Development of a model of disturbance and recovery dynamics for marine benthic ecosystems

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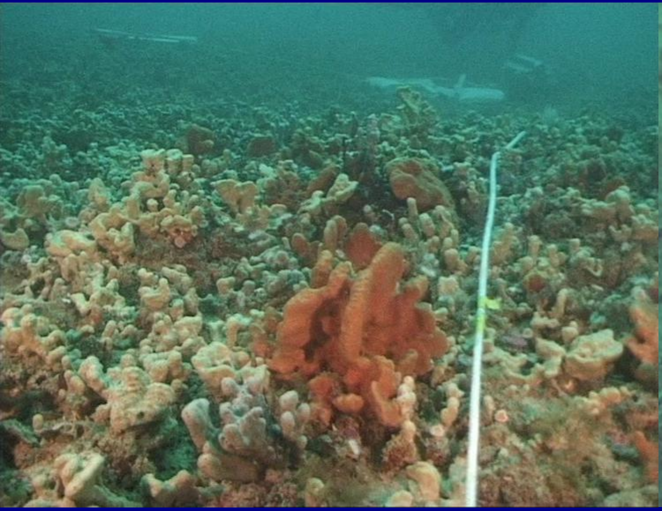

Funding

NIWA
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- MBIE Marine Futures (12-14)
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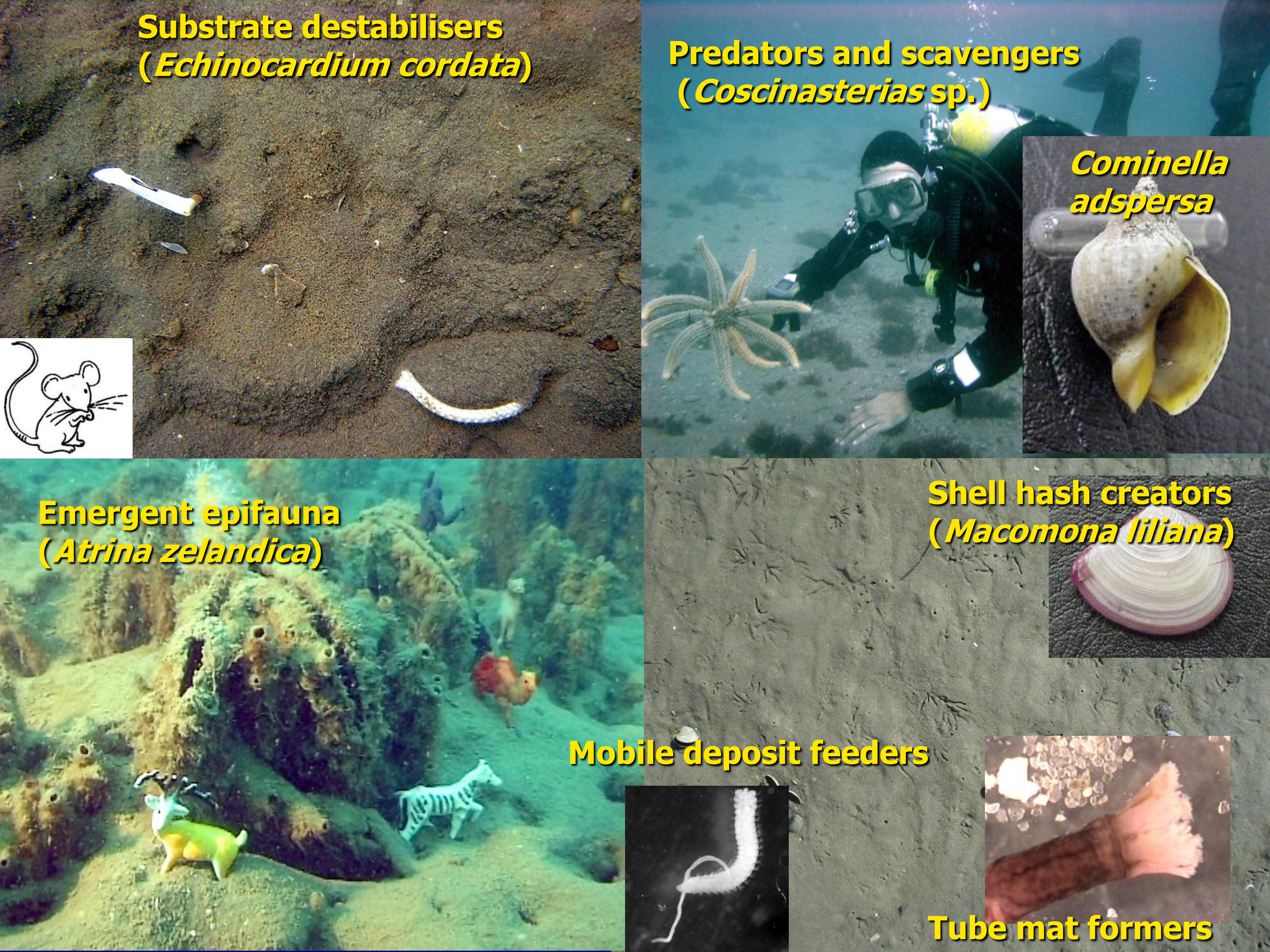
MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

ministry of science + innovation
TE PŪNAHA HIRINGA WHAKAEA

Foundation for RESEARCH SCIENCE & TECHNOLOGY


Substrate destabilisers
(*Echinocardium cordata*)
Predators and scavengers
(*Coscinasterias* sp.)
Cominella adspersa
Emergent epifauna
(*Atrina zelandica*)
Shell hash creators
(*Macomona liliana*)
Mobile deposit feeders
Tube mat formers

Disturbance/Recovery Dynamics and Marine Spatial Management

- Benthic fishing methods disturb the seafloor. The question is: How much do we need to leave undisturbed and for what timeframe to maintain the benthic system
- Empirical measurements are expensive and time-consuming at scale of management of EEZ
- We need to develop a simple heuristic model that captures these dynamics to inform an ecosystem-based management approach [and validate it]

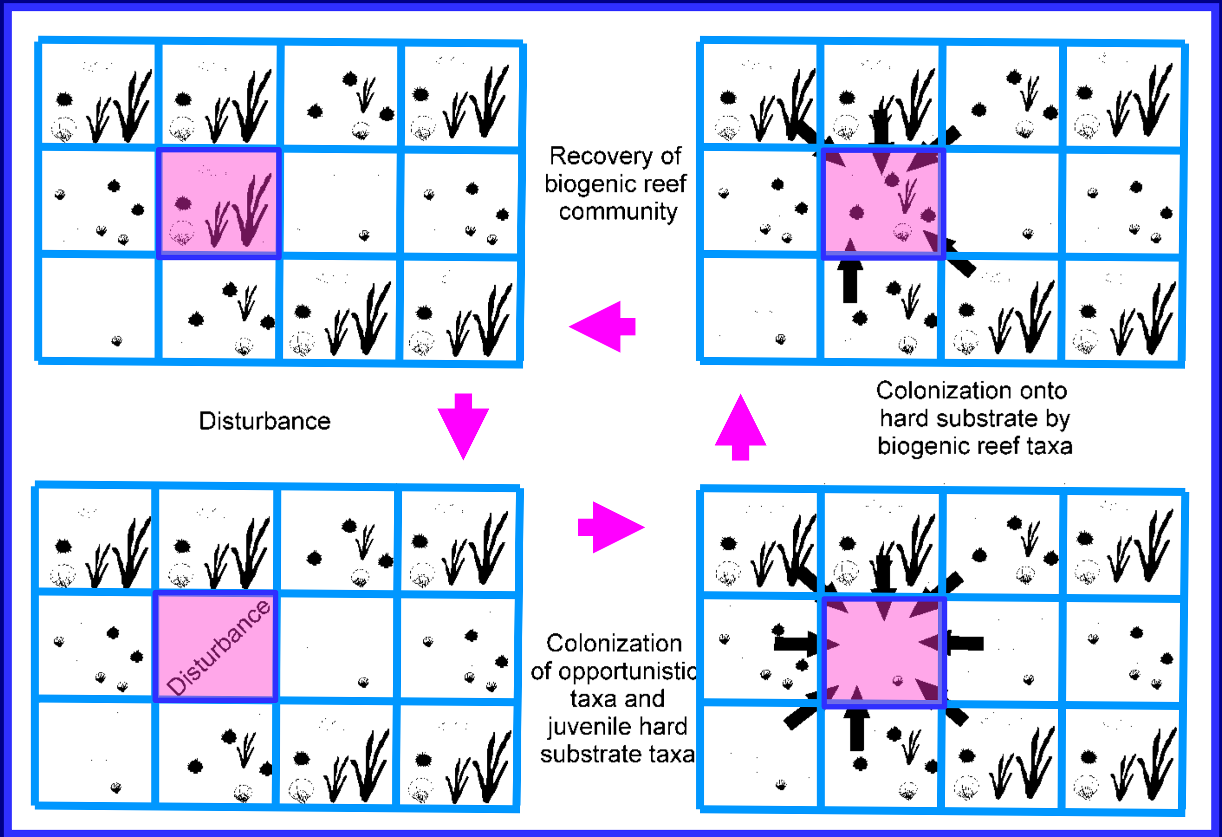
Glass half full?

- We do understand a lot about seafloor community dynamics (growth rates, maturity rates, dispersal – at least within orders of magnitude)*
- We can apply value to loss of seafloor habitat via contributions to ecosystem function and services, and we do have some data to quantify services that particular species provide*
- Functions directly relevant to fisheries: habitat structure, productivity, resilience, maintenance of adaptive capacity via species richness

*Better information will be used refine model predictions, validate the model for particular habitats, and determine gaps in knowledge that are critical for model dynamics

Simple heuristic models moving from patch dynamics to landscapes

- Community-based 'seascape' model originally developed for typical shallow, coastal benthic community archetypes
- Predict spatial and temporal scales of disturbance at which communities are able to respond and persist

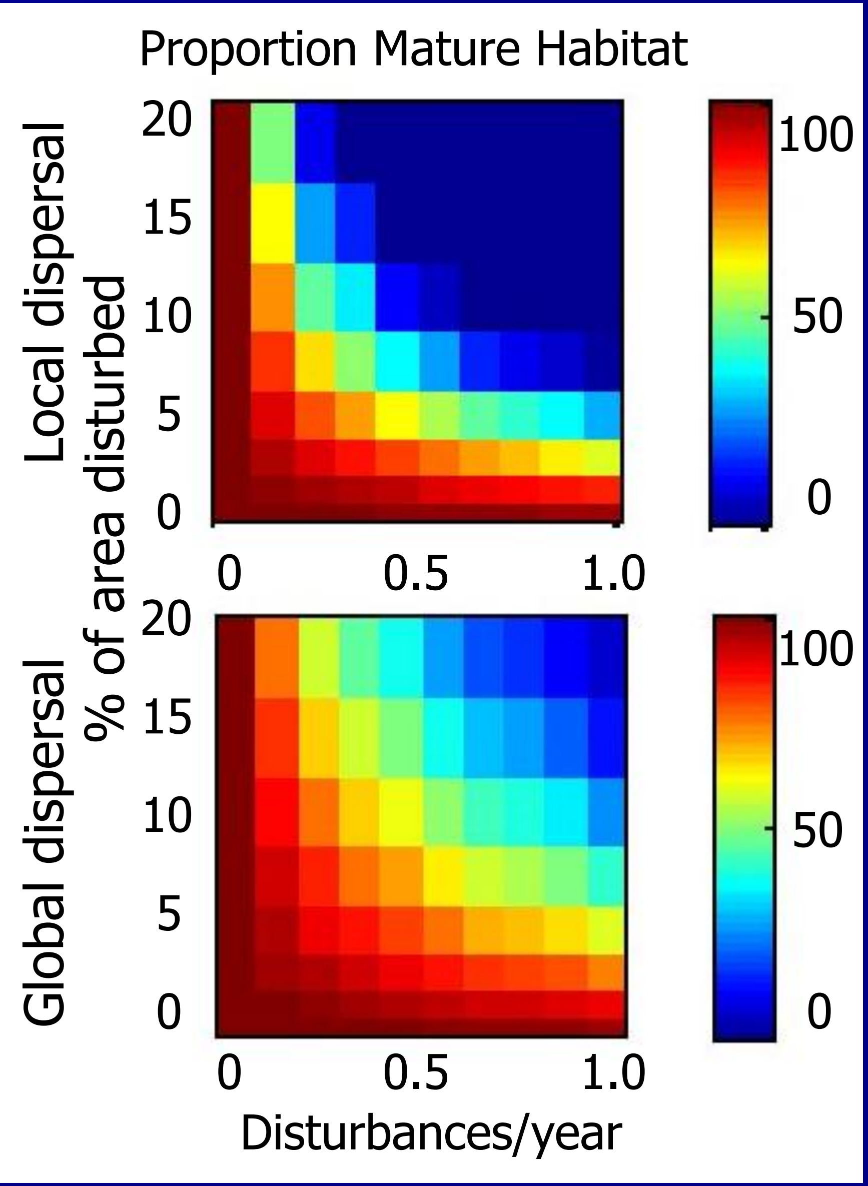


Model V1 Summary

- 100 by 100 cell grid (10,000 cells)
- Simplistic representation of community successional dynamic
- 3 archetypal communities based on time to mature successional stage (2, 6, 15 years)
- Each successional stage represented by discrete period of time
- Varying spatial extent and temporal frequency of random disturbance events within the landscape (1100 total scenarios)
- 100 time steps

