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SEVENTH FRAMEWORK PROGRAMME

Assessment of trawling impacts on benthic ecosystems with particular reference to shelf ecosystems

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IJmuiden, The Netherlands

Grant agreement number: 312088

Societal concern

Ecosystem Approach to Fisheries management

- Biodiversity conservation
- Loss of ecosystem services
  - ✓ Essential fish habitat (a place to live)
  - ✓ Fish production (food for fish)
  - ✓ Benthic – pelagic coupling
  - ✓ Nutrient regeneration

- How to incorporate the benthic ecosystem in the Ecosystem Approach to Fisheries Management?

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FP7 project BENTHIS (2012-2017)

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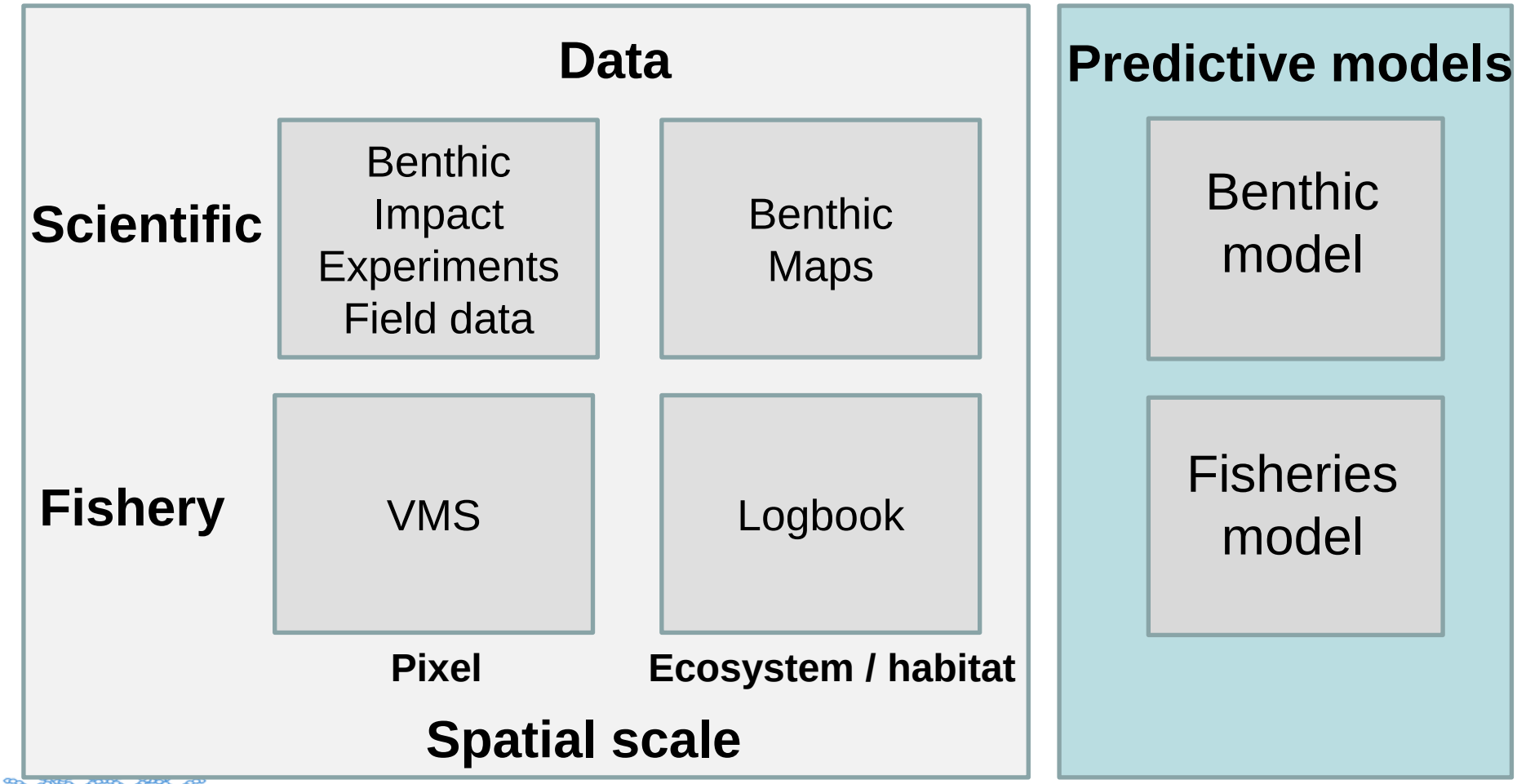
from observation to prediction
from pixel to management area



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Hiddink et al 2006 CJFAS ; Ellis et al 2014 CJFAS

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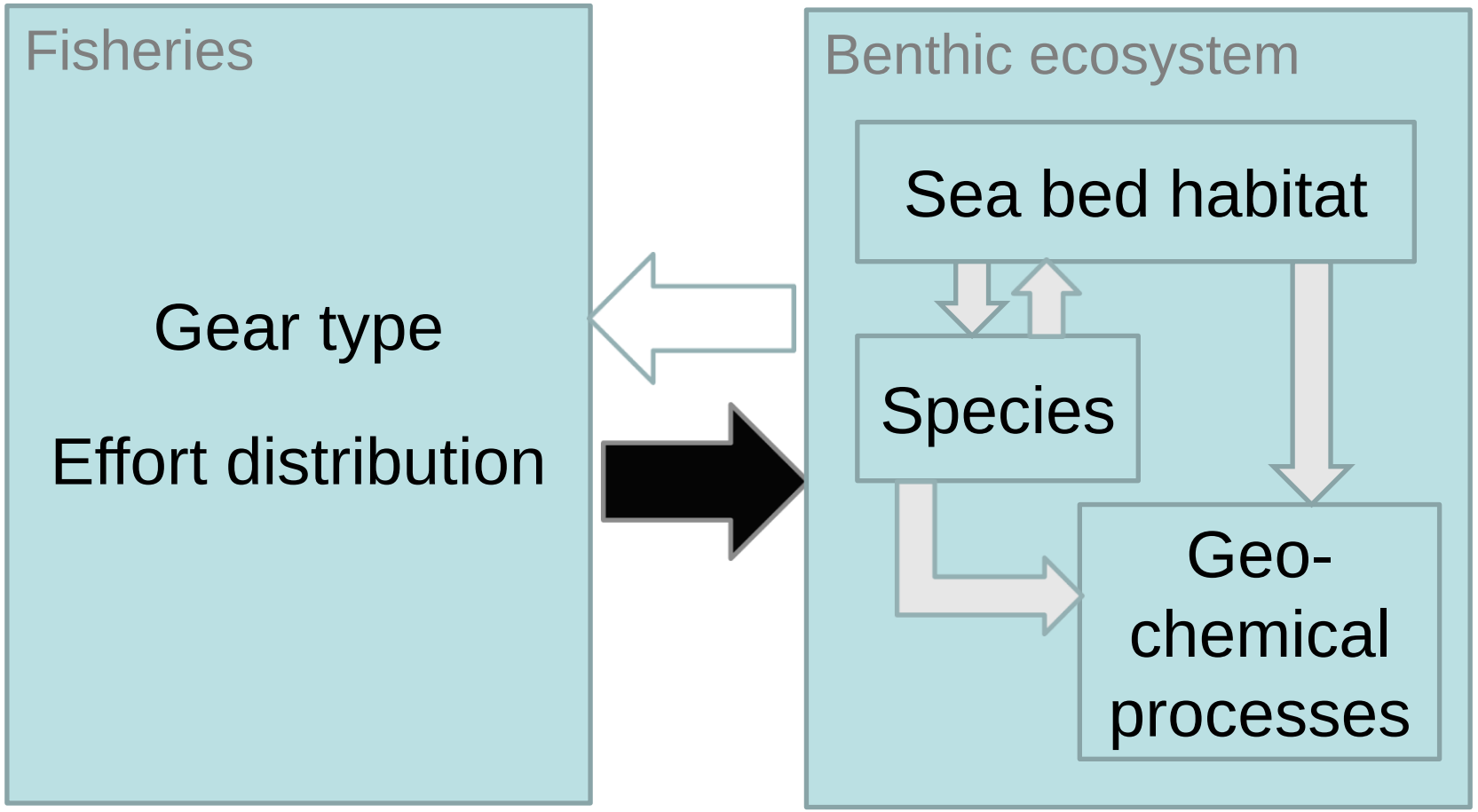
Trawling Impact Components



