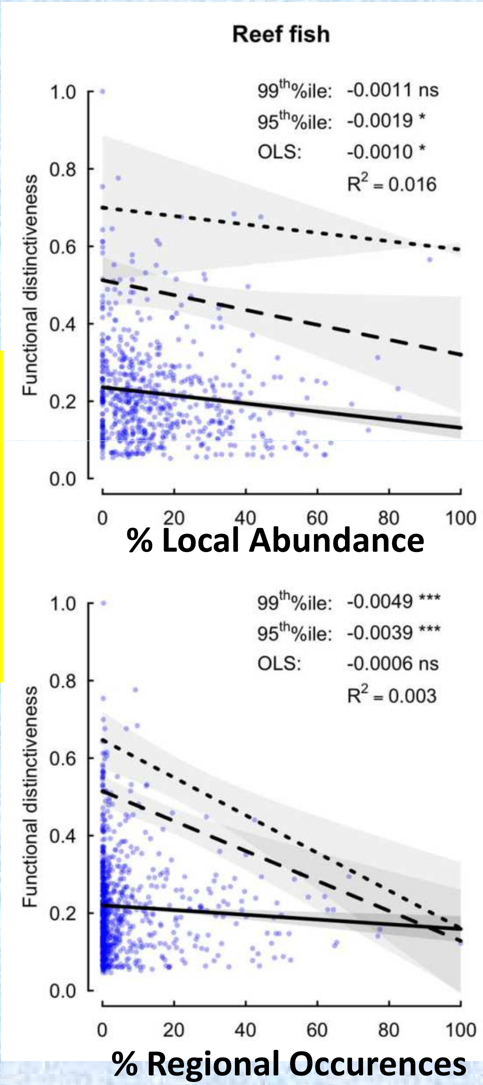
To be effective one would assume:

Protection max & Threat min. for the highest sensitivities

Some other sides of Vulnerability

So far we looked at presence/absence but vulnerability involves also abundance and connectivity