Model v1.1 and v1.2

- Restricted set of spatial and temporal disturbance regimes over which communities can persist.
- Dispersal/colonisation reduces the disturbance regime over which communities can persist.
- Temporal ≠ spatial scales

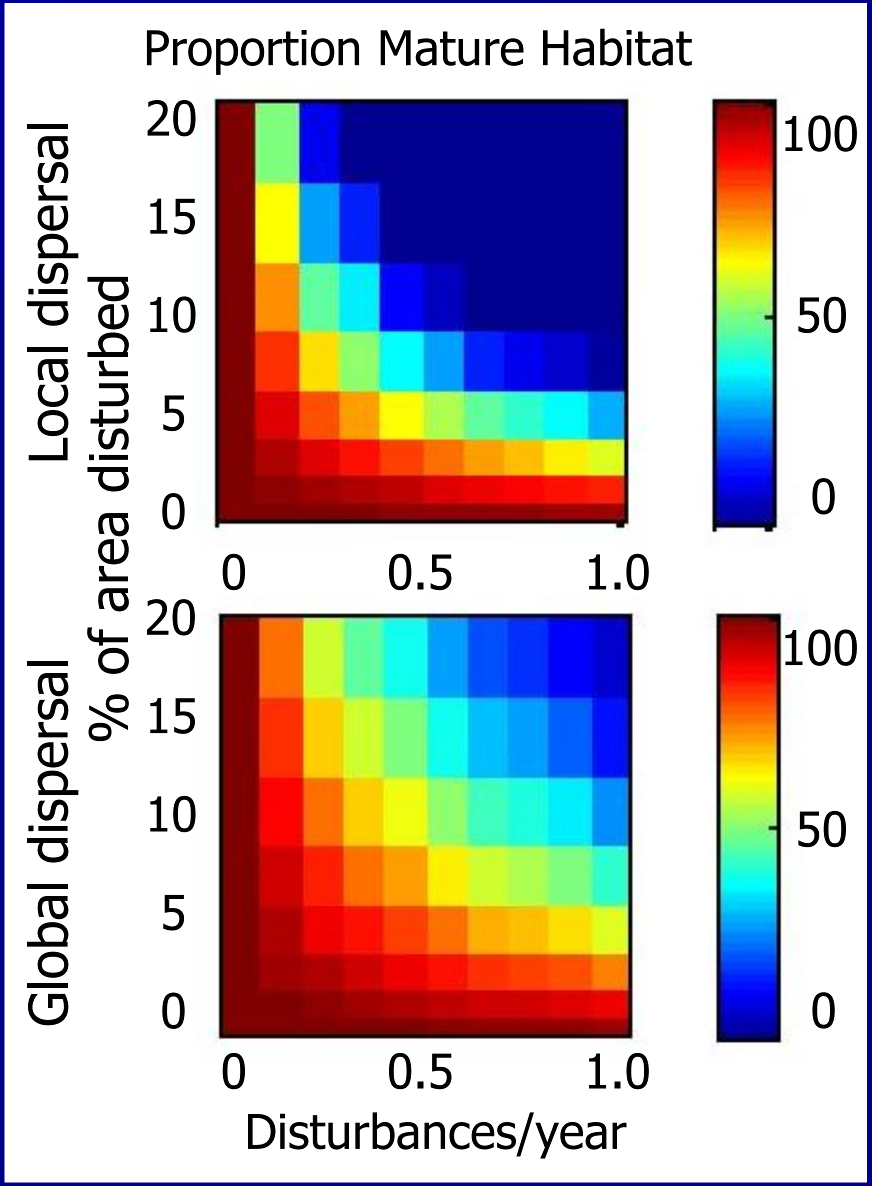


Lundquist CJ; Thrush SF; Coco G; Hewitt JE (2010) Interactions between disturbance and dispersal decrease persistence thresholds of a marine benthic community. *Marine Ecology Progress Series* 413: 217-228

Thrush SF; Lundquist CJ; Hewitt JE (2005) Spatial and temporal scales of disturbance to the seafloor: a generalized framework for active habitat management. *American Fisheries Society Symposium* 41: 639-649.

Model v1.1 and v1.2

- Martin Cryer, New Zealand continental slope, 2100 km^2, 20% of slope per year
- New England, 56% of region trawled per year
- Northern California, 1.5-3 times per year



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Thrush SF; Lundquist CJ; Hewitt JE (2005) Spatial and temporal scales of disturbance to the seafloor: a generalized framework for active habitat management. *American Fisheries Society Symposium* 41: 639-649.

Current Model (ZBD200925)

8 interacting functional groups characterised by:

- Age of maturity
- Age of mortality
- Seasonality of reproduction
- Dispersal properties
- Dependence on hard substrate for settlement
- Adult-juvenile interaction matrix that allow presence/absence of each group to impact colonisation/recovery potential after disturbance

1 - opportunistic

2 - opportunistic

3 - tubemat

4 - destabiliser

5 - shellhash

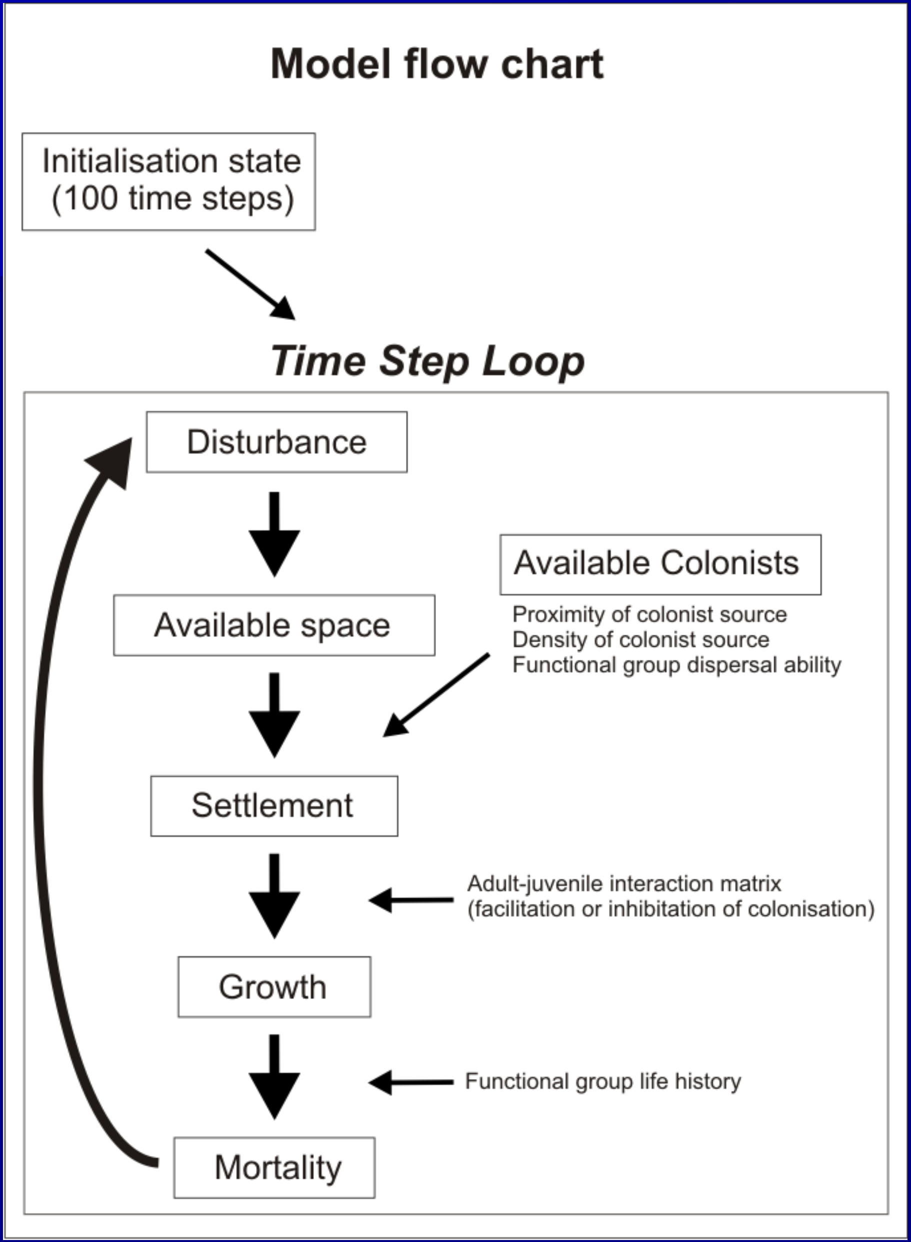
6 - epifauna

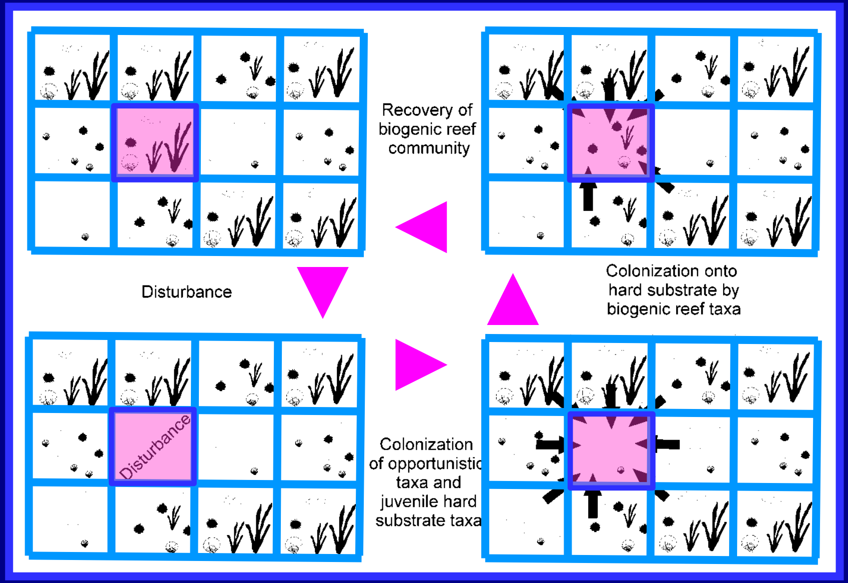
7 – deep burrow

8 - scavenger

Expert workshop = Conceptual Functional Groups

	Conceptual Functional Group	Typical taxa
1	**Opportunistic early colonists – limited substrate disturbance**	Sedentary species like capitellid and spionid polychaetes
2	**Opportunistic early colonists – considerable substrate disturbance**	Mobile deposit feeders and small scavengers, phoxocephalid amphipods and other small crustaceans
3	**Substrate stabilisers (Tube mat formers)**	Tube mat forming polychaetes (spionids, terebellids, chaetopterids); Amphipods
4	**Substrate destabilisers**	Spatangoid echinoids (*Echinocardium* sp.), holothurians, *Amphiura* sp., gastropods
5	**Shell hash-creating species**	Bivalves, gastropods
6	**Late colonisers – emergent epifauna**	Sponges, bryozoans, sea pens, sea whips, ascidians, gorgonians – primarily sedentary suspension feeders
7	**Late colonisers – burrowers**	Shrimps, crabs, large polychaetes
8	**Predators and scavengers**	Predatory starfish, brittlestars, crabs, gastropods, hermit crabs, worms – mostly large-bodied