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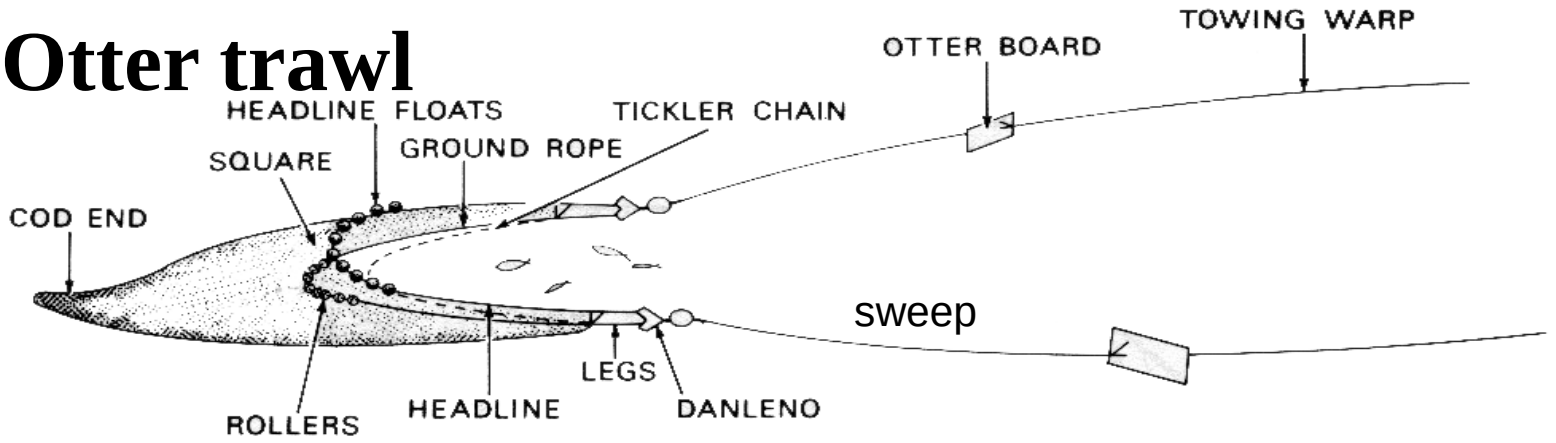
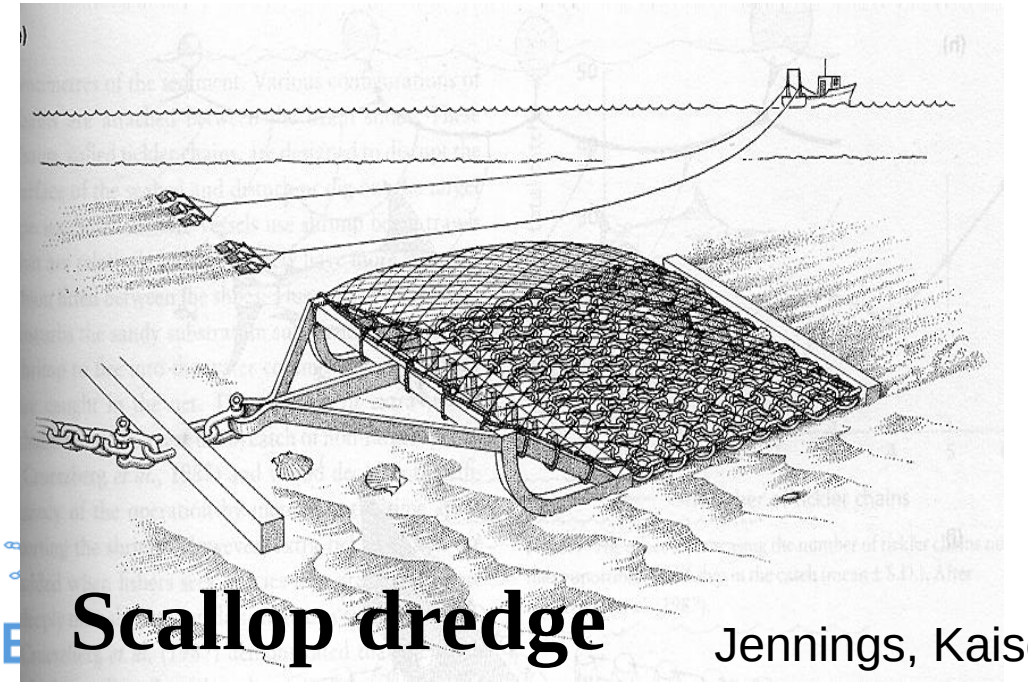
Gear types