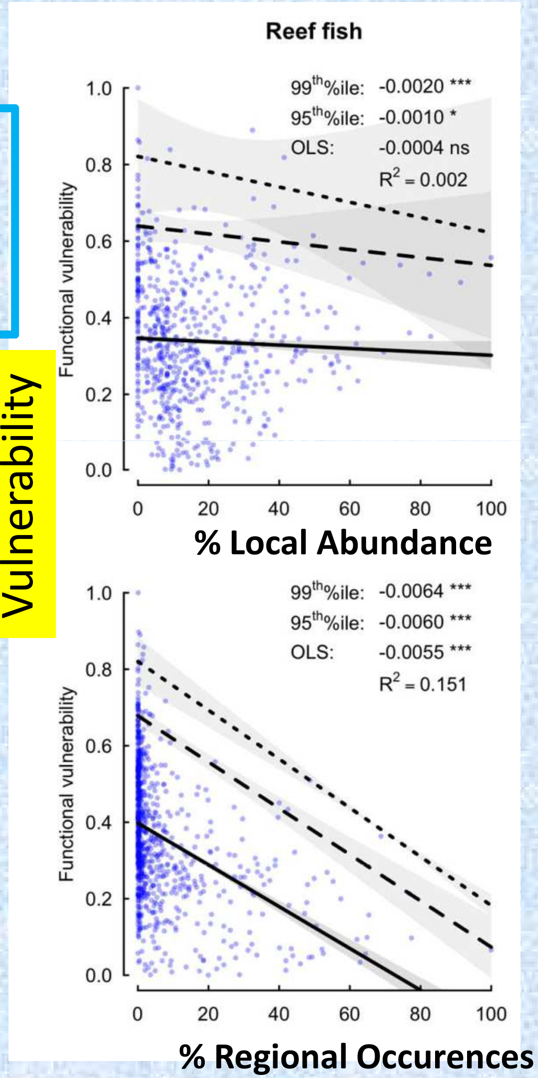
Distinctiveness



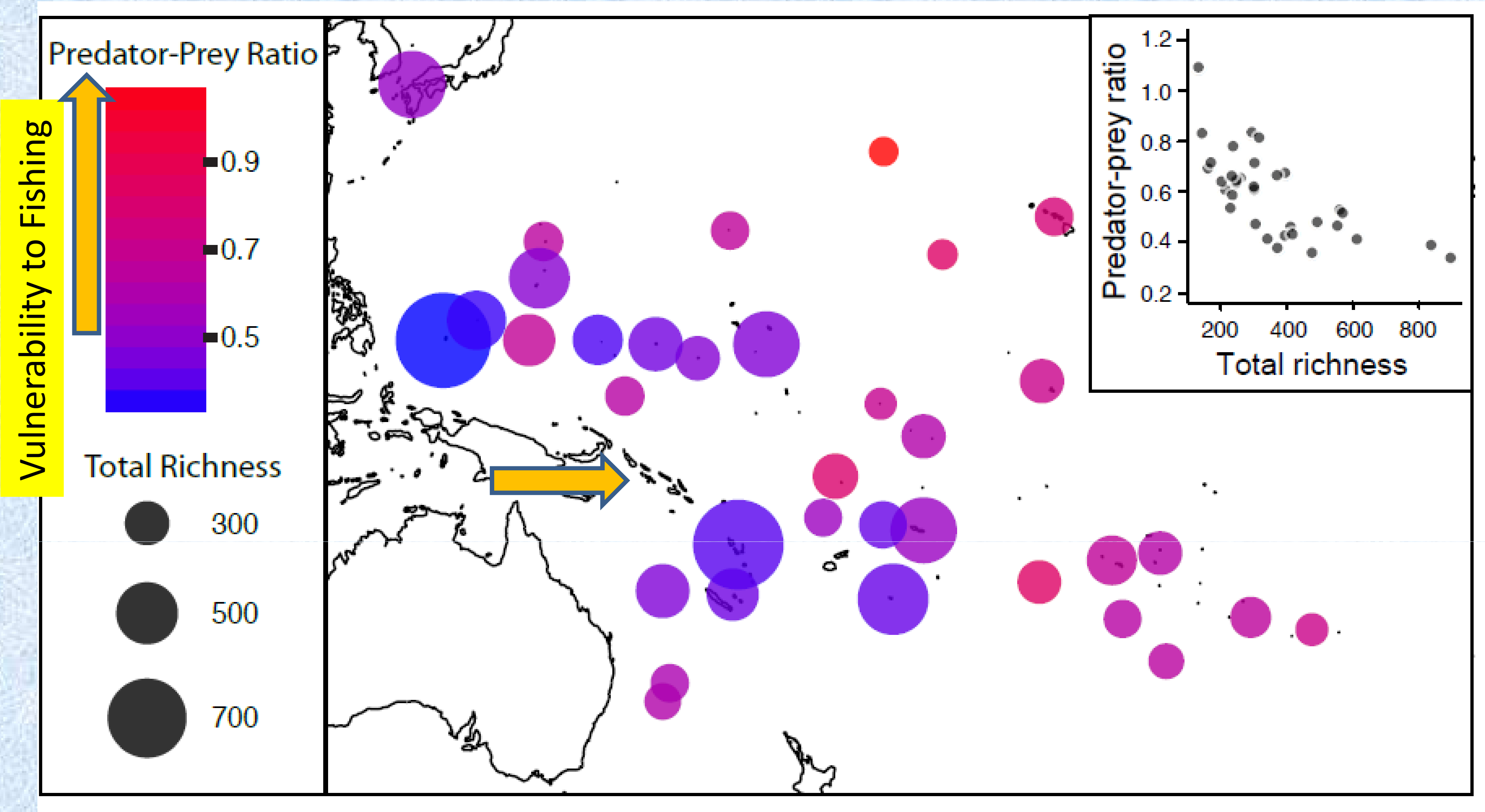
The rarest species tend to have specific functions more often than common species

The rarest species tend to belong to vulnerable functions more often than do common species

Vulnerability



Mouillot et al. 2013 Rare Species Support Vulnerable Functions in High-Diversity Ecosystems. PLoS Biol 11(5):