Model flow chart
Initialisation state (100 time steps)
Time Step Loop
Disturbance
Available space
Available Colonists
Proximity of colonist source
Density of colonist source
Functional group dispersal ability
Settlement
Adult-juvenile interaction matrix (facilitation or inhibitation of colonisation)
Growth
Functional group life history
Mortality


Recovery of biogenic reef community
Disturbance
Colonization onto hard substrate by biogenic reef taxa
Disturbance
Colonization of opportunistic taxa and juvenile hard substrate taxa

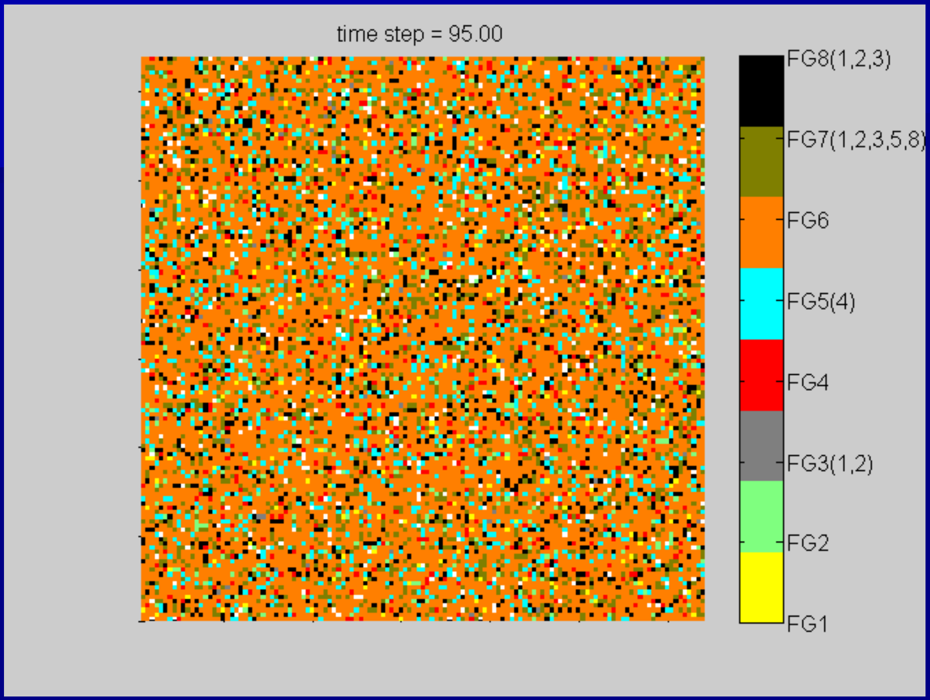
Defining parameters for Conceptual Functional Groups

	Conceptual Functional Group	**Juvenile Max Age (# of seasons)**	**Adult Max Age (# of seasons)**	**Reprod. seasons**	**Dispersal length (# cells)**
1	**Opportunistic – limited disturbance**	1	6	1 2 3	10
2	**Opportunistic – considerable disturbance**	1	6	1 2 3	10
3	**Substrate stabilisers (Tube mat formers)**	2	12	1 2	5
4	**Substrate destabilisers**	4	20	2	5
5	**Shell hash-creating species**	4	60	1 2	5
6	**Late colonisers – emergent epifauna**	8	200	2	1
7	**Late colonisers – burrowers**	6	20	2	5
8	**Predators and scavengers**	6	20	1 2 3 4	5

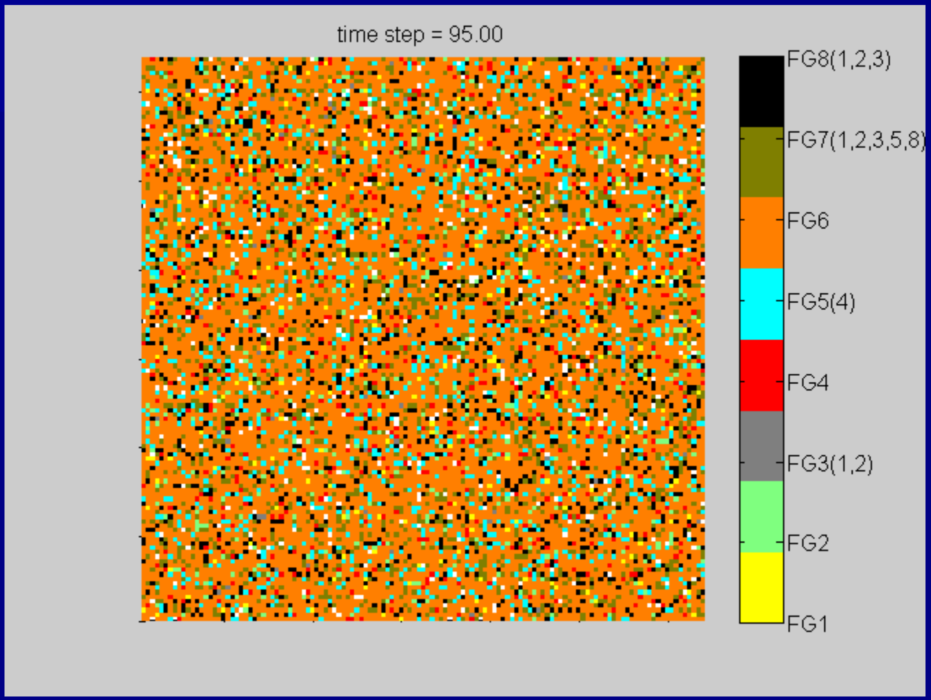
Adult-Juvenile Interaction Matrix

	Functional Group	1	2	3	4	5	6	7	8
1	**Opportunistic early colonists – limited substrate disturbance**	0	0	-1	0	-1	0	0	0
2	**Opportunistic early colonists – considerable substrate disturbance**	-1	-1	-1	-1	-1	-1	-1	-1
3	**Substrate stabilisers (Tube mat formers)**	1	1	1	1	1	1	0	0
4	**Substrate destabilisers**	-1	0	-1	0	-1	-1	-1	-1
5	**Shell hash-creating species**	-1	-1	1	1	1	1	0	1
6	**Late colonisers – emergent epifauna**	0	0	0	1	0	1	0	1
7	**Late colonisers – burrowers**	0	0	-1	-1	-1	-1	-1	-1
8	**Predators and scavengers**	-1	-1	-1	-1	-1	-1	-1	-1

Model simulations

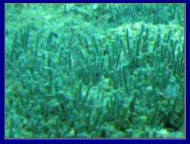


20 x 20 disturbance between timesteps 25 & 63 equating to approximately **10 % of landscape** disturbed per year (4 time steps/yr)



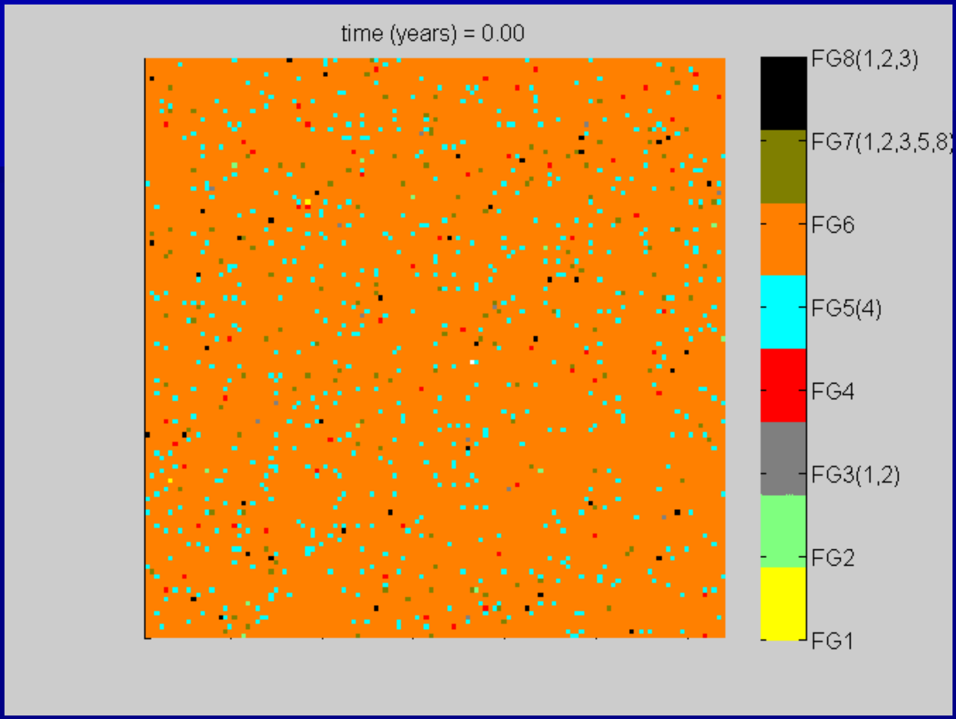
10 x 10 disturbance between timesteps 25 & 63 equating to approximately **2 % of landscape** disturbed per year (4 time steps/yr)

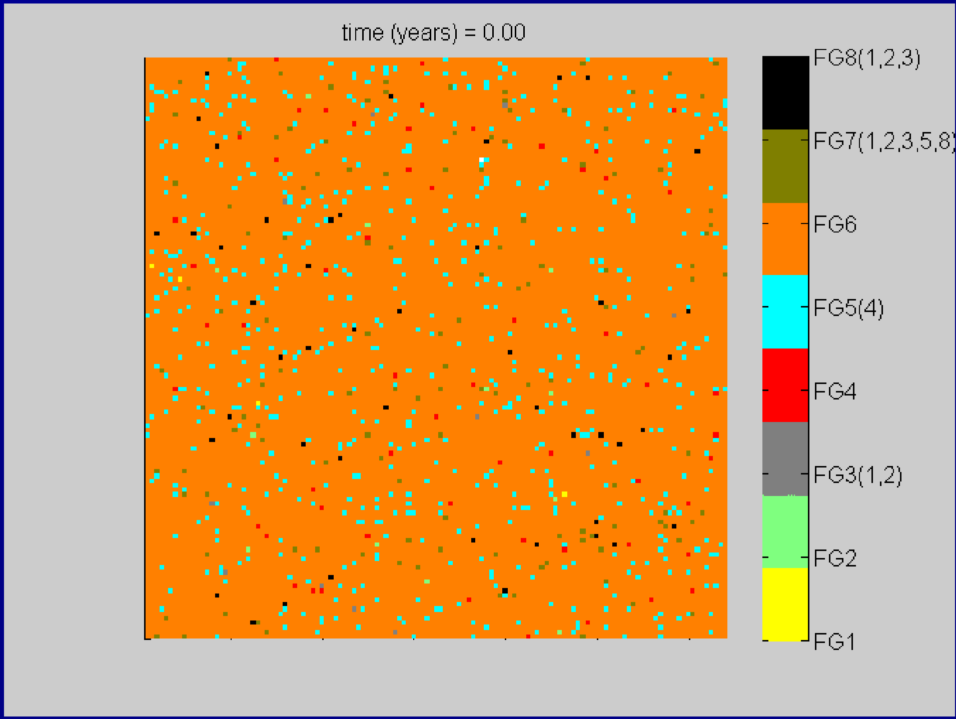







Model simulations





20 x 20 disturbance between timesteps 25 & 63 equating to approximately **10 % of landscape** disturbed per year (4 time steps/yr)