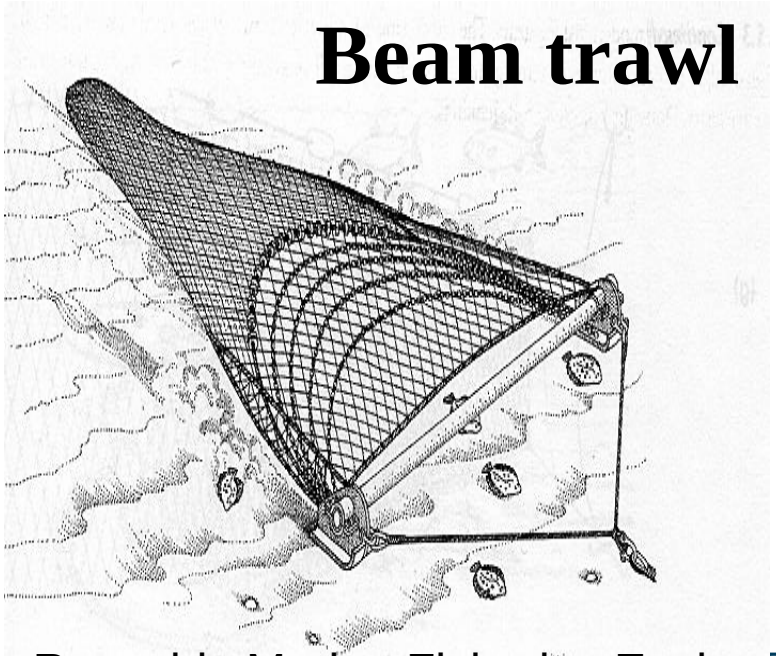
Otter trawl





Scallop dredge

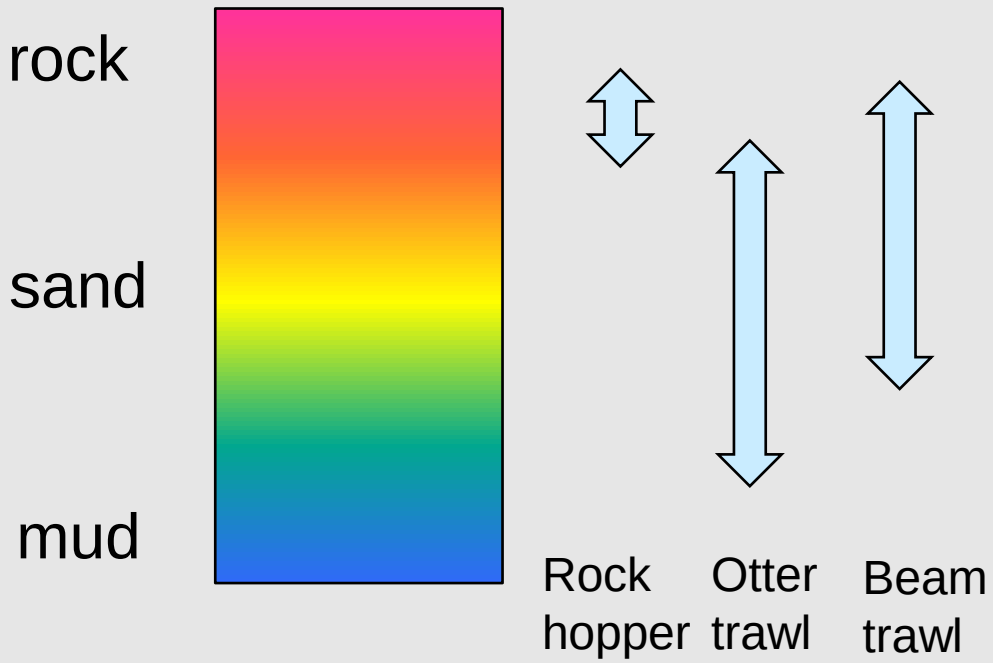
Beam trawl



Jennings, Kaiser, Reynolds Marine Fisheries Ecology

Gear type – habitat relationship

Gear type fine tuned to sea bed type



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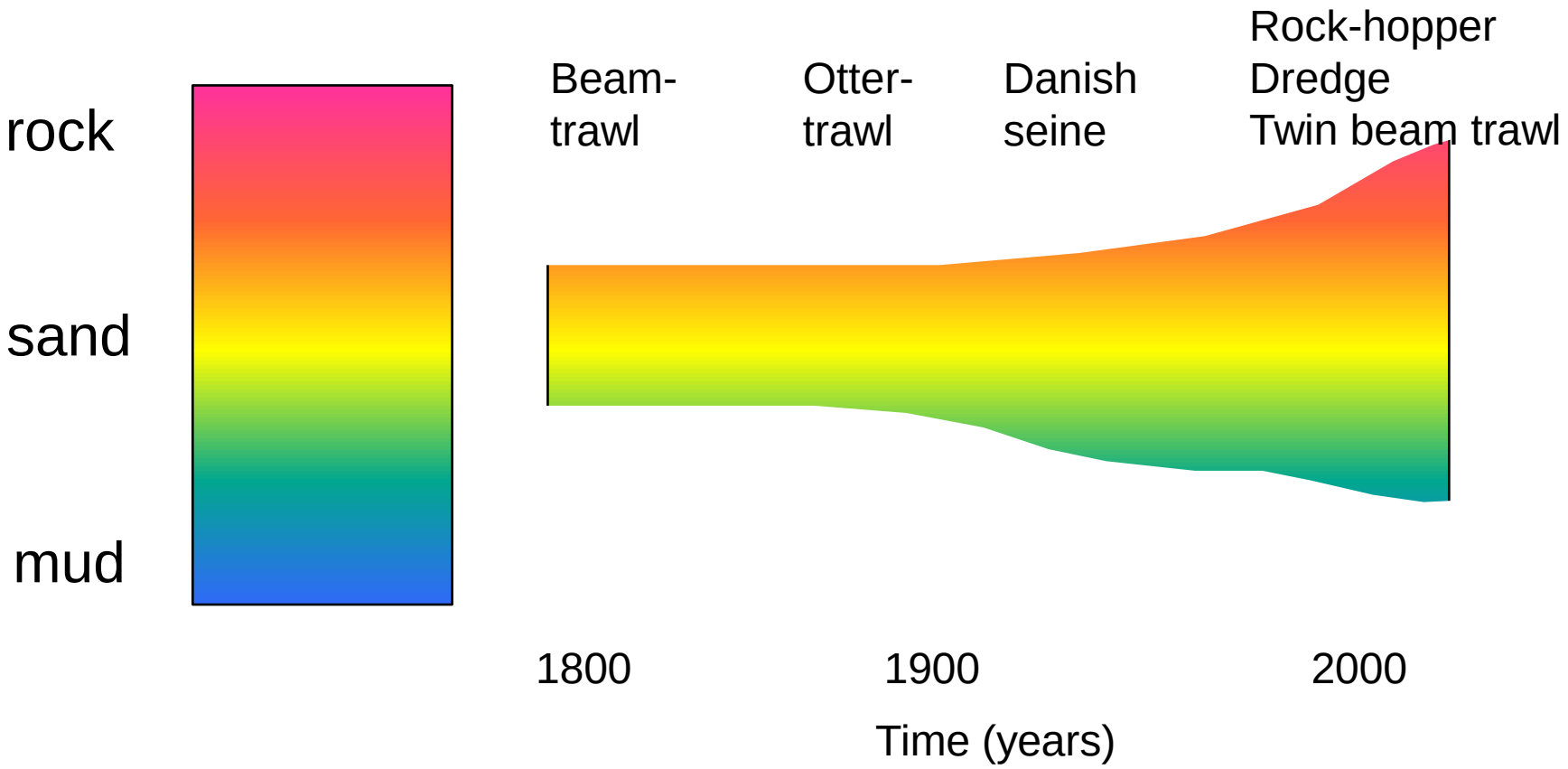
Evolution bottom trawl gear



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Expansion bottom trawling North Sea

	A	B	C	D	E	F	G	H	J	K	L	M	N	
22						240	279							22
21			245	176	538	358	###							21
20		###	###	###	###	###	###							20
19		###	###	###	###	###	###		105					19
18	###	###	###	###	###	###	###	685	###					18
17	###	###	###	###	###	###	###	###	252					17
16	###	###	###	###	###	###	###	###		###				16
15		###	###	###	###	###	###	###	###	###				15
14		###	###	###	###	###	###	###	###	761	###	###		14
13		75	###	###	###	###	###	###	###	###	###	###		13
12		###	###	###	###	###	###	###	###	###	###	###		12
11		###	###	###	###	###	###	###	###	###	###	###		11
10		###	###	###	###	###	###	###	###	###	###	###	908	10
9			###	###	###	###	###	###	###	###	###	###		9
8			###	###	###	###	###	###	###	###	###	###	###	8
7				###	###	###	###	###	###	###	###	###	373	7
6					###	###	###	###	###	###	###	###		6
5					###	###	###	###	###	125				5
4						###	###	###	###					4
3						656	###	###						3
2						##	###							2
1						##	###							1
								H	J	K	L	M	N	

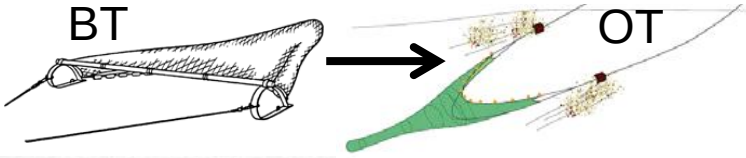
50%

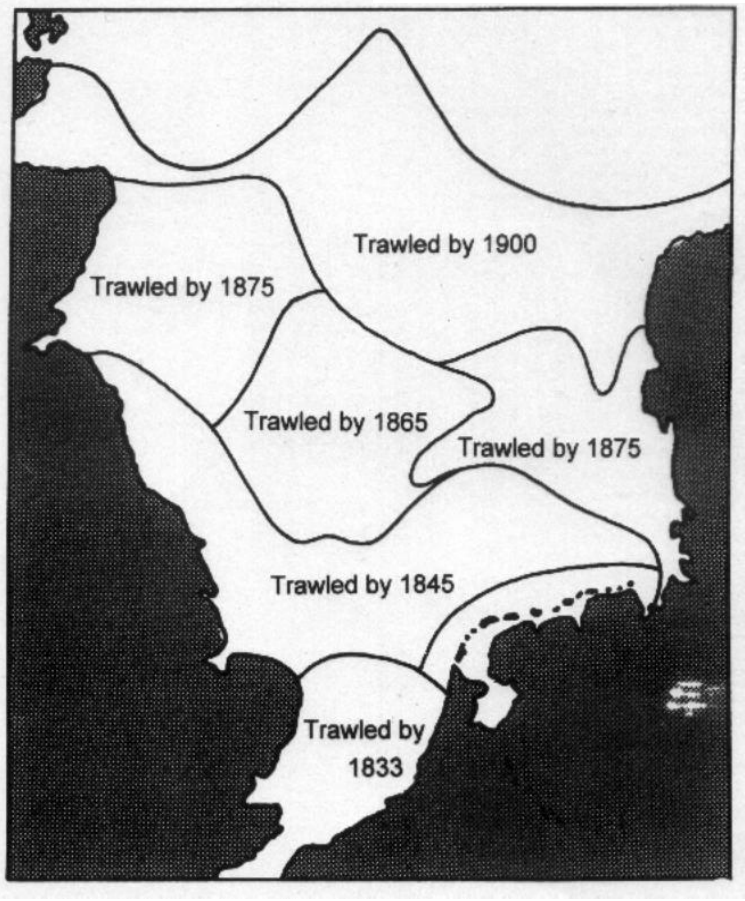
90%

of UK effort

1924

Engelhard (CEFAS)