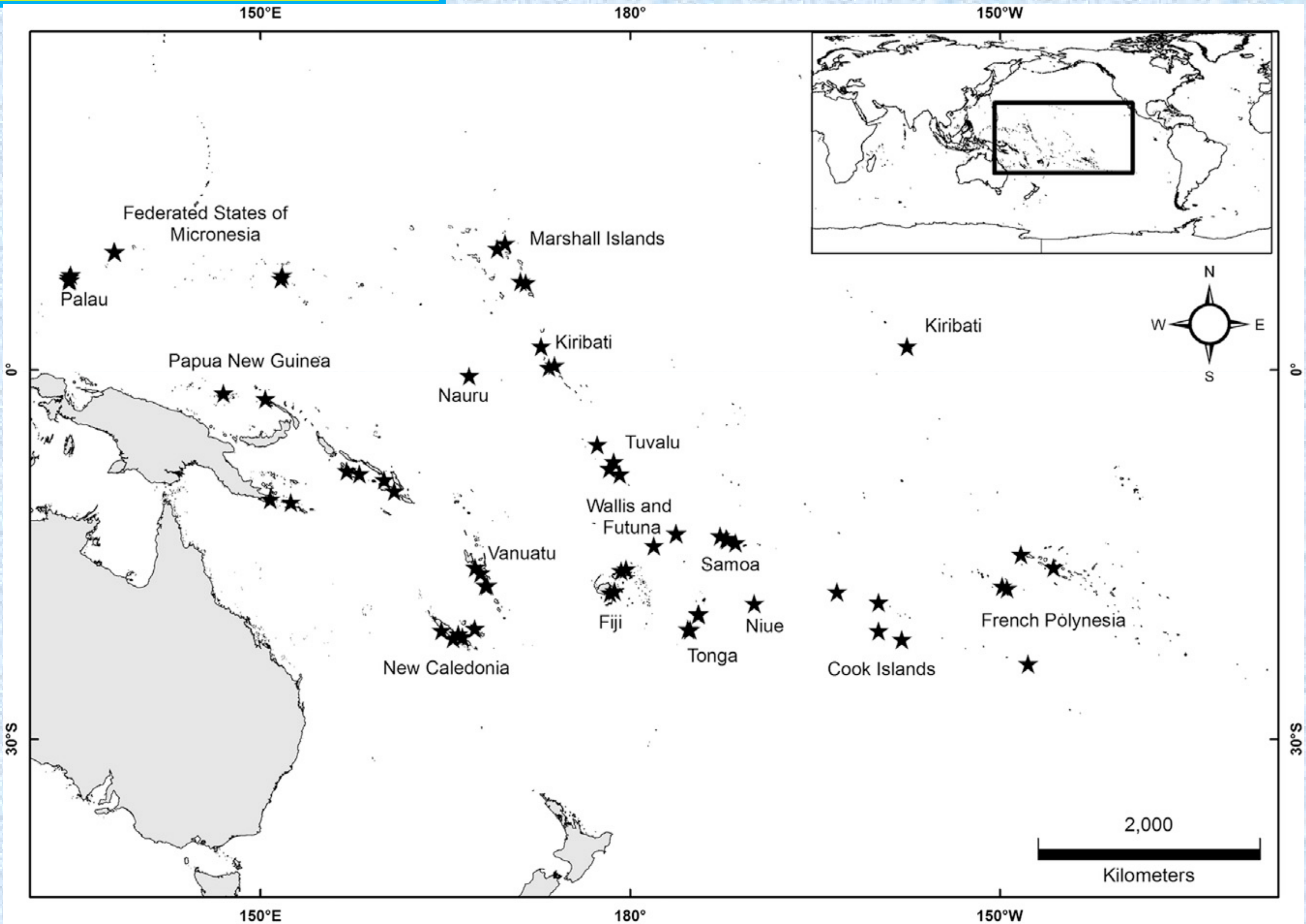


The proportion of predators increases as islands become smaller & isolated
Vulnerability to fishing increases similarly as predators are 1st targets

Stier et al. 2014 Larval dispersal shapes trophic structure across the Pacific. Nature communications

First analyses on the local effects of man

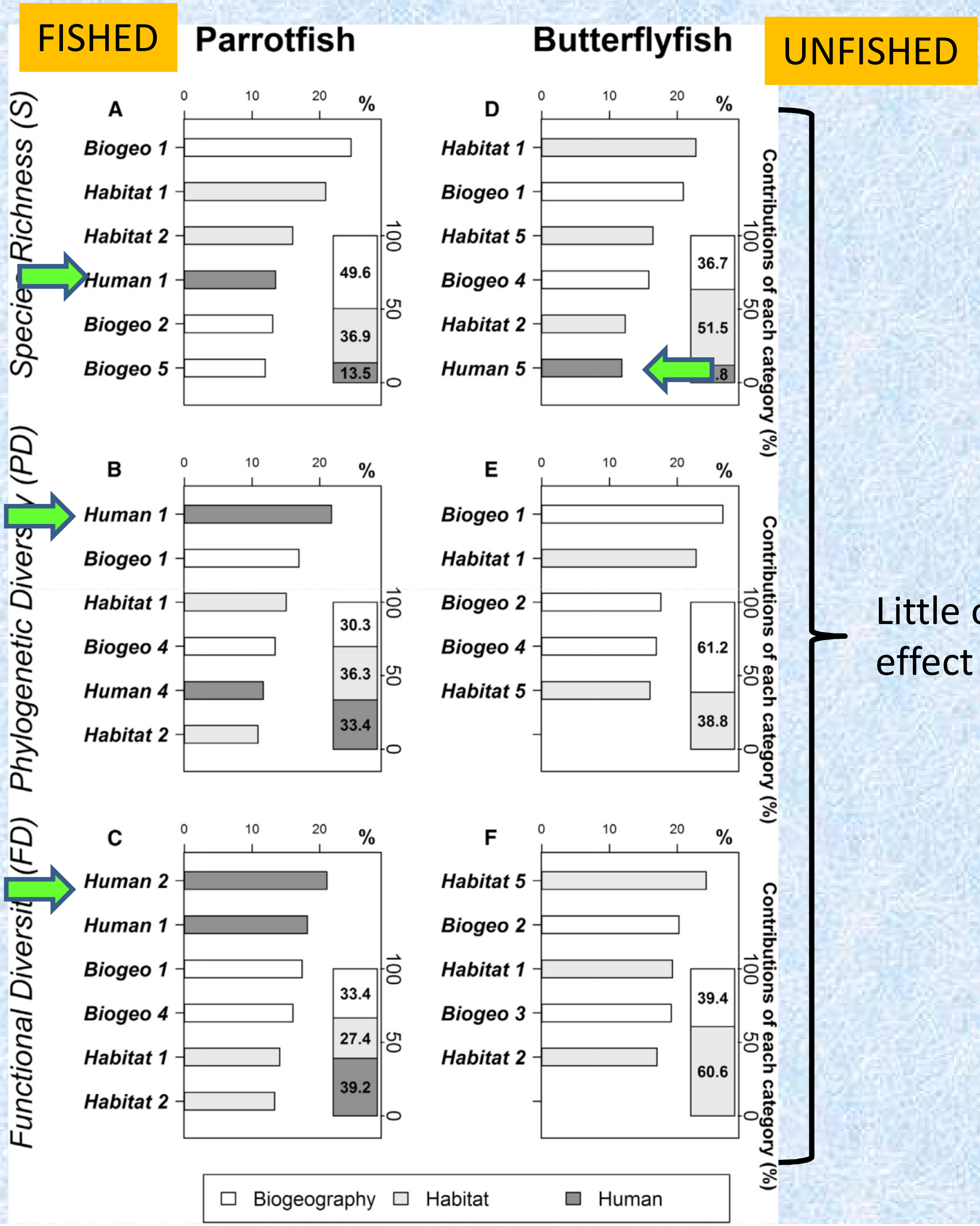
Are functions more robust than species to perturbations ?