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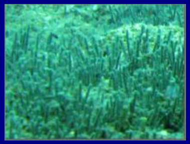
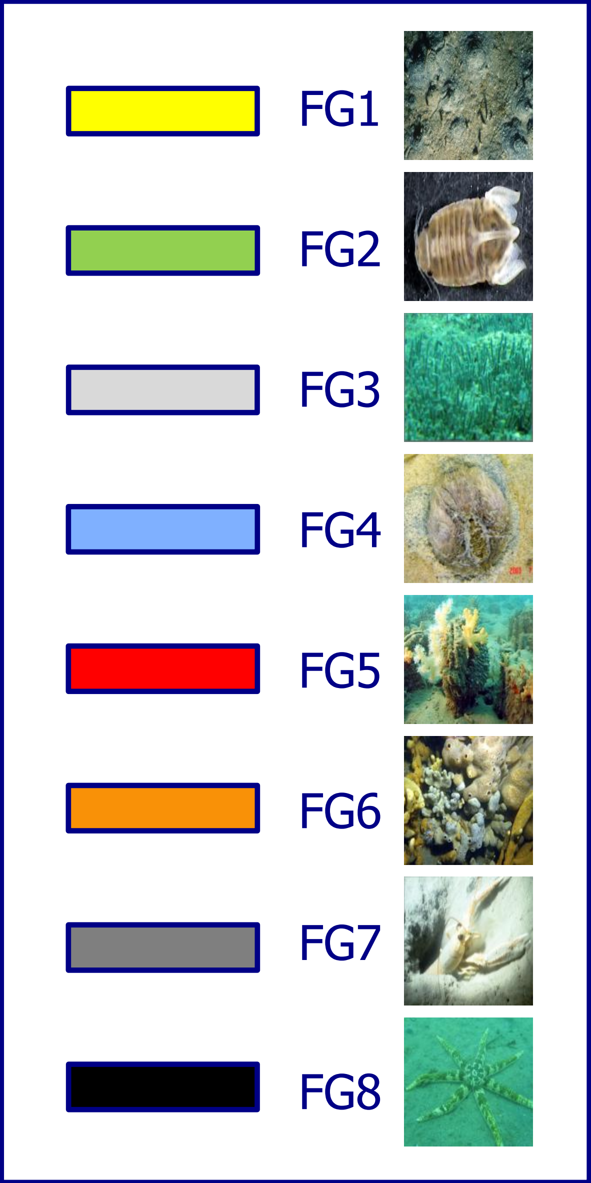
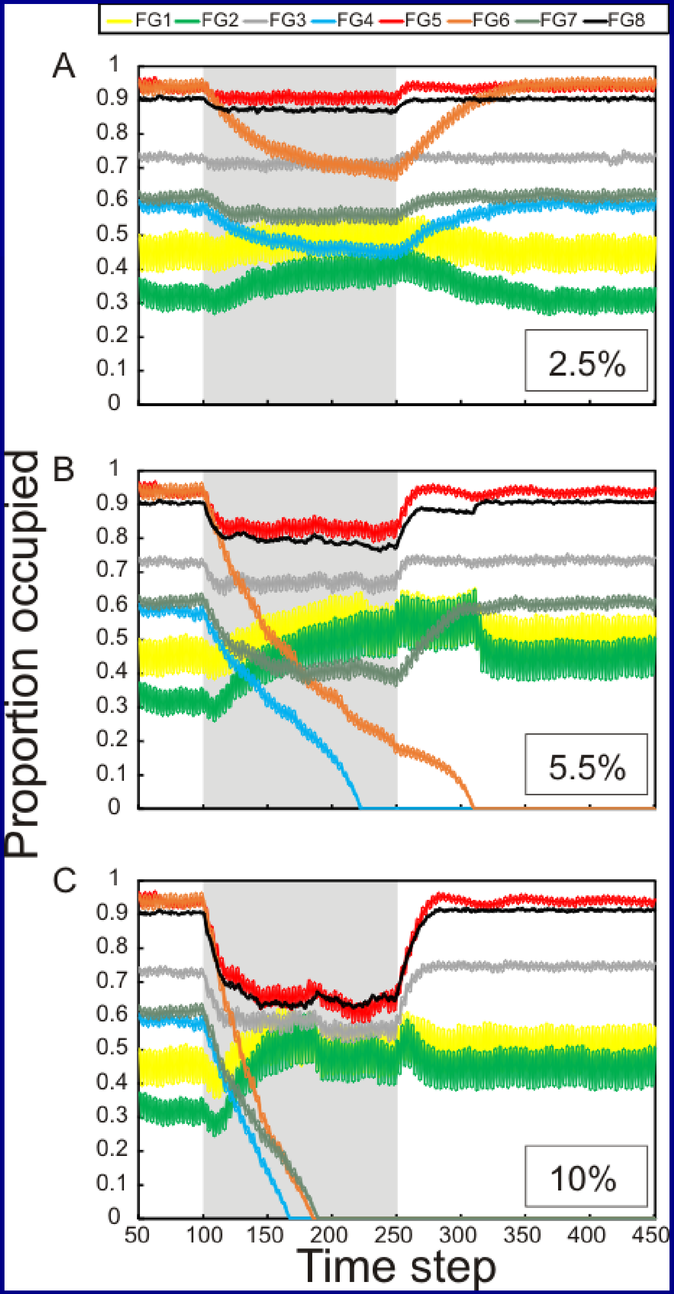