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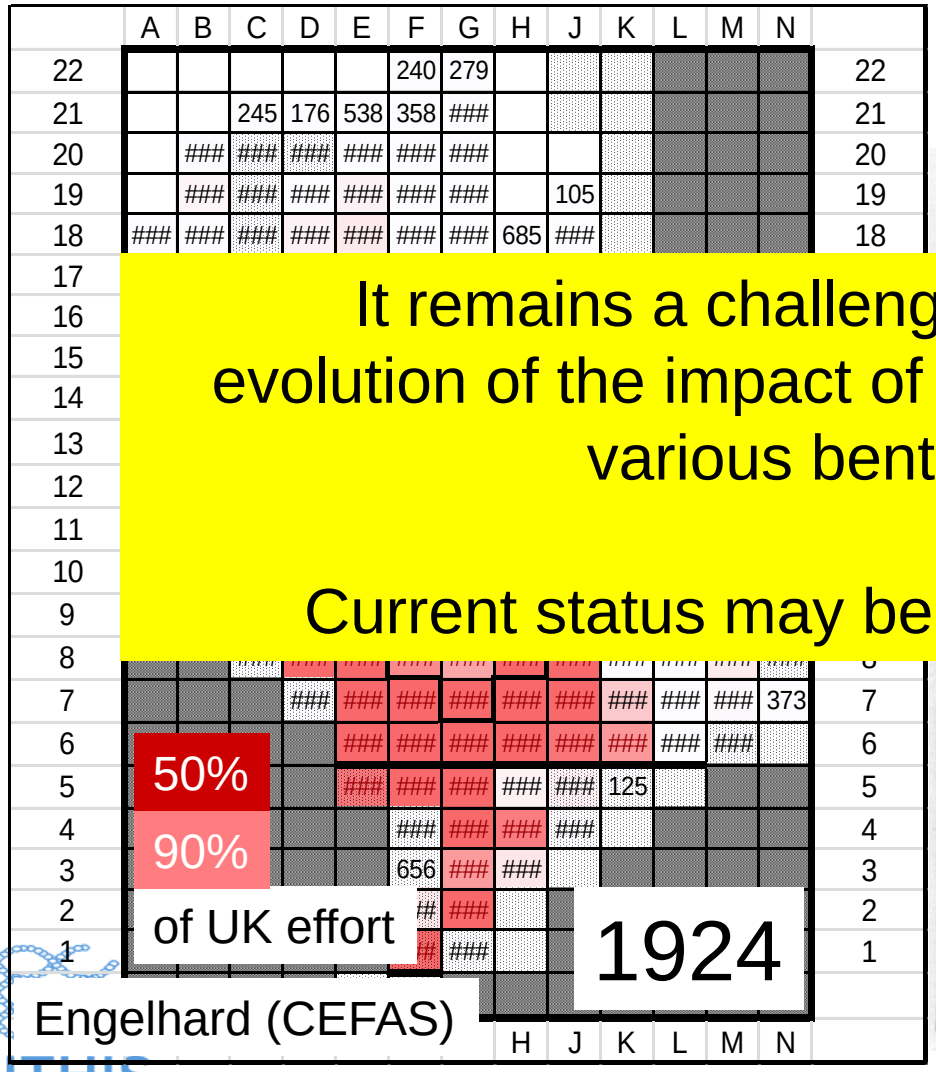
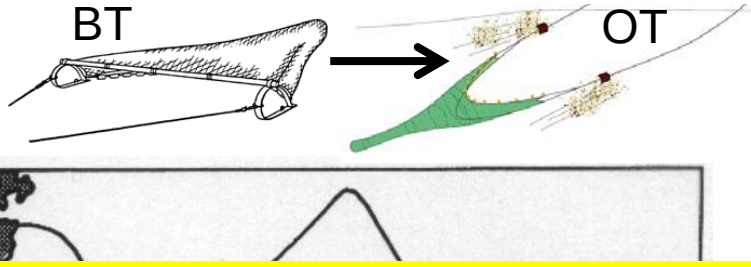
Expansion bottom trawling North Sea

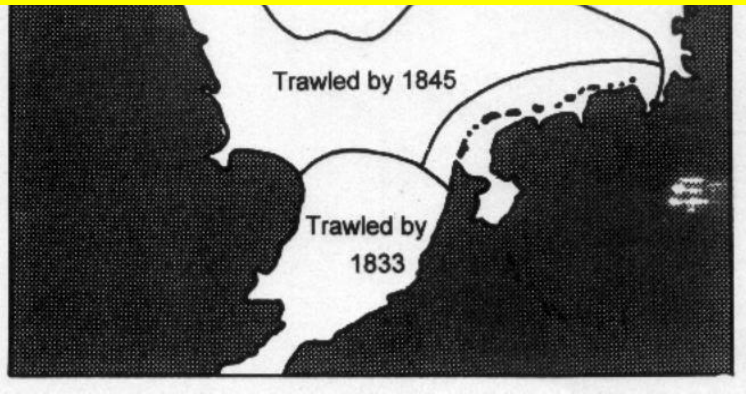


Engelhard (CEFAS)



It remains a challenge to reconstruct the evolution of the impact of bottom trawl fisheries on various benthic habitats

Current status may be a shadow of the past



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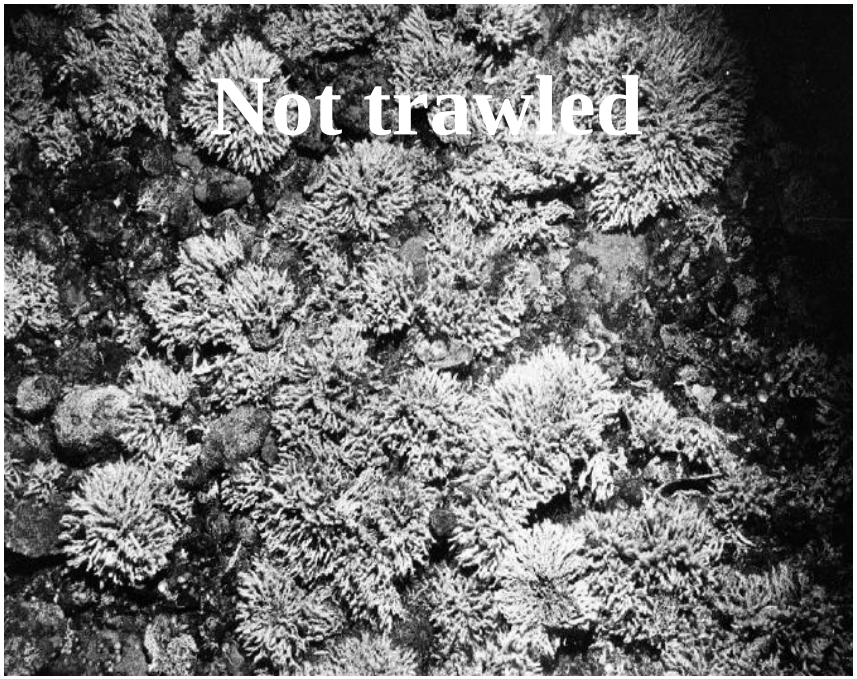
Field studies trawling impact

- BACI experiments (Before After Control Impact)
- Trawling gradient



Collie et al. 2000 ICES Journal of Marine Science, 57: 987–1001

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Field studies trawling impact

- BACI experiments (Before After Control Impact)

★ P<0.05

	Size (mm)	Gear type (m)	Mortality
Bivalves	Length		
Arctica islandica	2–3	12	20
Corbula gibba	1–11	12	9
Donax vittatus	20–35	4	10
Mysella bidentata	2–3	12	4
Nucula nitidosa	2–10	12	4
Spisula spec. juv.	1–6	4	20
Tellimya ferruginosa	2–7	4	19* ★
Gastropods	Height		
Cylichna cylindracea	3–8	12	14
Turritella communis	5–15	12	20* ★
Echinoderms	Diameter		
Amphiura sp.	2–6	12	9
Crustaceans	Length	12	
Callinassa subterranea	5–40	12	4
Cumacea	3–7	12	22* ★
Gammaridea	2–11	12	28
Annelids	Length		
Pectinaria koreni	4–20	12	31* ★
Magelona papillicornis		12	30* ★
Scoloplos armiger		12	18
24 spp. (excl. *Pectinaria*)		12	<0.5