D'agata et al. 2014. Humans prune the Tree of Life on coral reefs. Current Biology

Little effect of man on Species Richness

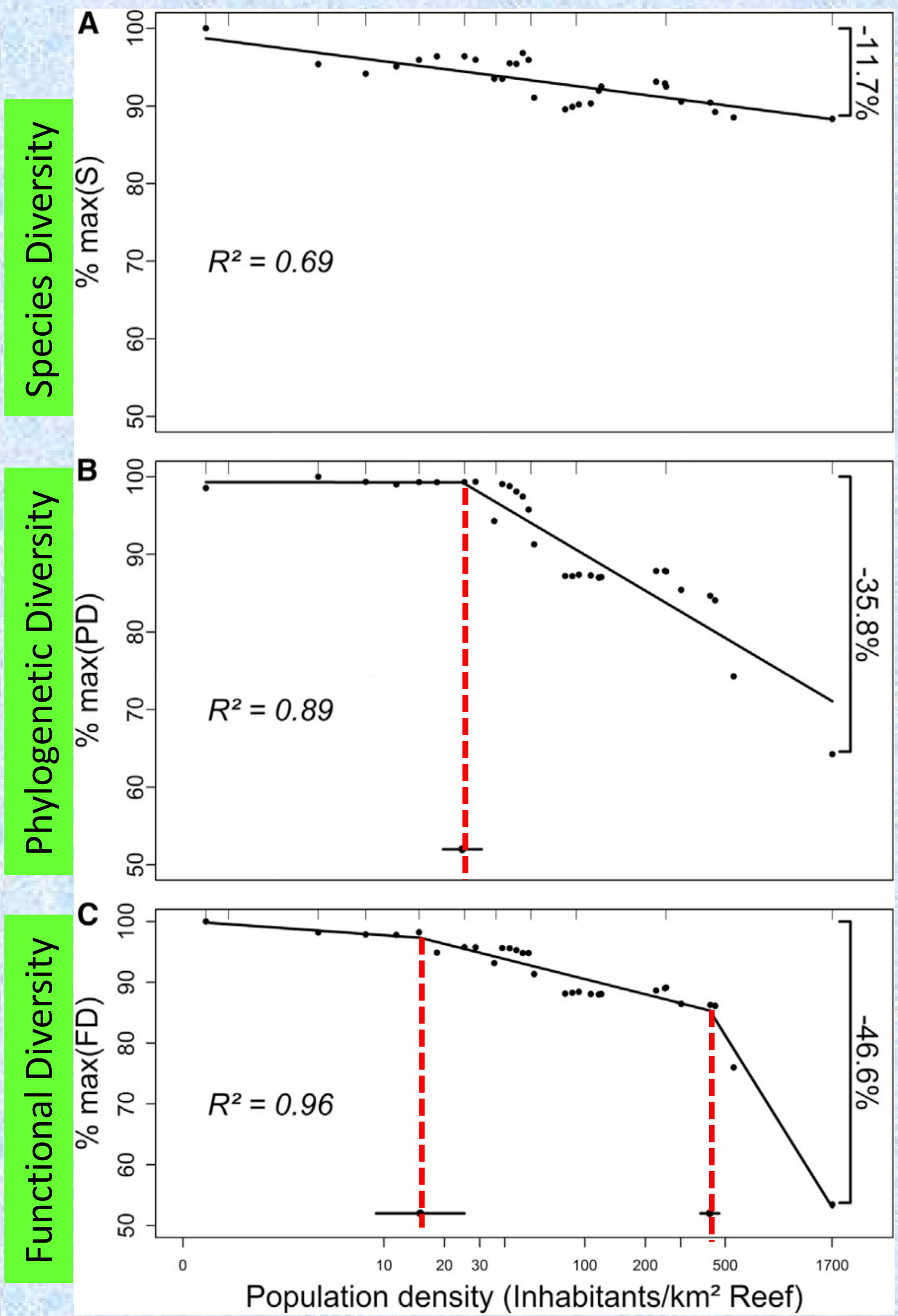
Man important for both Phylogenetic & Functional Diversities