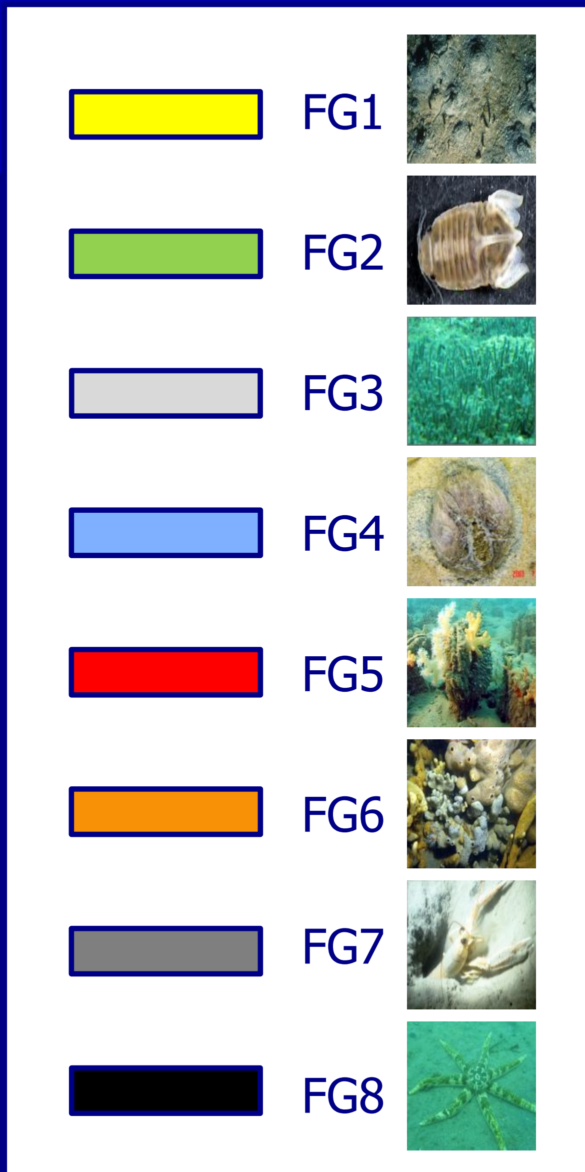


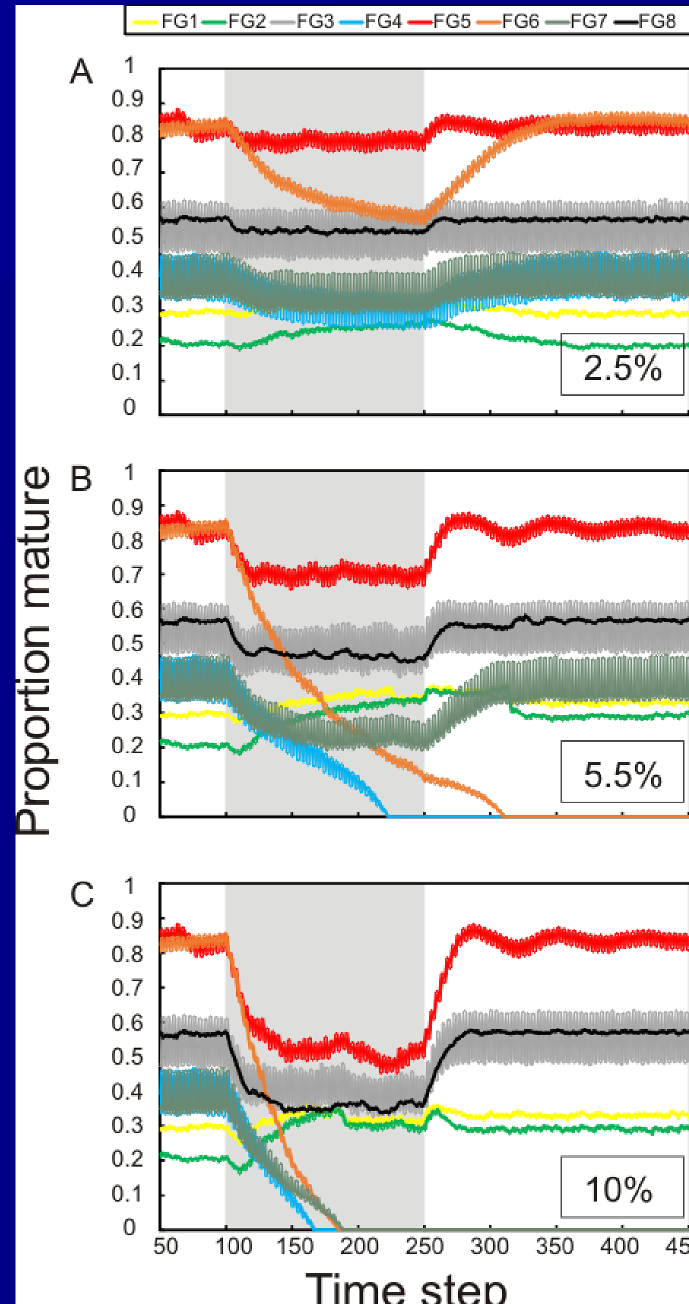

Proportion occupied



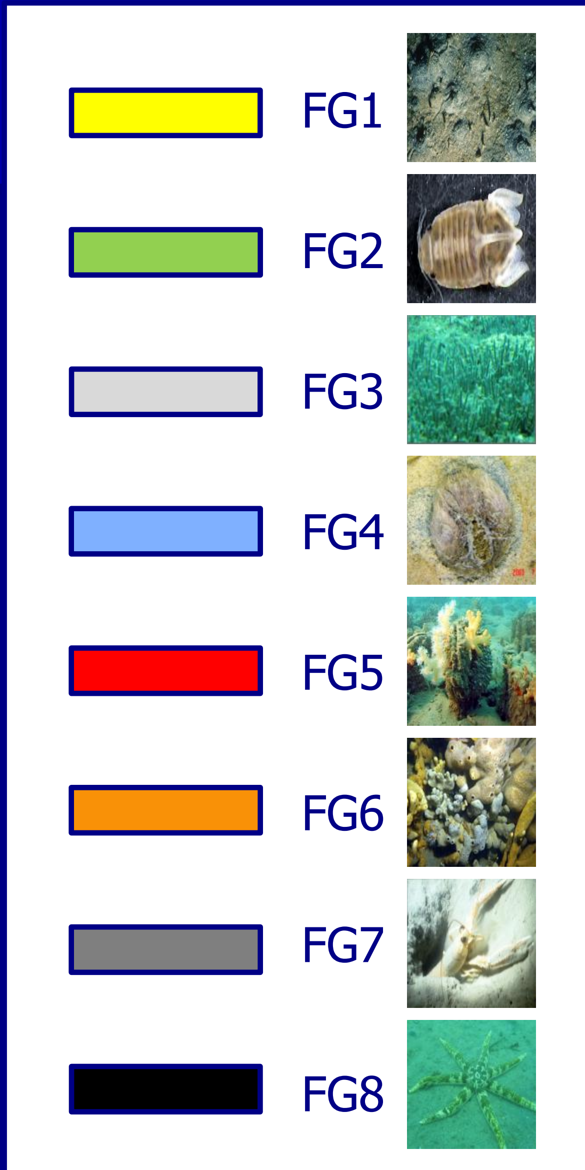


Proportion mature

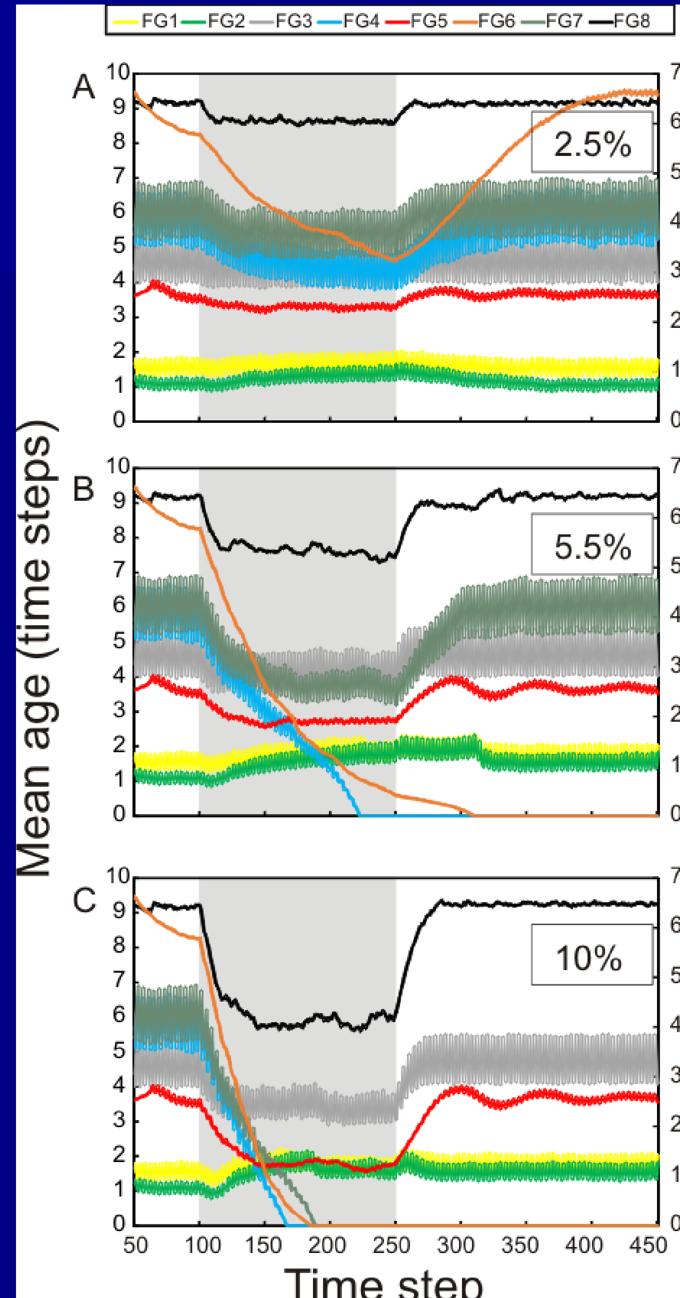




Mean age

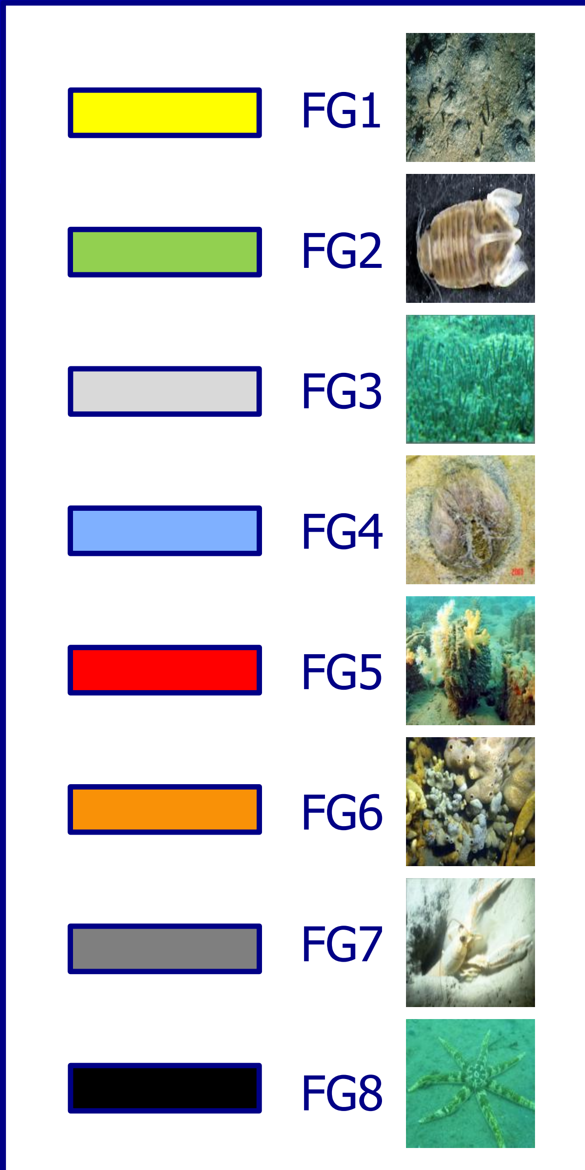


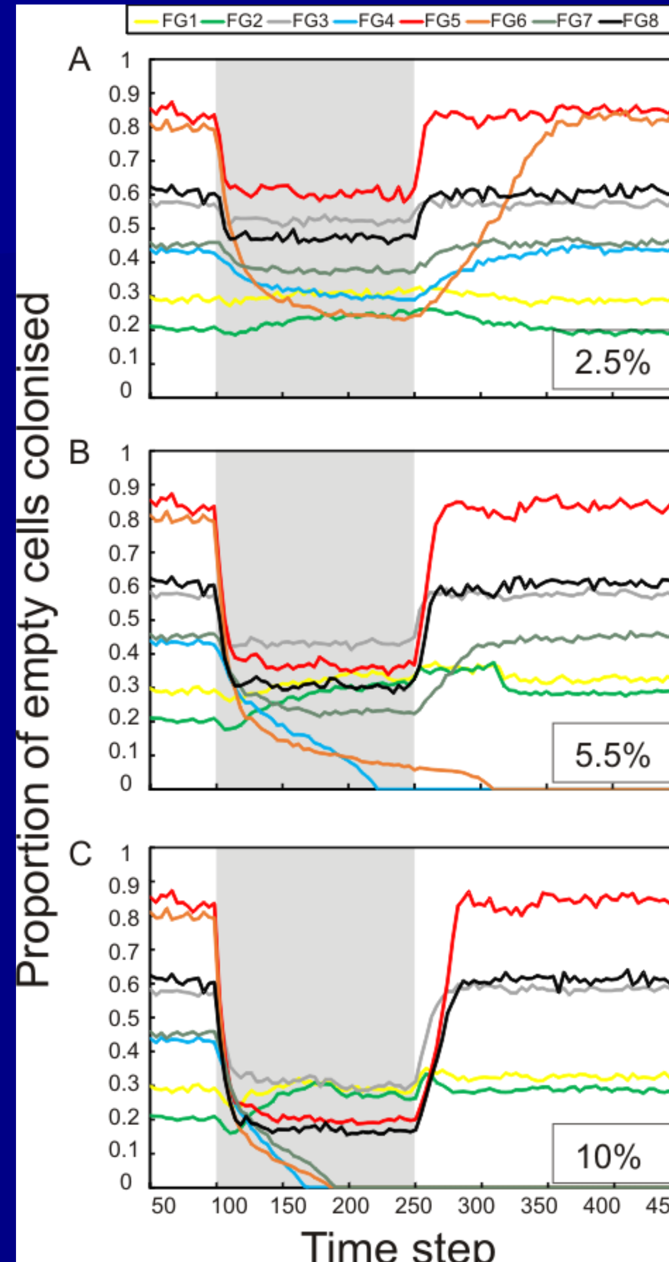
FG1
FG2
FG3
FG4
FG5
FG6
FG7
FG8



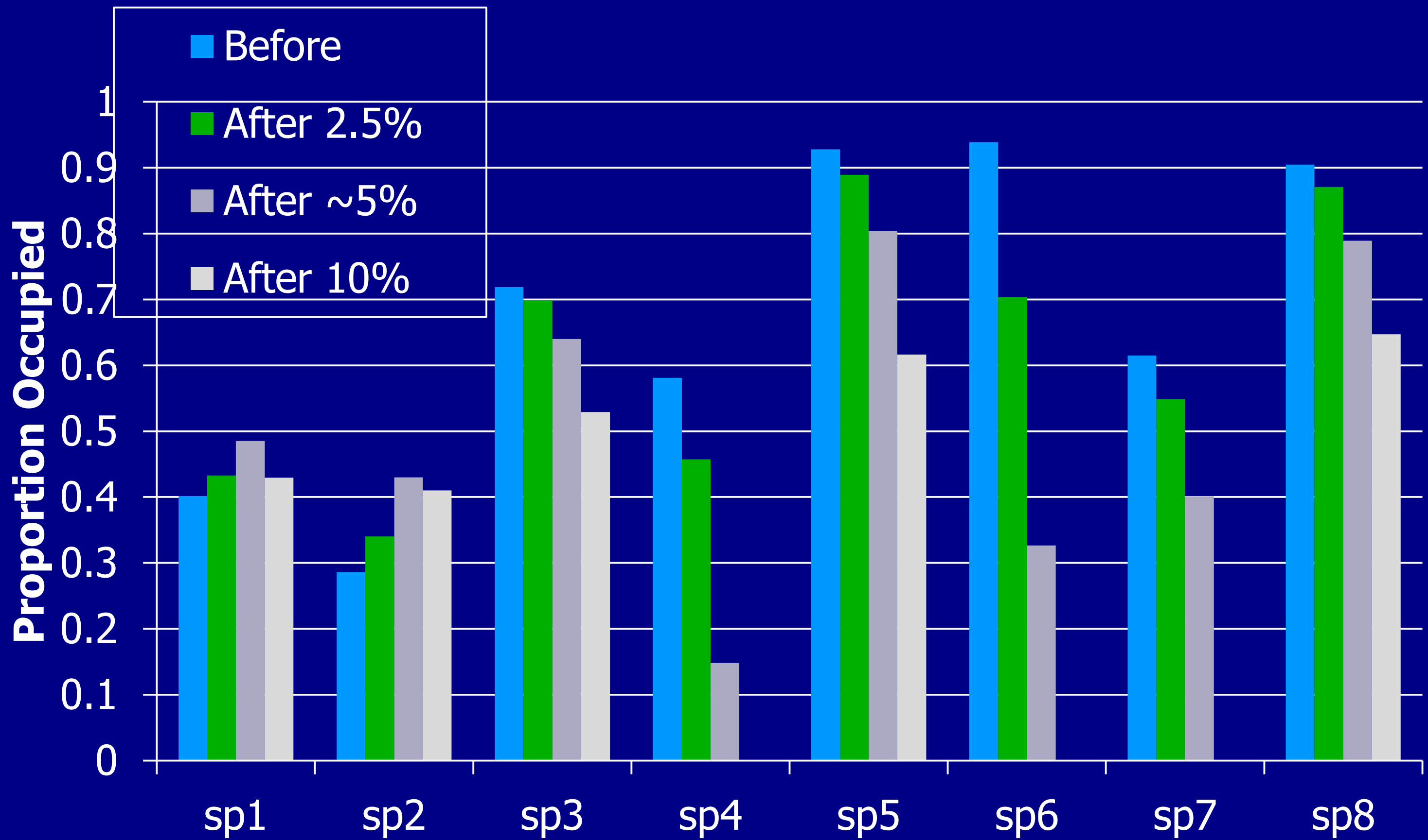
FG1 FG2 FG3 FG4 FG5 FG6 FG7 FG8
A
2.5%
B
5.5%
C
10%
Mean age (time steps)
Time step
0 1 2 3 4 5 6 7 8 9 10
0 10 20 30 40 50 60 70
50 100 150 200 250 300 350 400 450