Bergman & Santbrink 2000 IJMS

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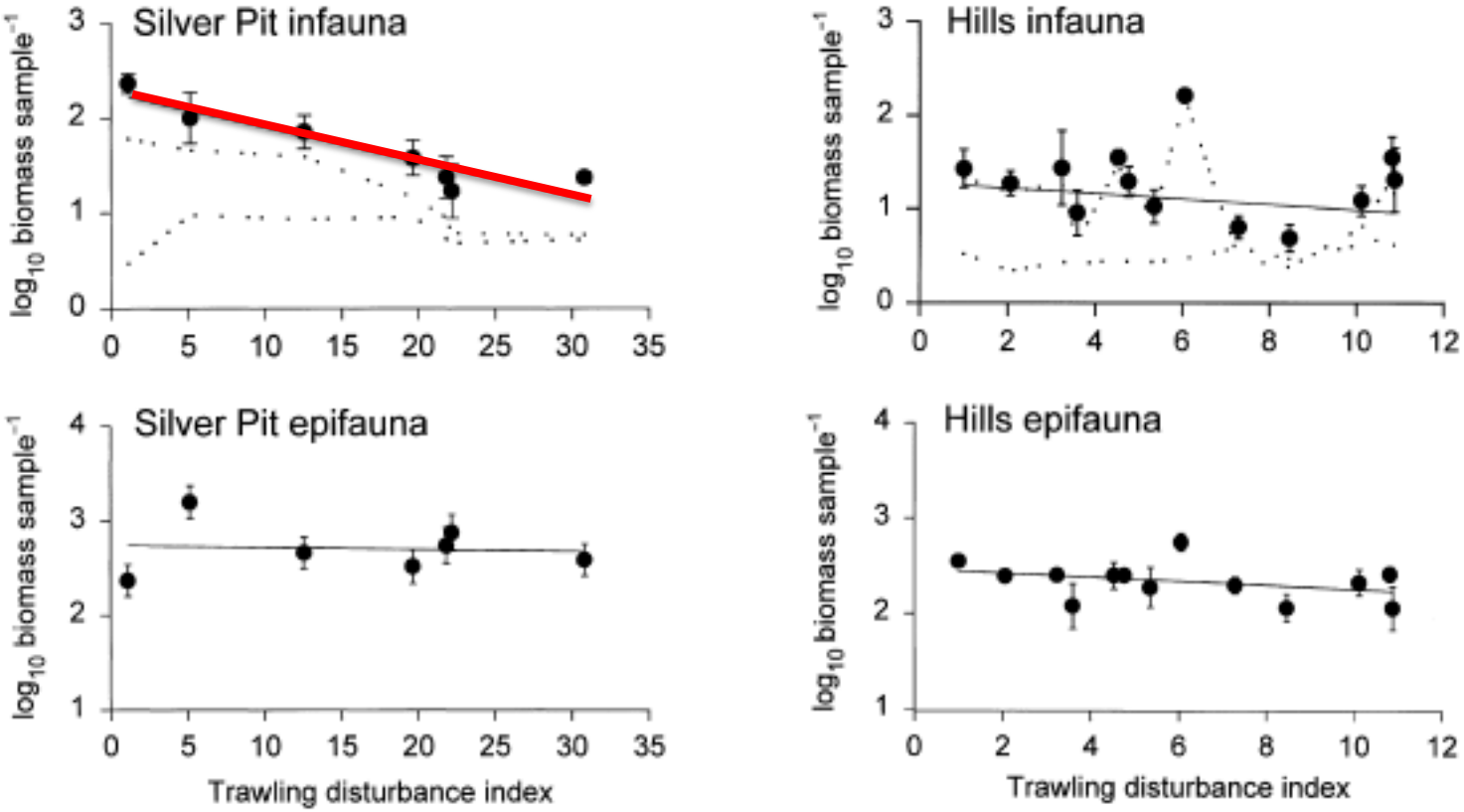
Field studies trawling impact

- Trawling gradient



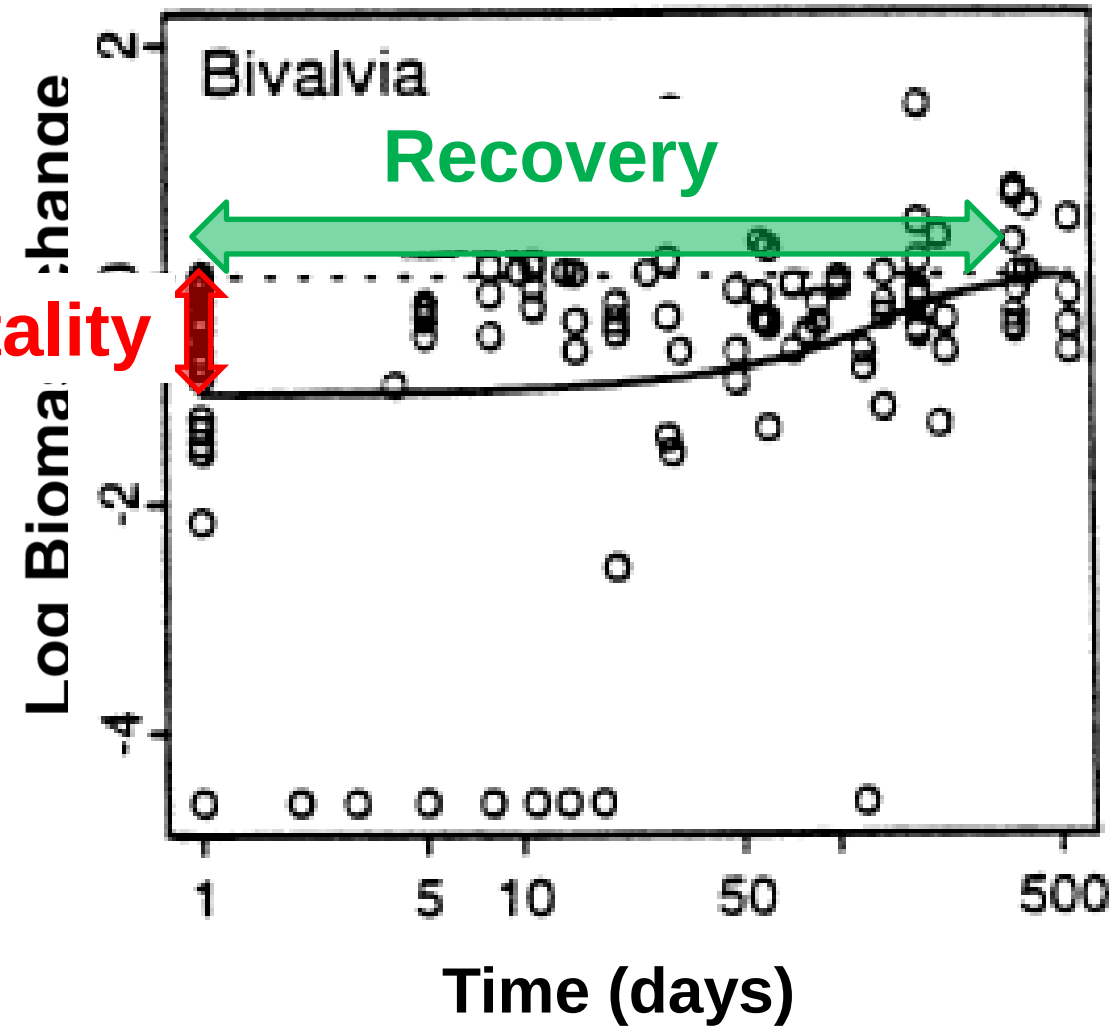
Jennings et al (2001) J Anim Ecol 70: 459-475

Meta-analysis trawling impact

- Direct mortality
- Recovery

Reviews:

- Collie et al (2000)
- Kaiser et al (2006)