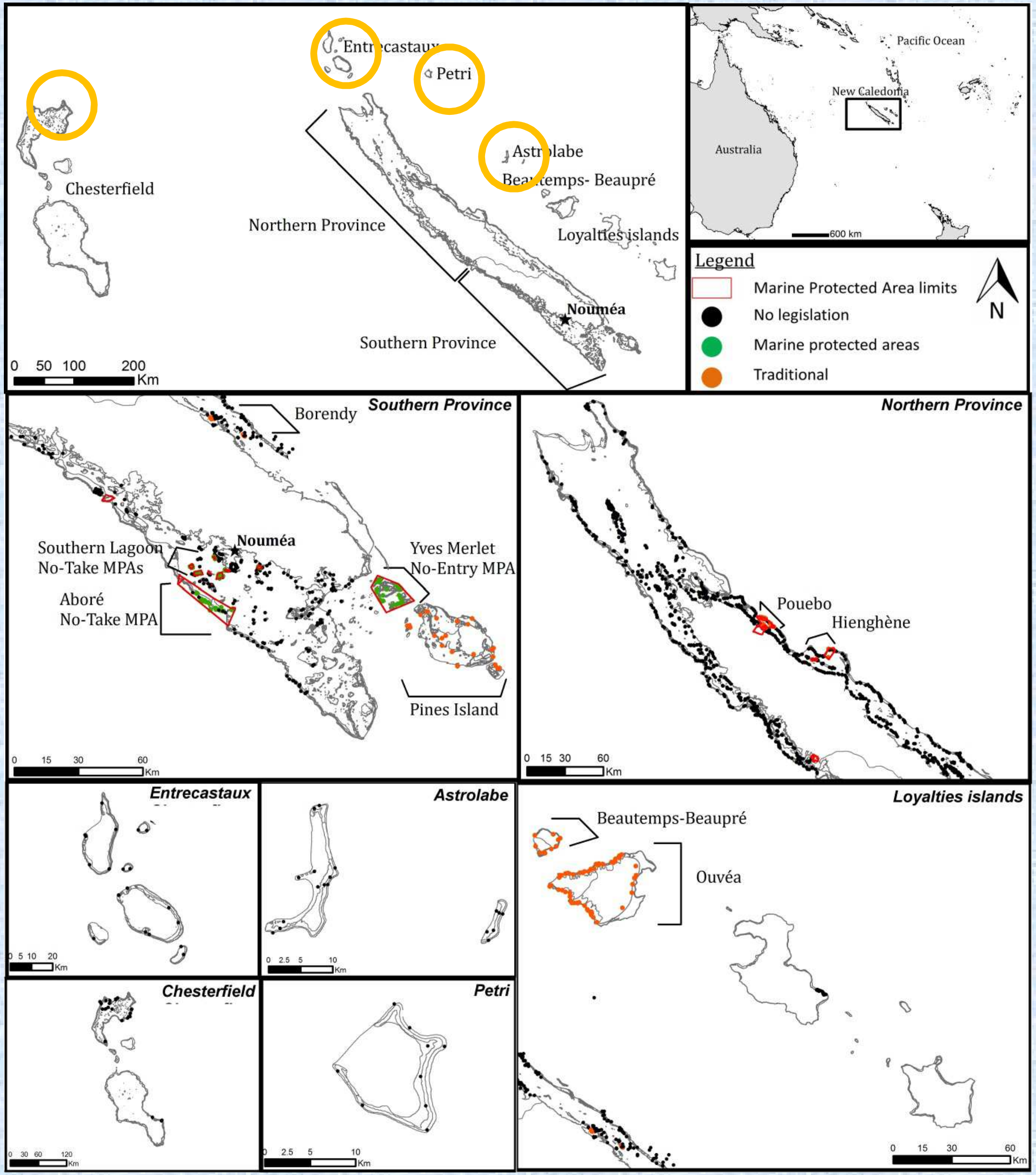
Little or no effect of Man

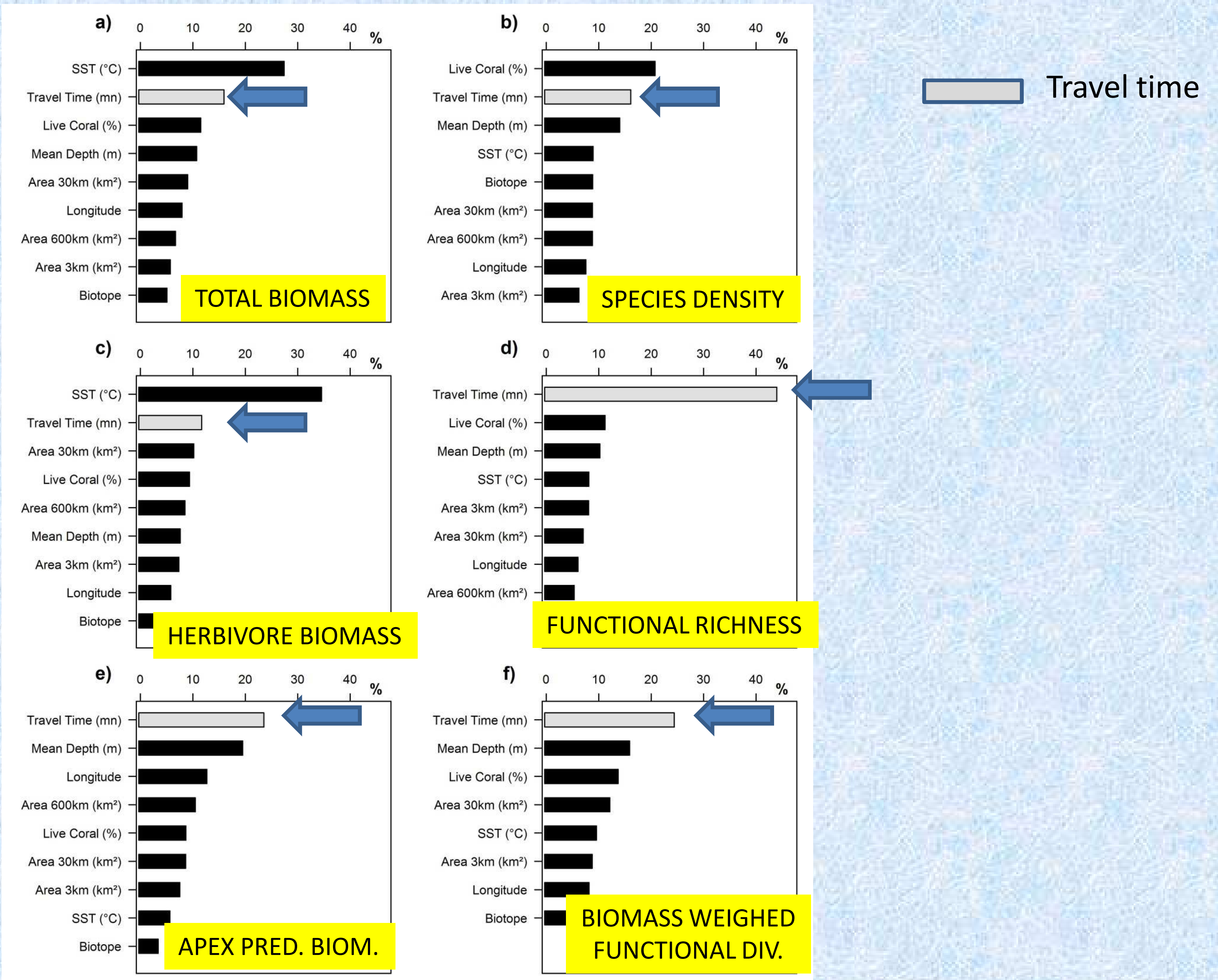
PARROT FISH

Thresholds found at rather low