Proportion colonised





Change in f-groups with increasing rate of disturbance



sp1


sp2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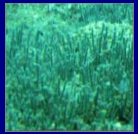

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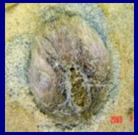


sp5

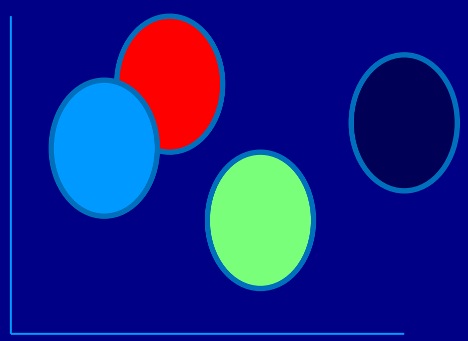

sp6


sp7


sp8

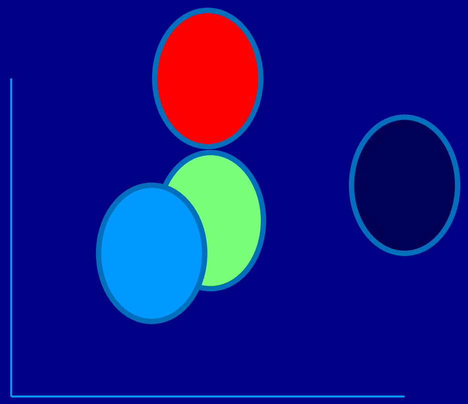

Model predictions match our conceptual idea of what is going on, with main drivers of age of functional groups and interaction matrix. But – is it relevant to real communities?

- Analyse real datasets (inshore & offshore)
- Determine functional traits for all species in observed datasets
- Convert species abundance data to functional groups via functional trait 'fuzzy' logic



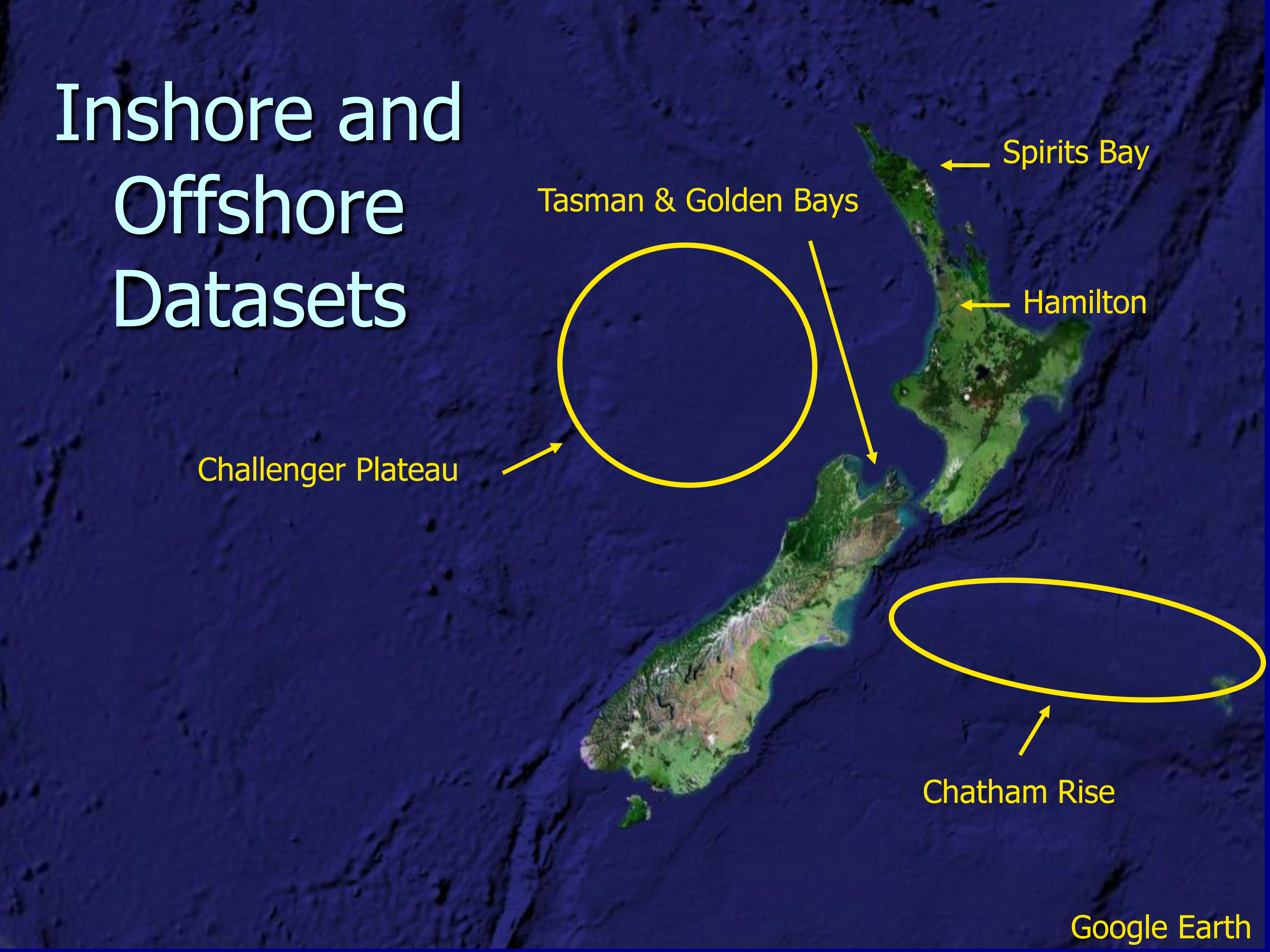
Ordination of field data along disturbance gradient -

?

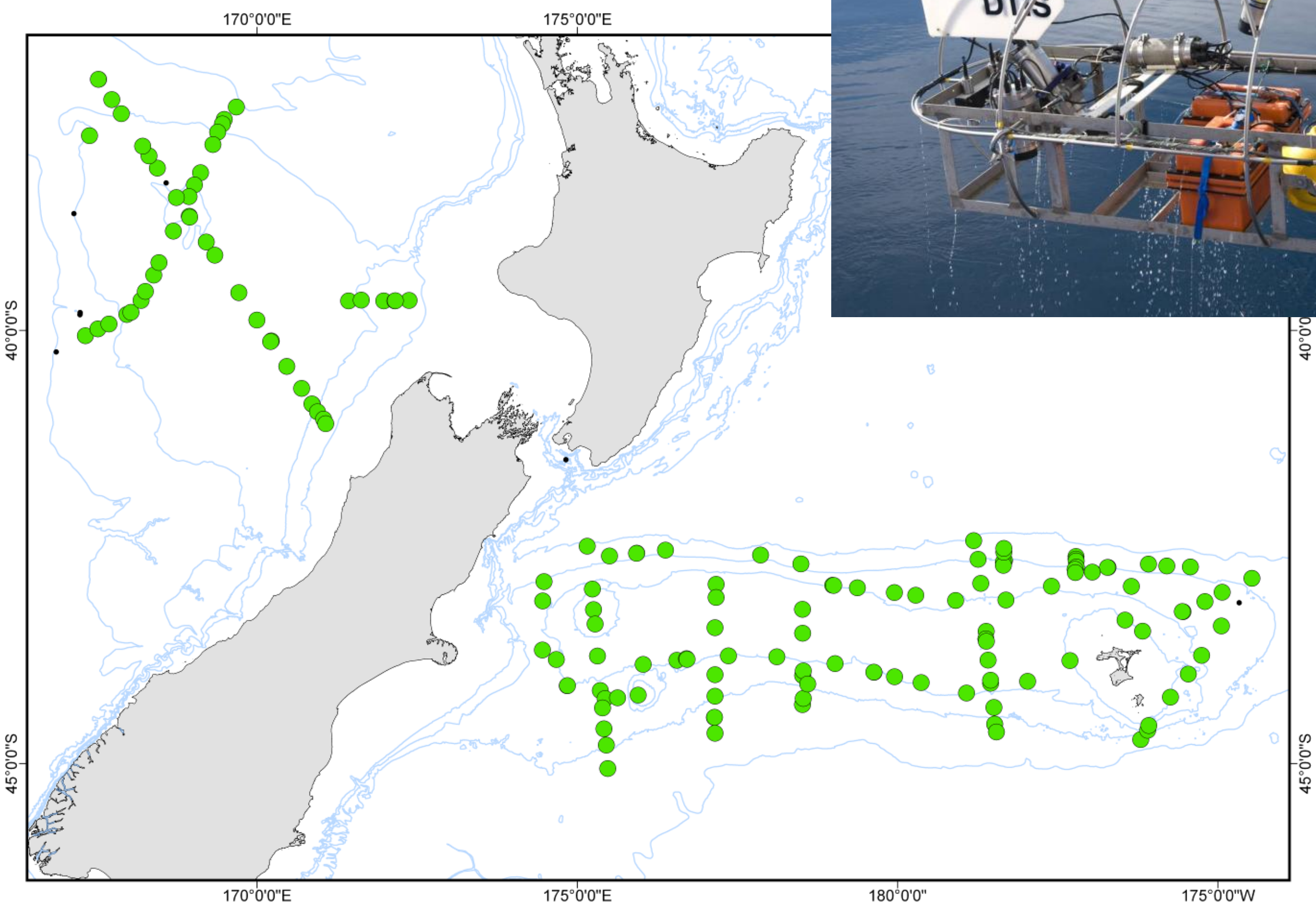


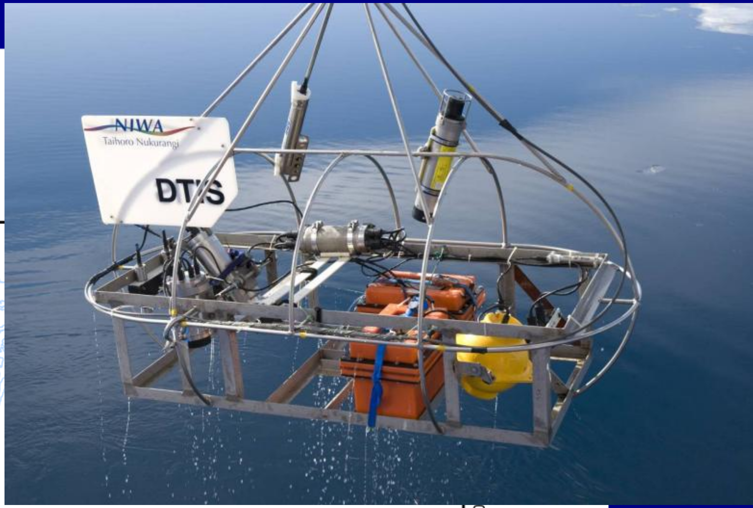
Ordination of model landscape along disturbance gradient -