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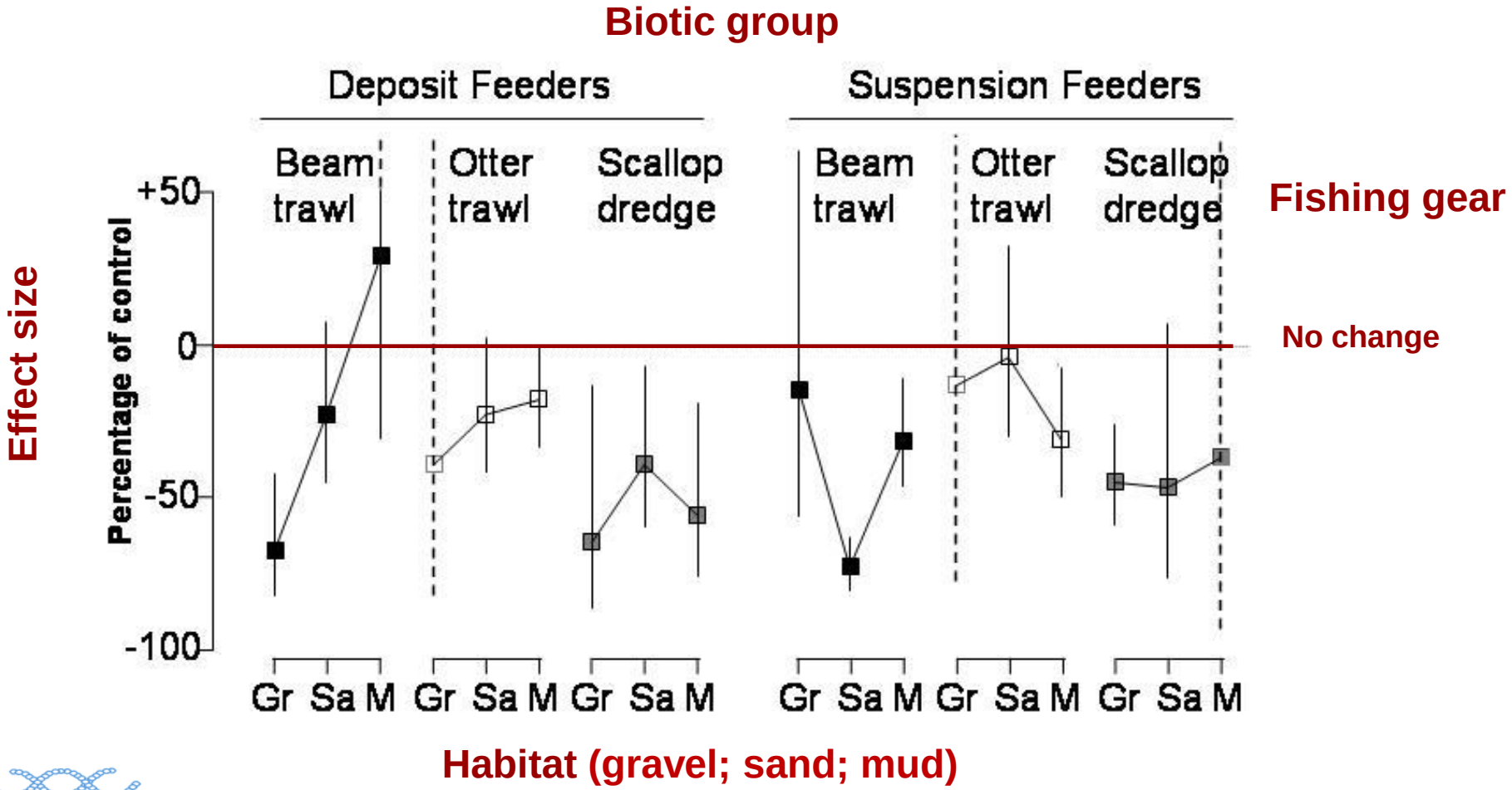
Trawling mortality: depends on gear, species, habitat



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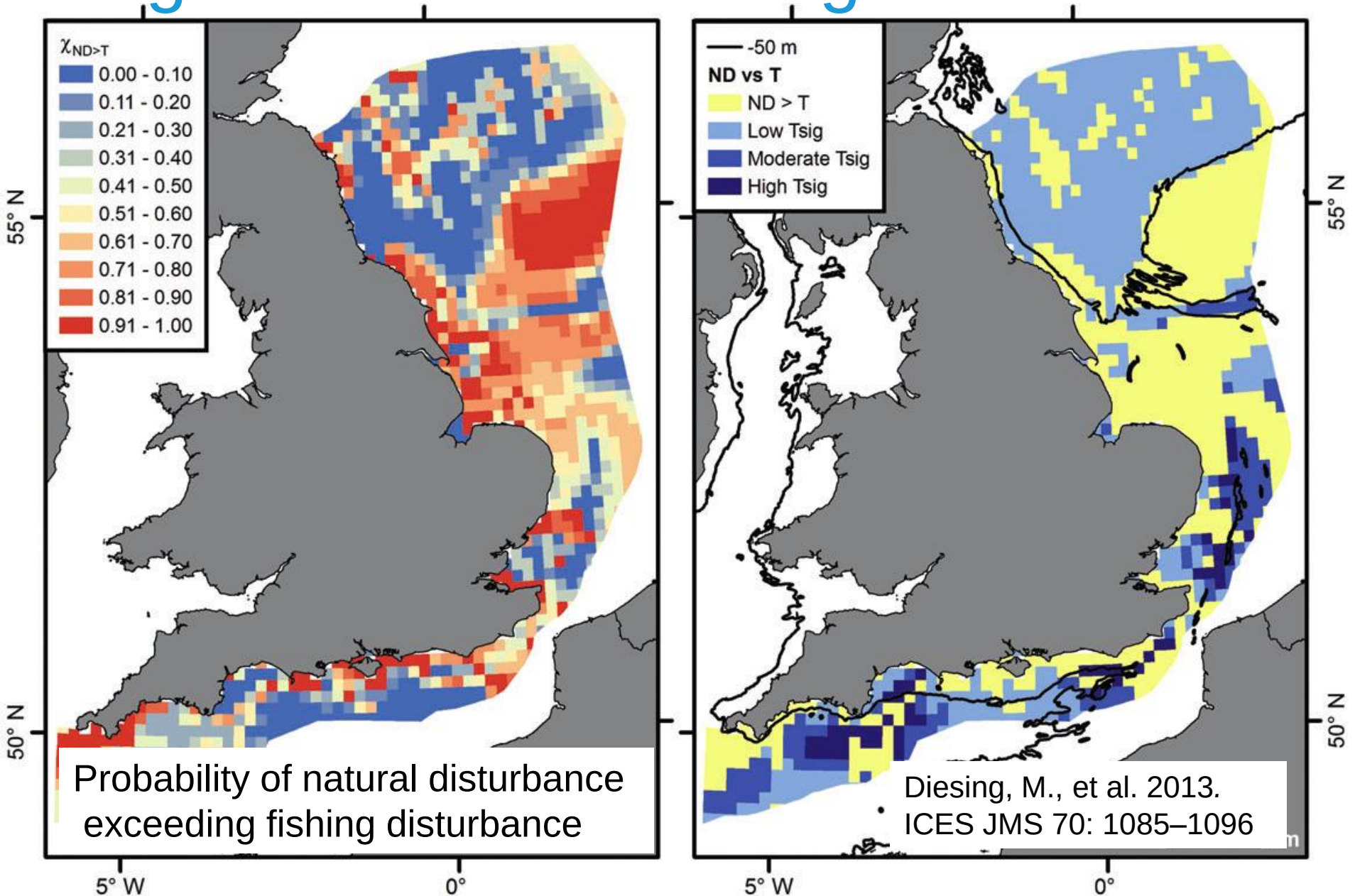
Kaiser et al (2006) MEPS

High natural vs trawling disturbance



Probability of natural disturbance exceeding fishing disturbance

Diesing, M., et al. 2013. ICES JMS 70: 1085–1096

Recovery

- Recovery rate
  - Body growth
  - Recruitment
  - Immigration
- Life history traits
  - Maximum size
  - Longevity
  - Mobility