human densities (10-30 persons/km² of Reef)

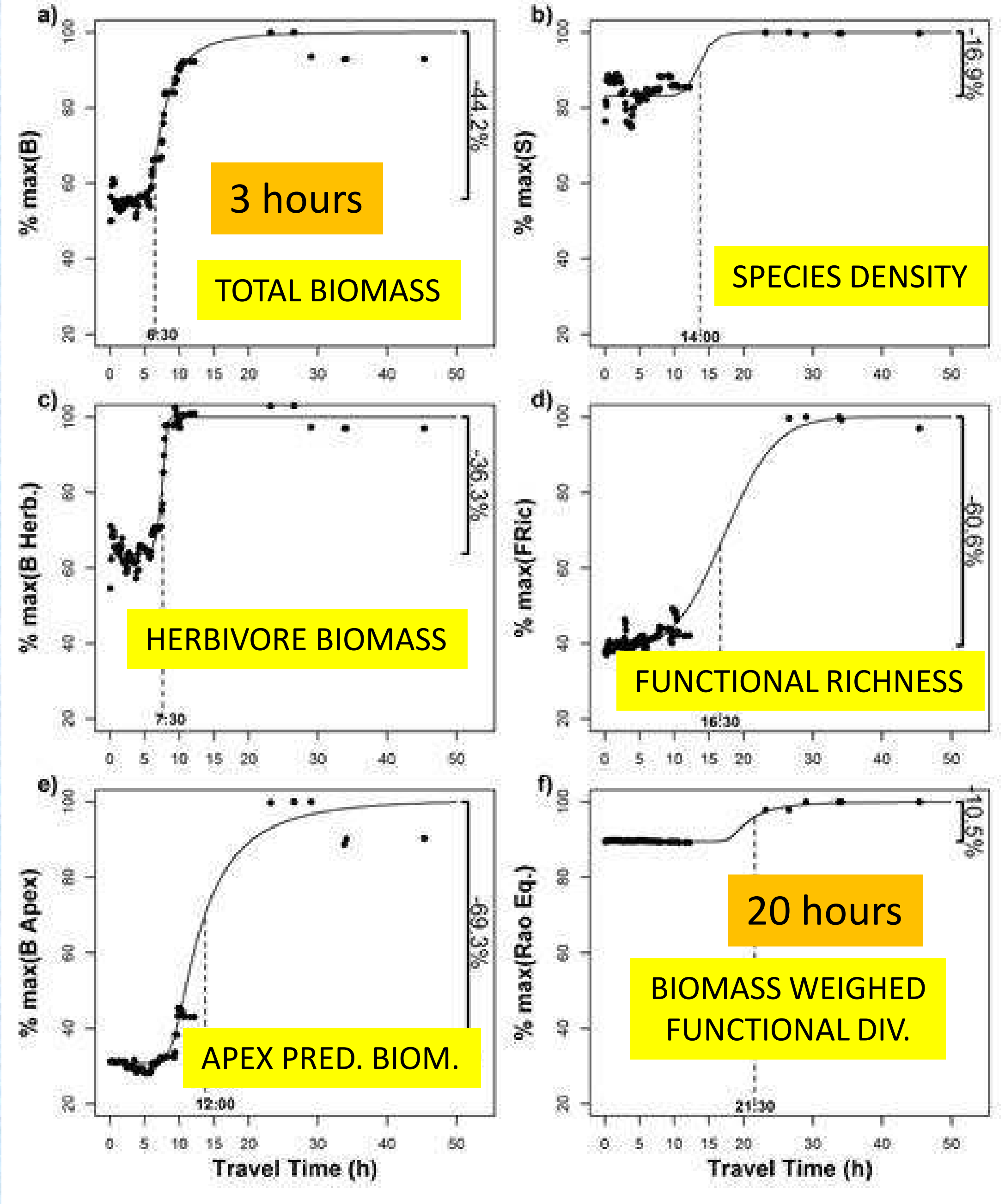


« PRISTINE » ZONES do they represent a baseline for MPAs ?