Inshore and Offshore Datasets



Chatham/Challenger OS2020 dataset



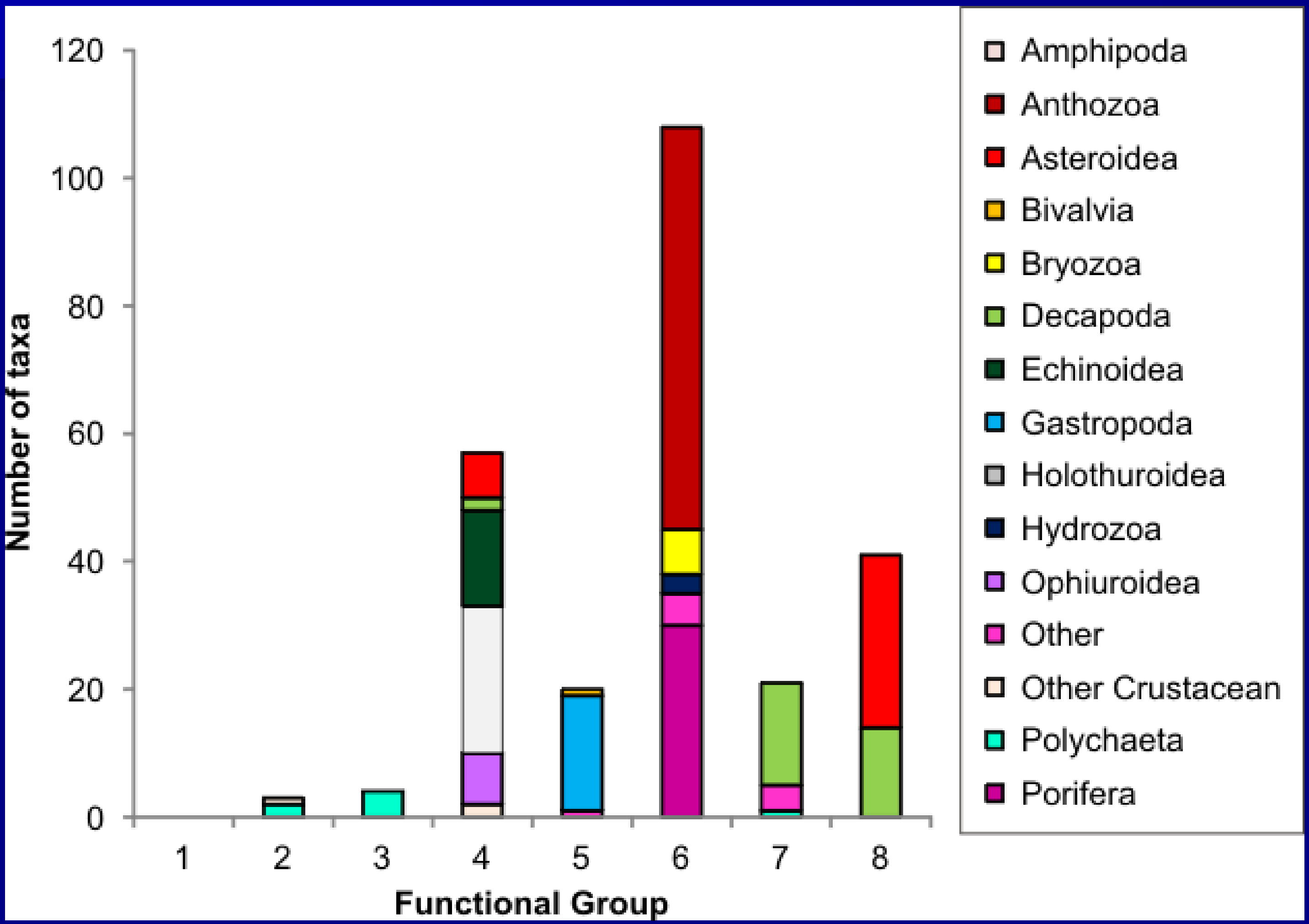


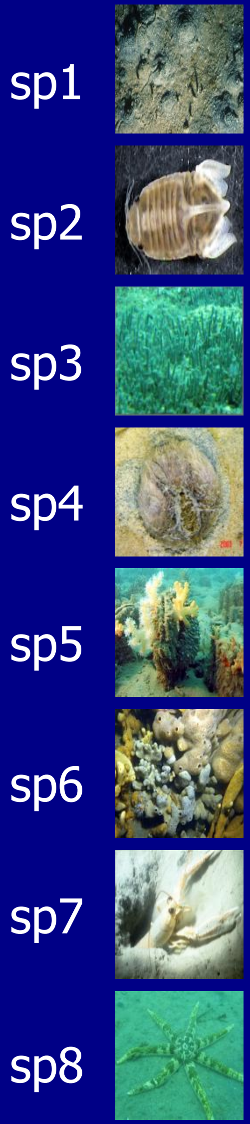
Traits used to derive conceptual functional groups

Based on BTA, Bremner, Rodgers and Frid 2003

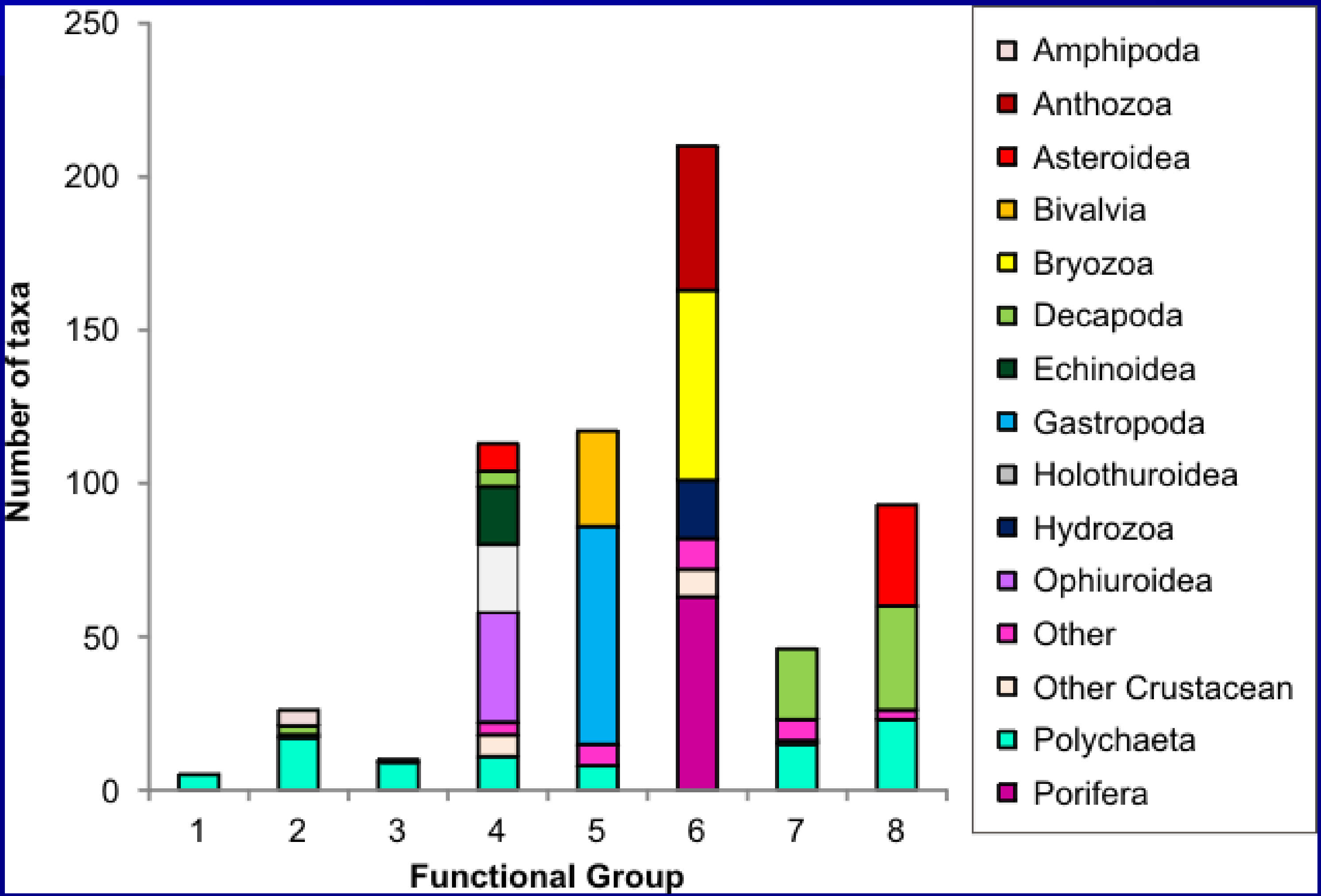
	Conceptual Functional Group	Traits used
1	Opportunistic early colonists – limited substrate disturbance	Sedentary; Short-lived; Deposit feeder
2	Opportunistic early colonists – considerable substrate disturbance	Limited or high mobility; Short-lived; Small-bodied; Deposit feeder
3	Substrate stabilisers (Tube mats)	Crustacean or Polychaete; Erect structure; Intermediate or Long-lived
4	Substrate destabilisers	High mobility; Deposit feeder; Surface dweller; Intermediate-lived
5	Shell hash-creating species	All bivalve and gastropod species
6	Late colonisers – emergent epifauna	Surface dwelling; Long lived; Suspension feeders
7	Late colonisers – burrowers	Not surface dwelling; not sedentary
8	Predators and scavengers	Predator/scavenger; Large bodied; Highly mobile

Chatham Rise and Challenger Plateau: total number of taxa across conceptual functional groups – DTIS video





Chatham Rise and Challenger Plateau: total number of taxa across conceptual functional groups – benthic sled



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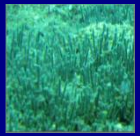

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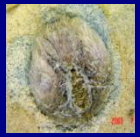