Spatial scale

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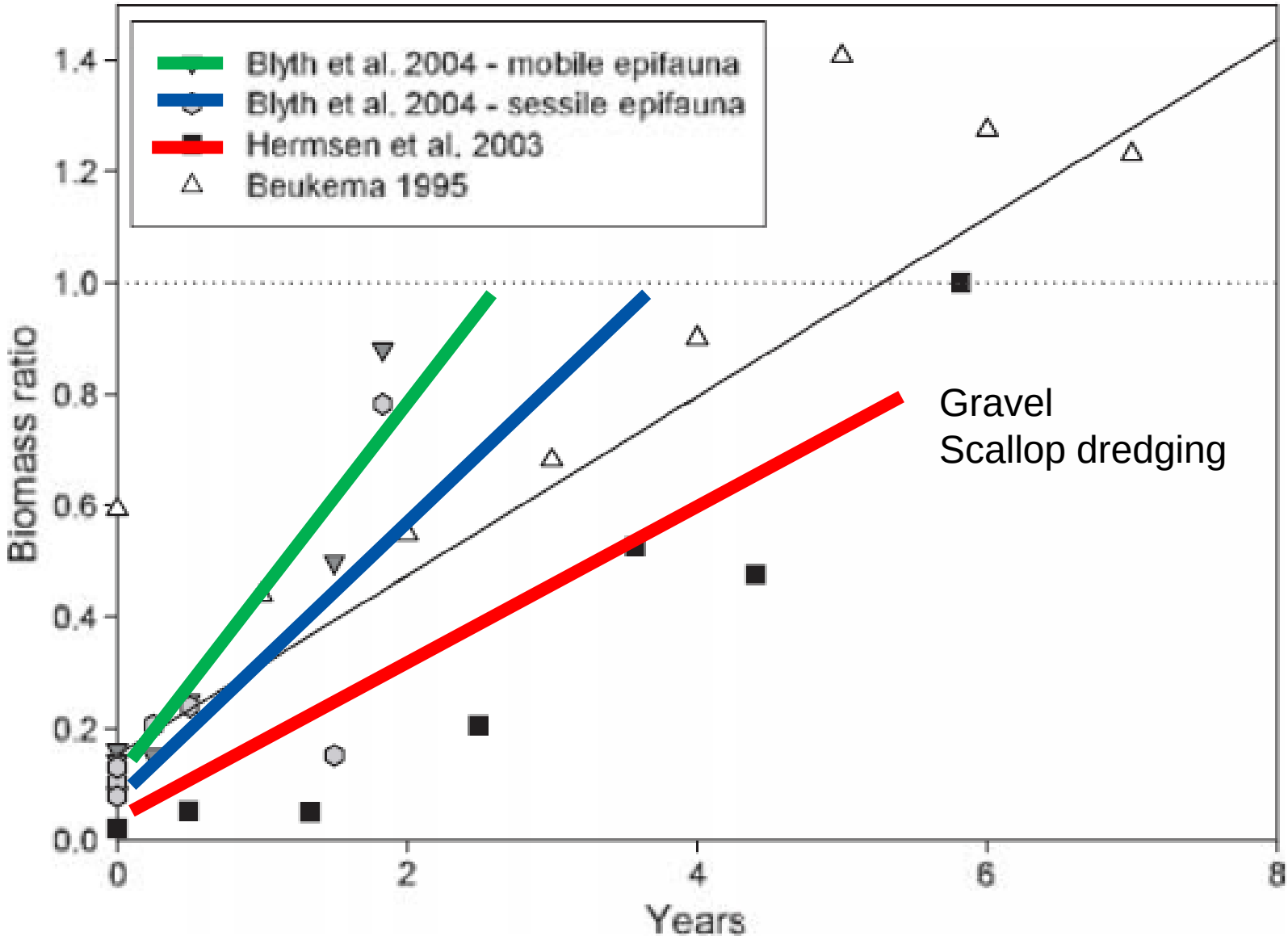

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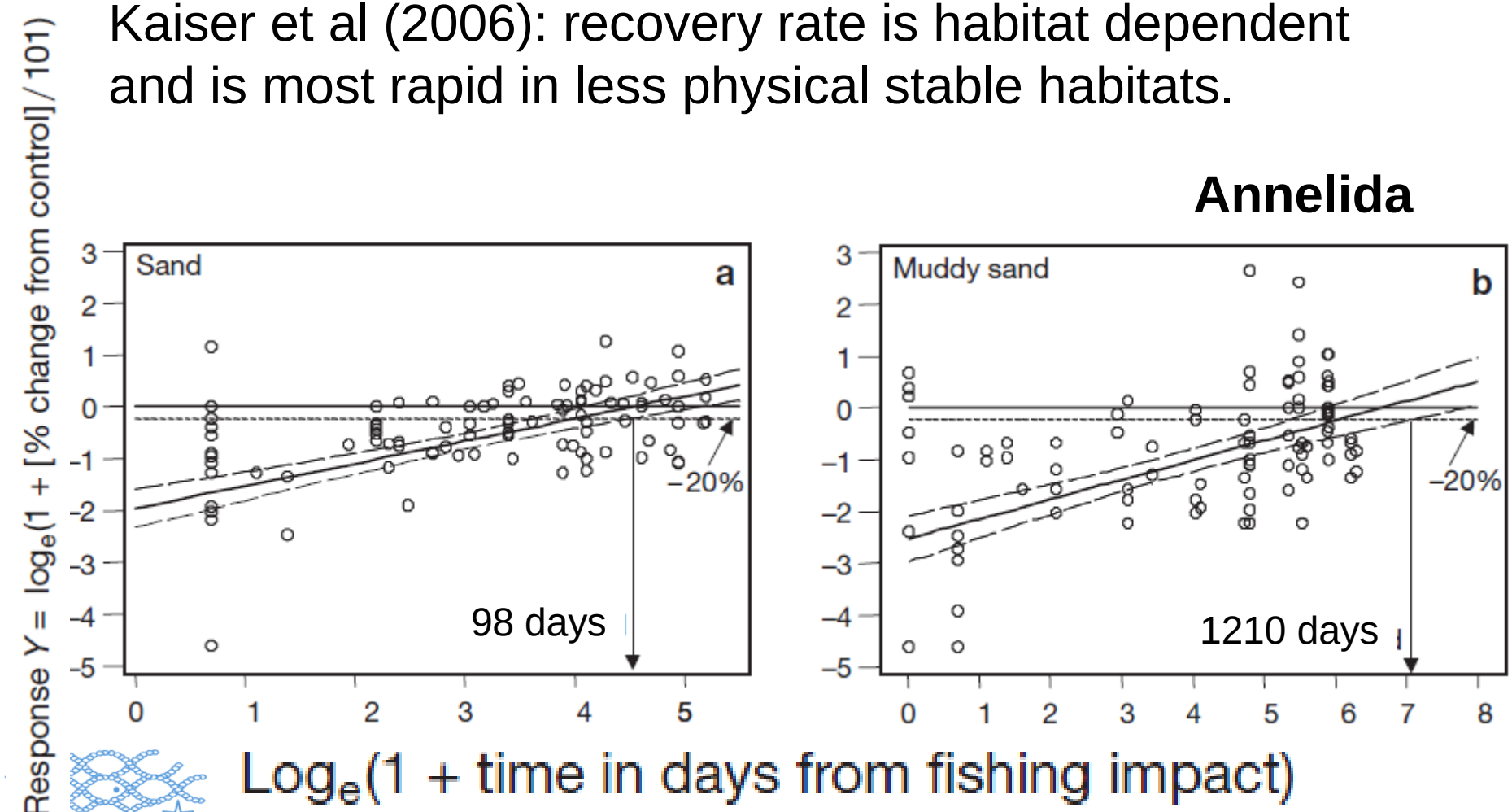
Hiddink et al (2006) Ecosystems 9: 1190-1199

Recovery

Kaiser et al (2006): recovery rate is habitat dependent and is most rapid in less physical stable habitats.

Annelida



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How to extrapolate experiments to all gears and all biota?

- Develop predictive tools to estimate the mortality & recovery imposed by the gear based on the characteristics of the gear, the habitat and the species