a)
SST (°C)
Travel Time (mn)
Live Coral (%)
Mean Depth (m)
Area 30km (km²)
Longitude
Area 600km (km²)
Area 3km (km²)
Biotope
TOTAL BIOMASS
b)
Live Coral (%)
Travel Time (mn)
Mean Depth (m)
SST (°C)
Biotope
Area 30km (km²)
Area 600km (km²)
Longitude
Area 3km (km²)
SPECIES DENSITY
c)
SST (°C)
Travel Time (mn)
Area 30km (km²)
Live Coral (%)
Area 600km (km²)
Mean Depth (m)
Area 3km (km²)
Longitude
Biotope
HERBIVORE BIOMASS
d)
Travel Time (mn)
Live Coral (%)
Mean Depth (m)
SST (°C)
Area 3km (km²)
Area 30km (km²)
Longitude
Area 600km (km²)
FUNCTIONAL RICHNESS
e)
Travel Time (mn)
Mean Depth (m)
Longitude
Area 600km (km²)
Live Coral (%)
Area 30km (km²)
Area 3km (km²)
SST (°C)
Biotope
APEX PRED. BIOM.
f)
Travel Time (mn)
Mean Depth (m)
Live Coral (%)
Area 30km (km²)
SST (°C)
Area 3km (km²)
Longitude
Biotope
BIOMASS WEIGHED FUNCTIONAL DIV.
0 10 20 30 40 %
Travel time



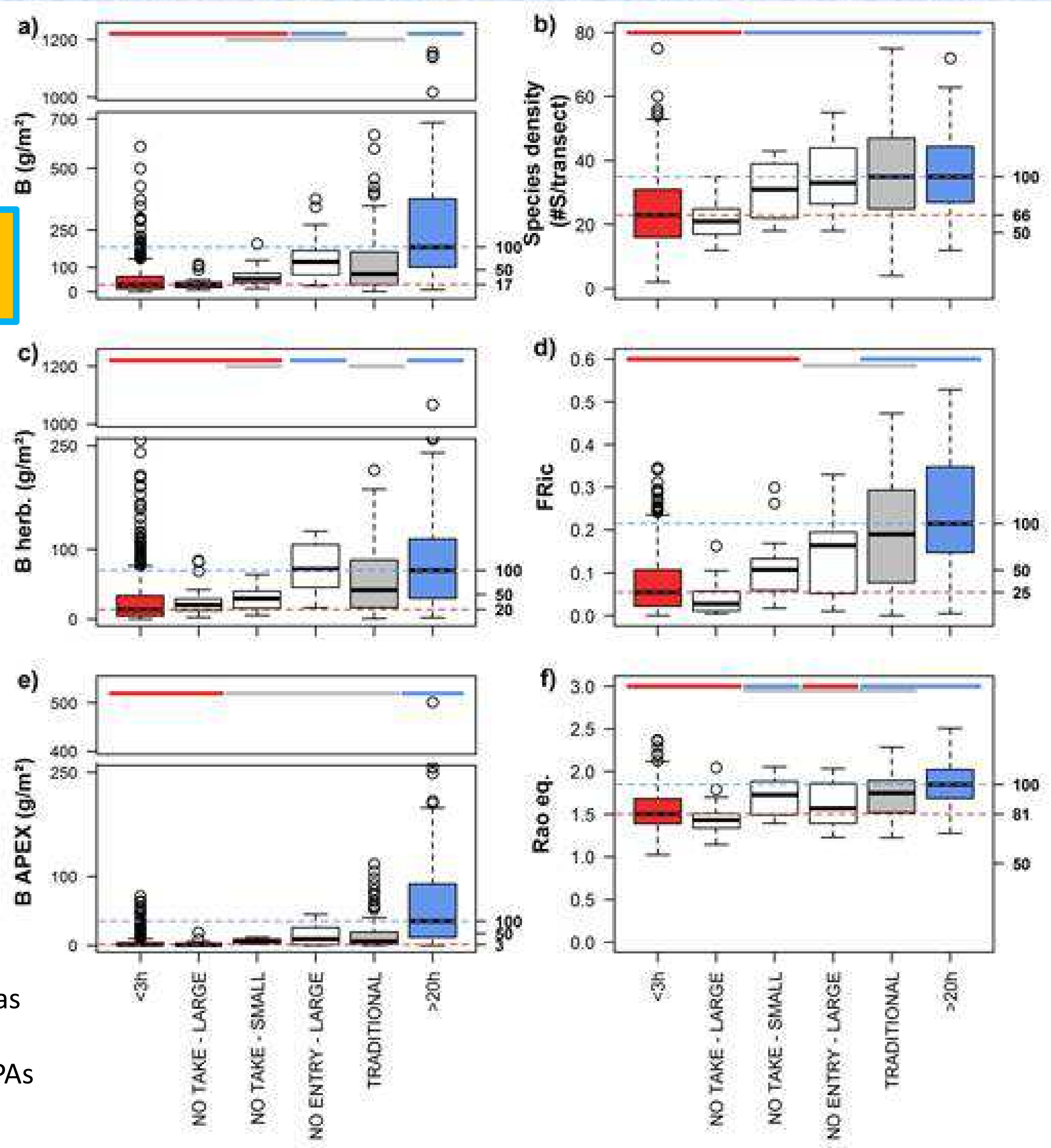
Thresholds
for Travel Time

Beyond a limit there
are sudden and very
significant changes in the
characteristics of the
fish assemblages