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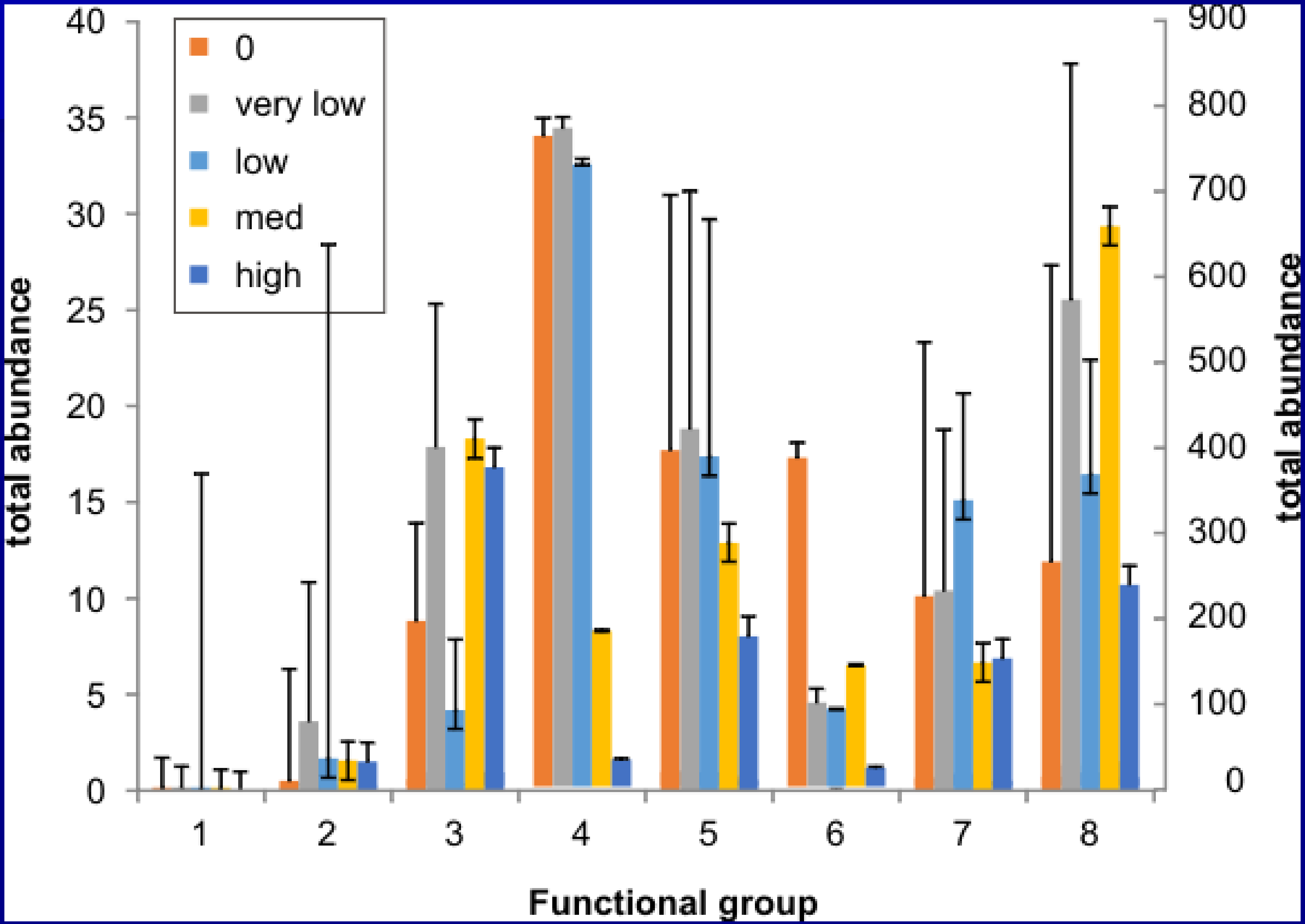
Disturbance rates – Chatham/Challenger



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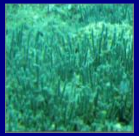
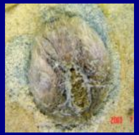
sp3 

sp4 

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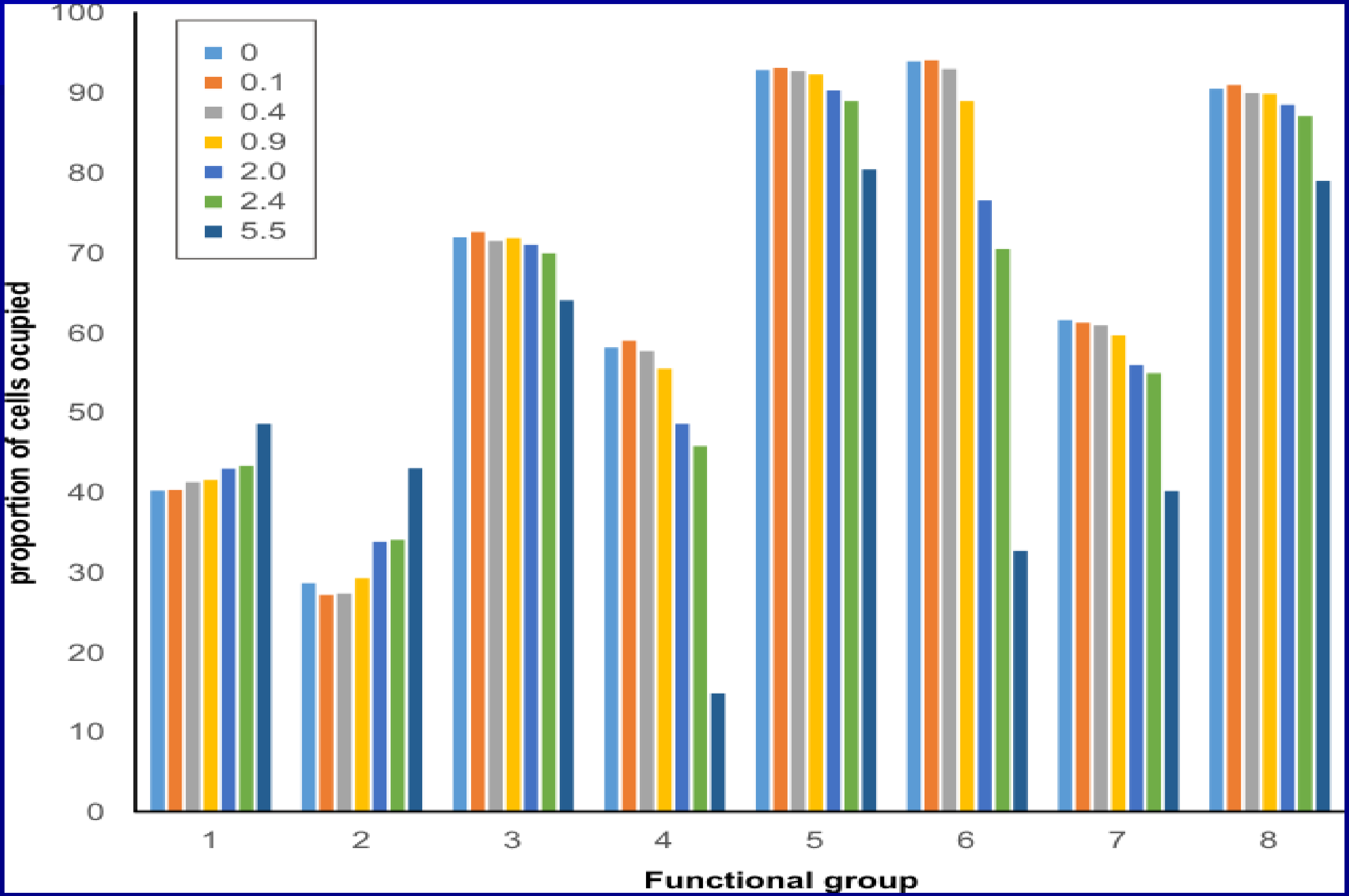
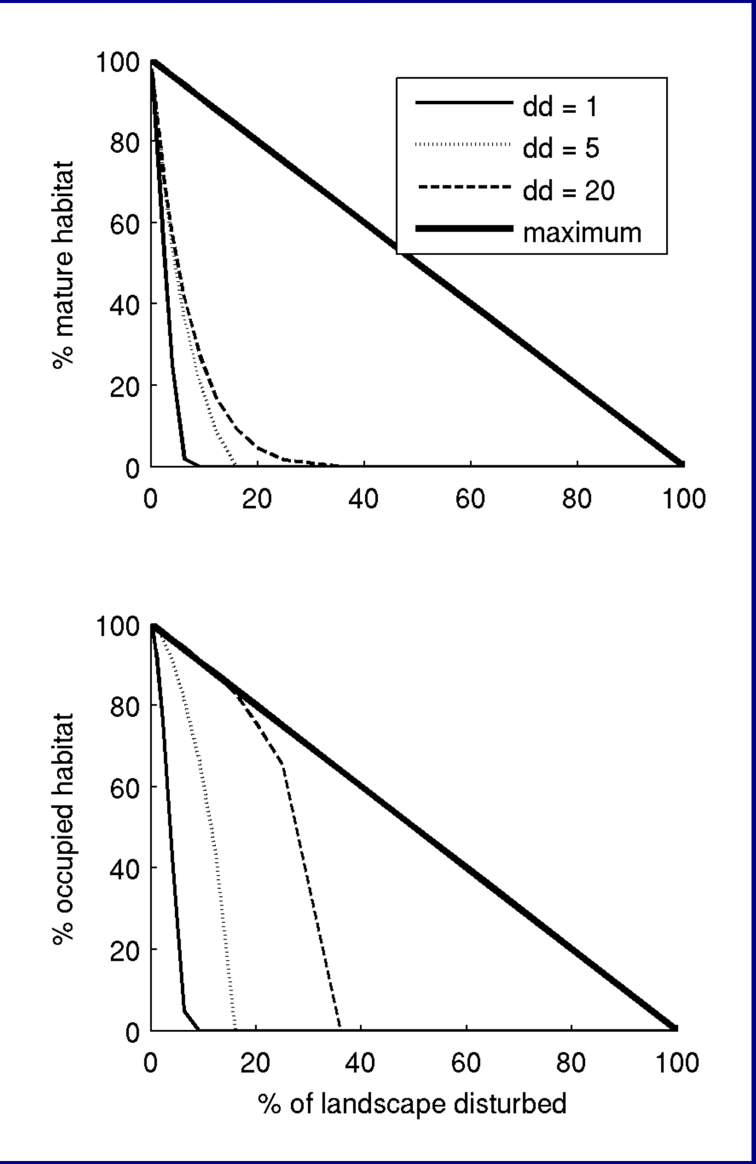
Disturbance rates – Model



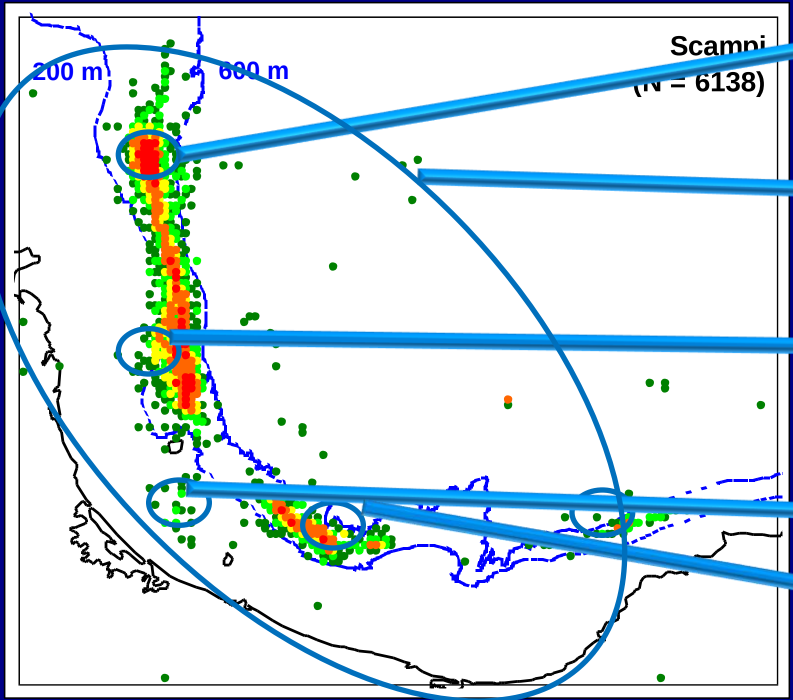
Marine Futures

- Disturbance thresholds
- Benthic community resilience
- Disturbance intensity
- Indicators and warning signs for threshold shifts



Lundquist CJ; Thrush SF; Coco G; Hewitt JE (2010) Interactions between disturbance and dispersal decrease persistence thresholds of a marine benthic community. *Marine Ecology Progress Series* 413: 217-228

(Exploratory) tool for regional management and policy



- Considering effort in high impact areas against ecosystem function and biodiversity
- Management of region is spatially explicit
- Predicting effects across gradients
- Effects thresholds
- Restoration potential

After Cryer et al. 2002 (*Ecological Applications*)

Thank you!