Performances of various MPAs versus Pristine Areas

Pristine areas

Exploited areas



similar to Pristine Areas

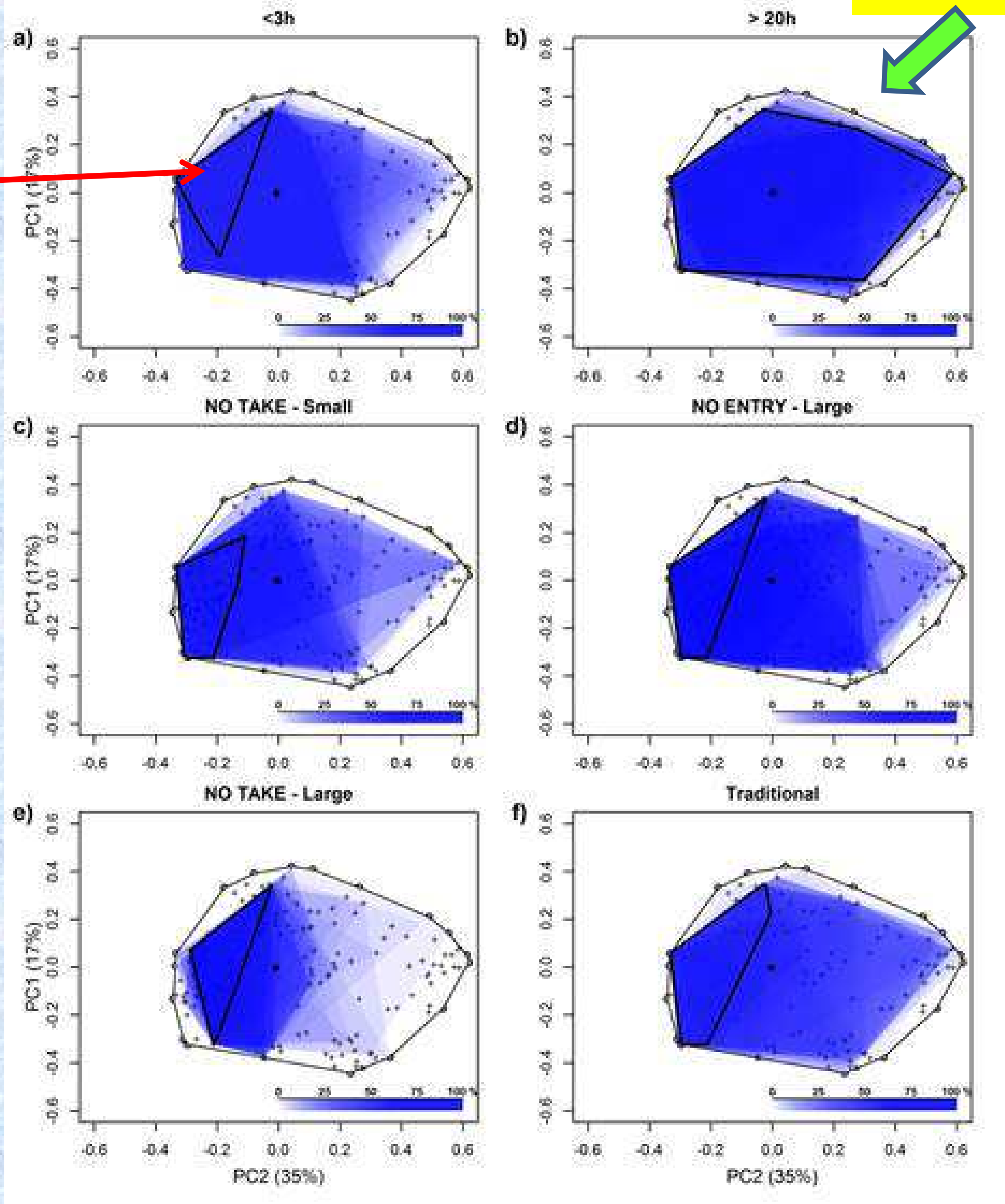
similar to exploited Areas

similar to traditional MPAs

Functional volume filled by > 50% of the assemblages

There is a huge loss in functional space from Pristine Areas to any management type

Pristine zones



What next ?

We have so far mainly focused on diversity (taxonomic & functional)

Need to integrate more Abundance, Biomass and Production

Need to integrate the social & economical aspects to a much larger extent

Need to build robust, pragmatic and transferable predictive models

Reef Fish prove to be an excellent model for general questions in Ecology

Comparative analyses with other vertebrates (birds, mammals, FW fish)

Increasing interest from theoretical ecologists because unique Data Base

Small is at times beautiful


THANK YOU