- Trait based approach
  - Fishing gear
  - Biota

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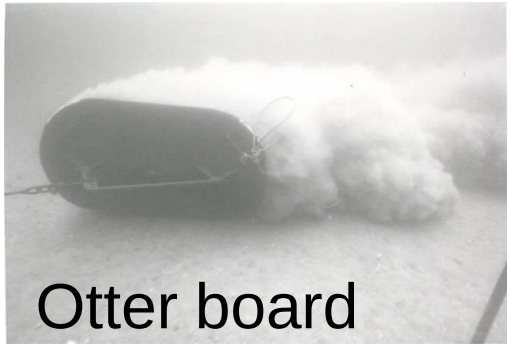
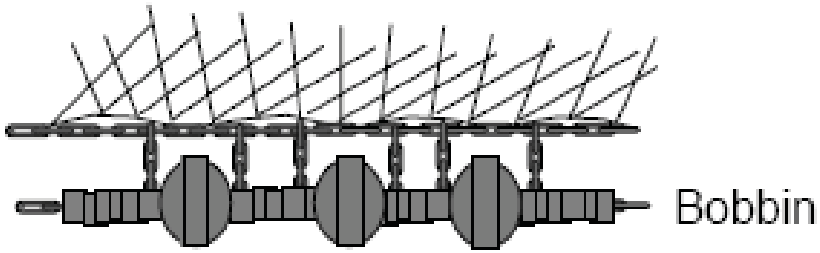
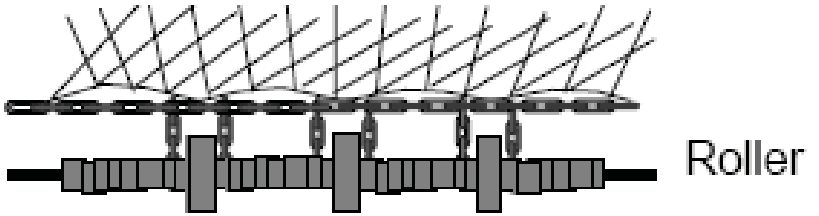
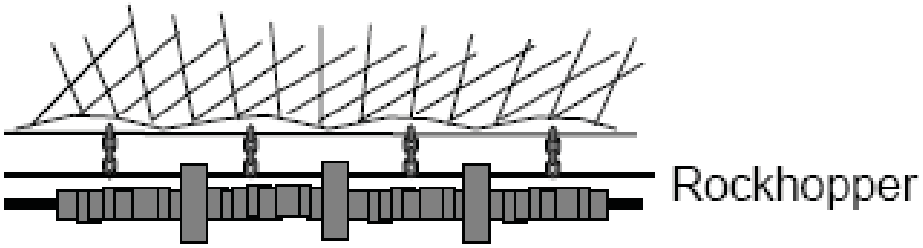
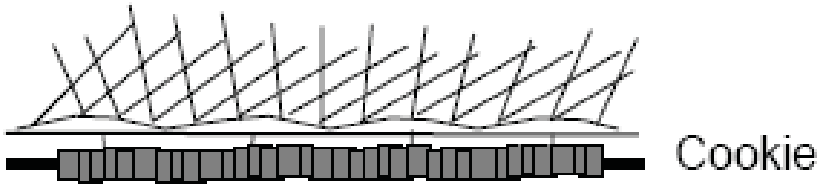
Gear traits: examples



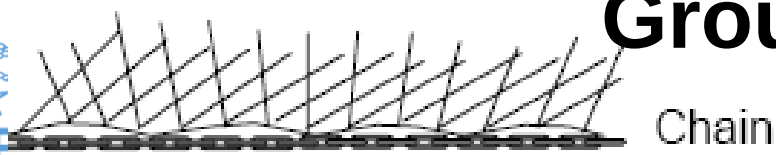


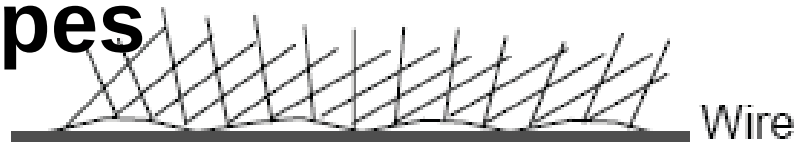




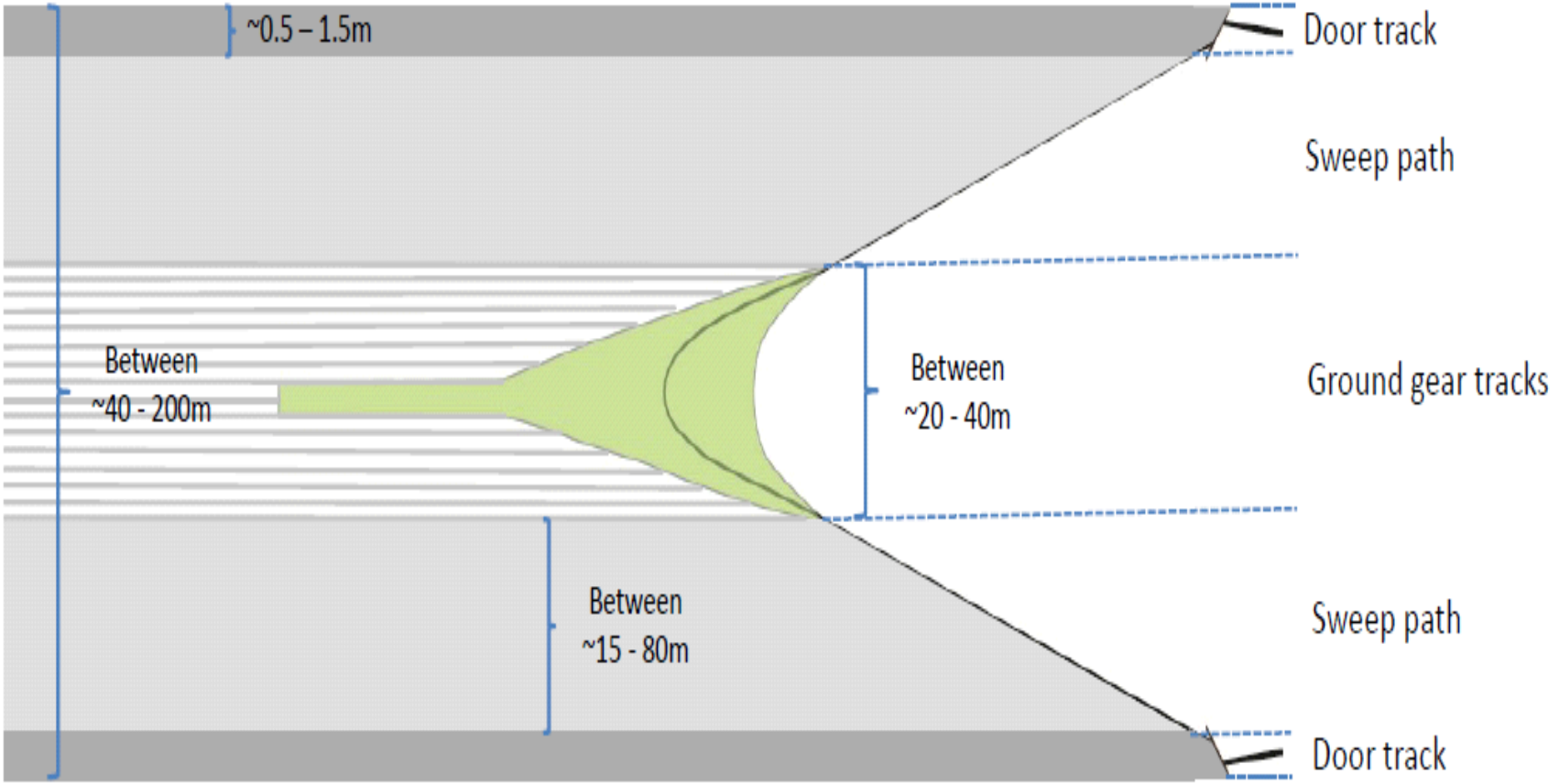


Ground ropes



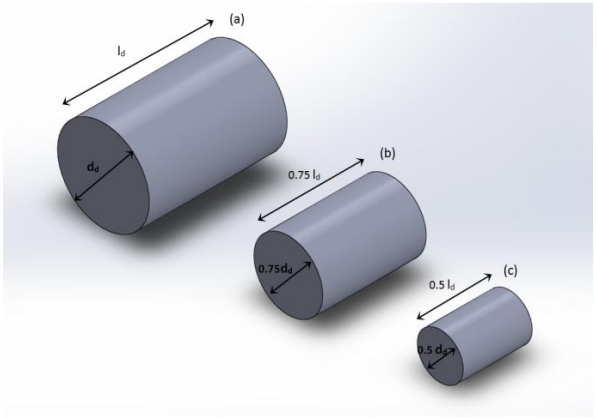


from components to gear foot print



Buhl-Mortensen et al 2013 Fisken og Havet No 2

Physical modelling / experiments



- Model sediment displacement and penetration depth

Ivanovich (University Aberdeen)
O'Neill (Marine Scotland)

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Trait based classification of biota

- Population dynamic traits (recovery dynamics): longevity, body size, age at maturation, mode of reproduction
- Habitat (vulnerability to trawling): Epibenthos, infauna (shallow, deep)
- Morphology (vulnerability to trawling): Soft, Tunic, Exoskeleton, Crustose, Cushion, Stalked
- Living Habit (vulnerability to trawling): Tube-dwelling, Burrow-dwelling, Free-living, Crevice/hole/under stones, etc
- Mobility (recovery dynamics): Sessile, Swim, Crawl/creep/climb
- Bioturbation (ecological function): none, mixing, conveyor, ect
- Feeding (ecological function): Suspension, deposit, scavenger, predator, parasite

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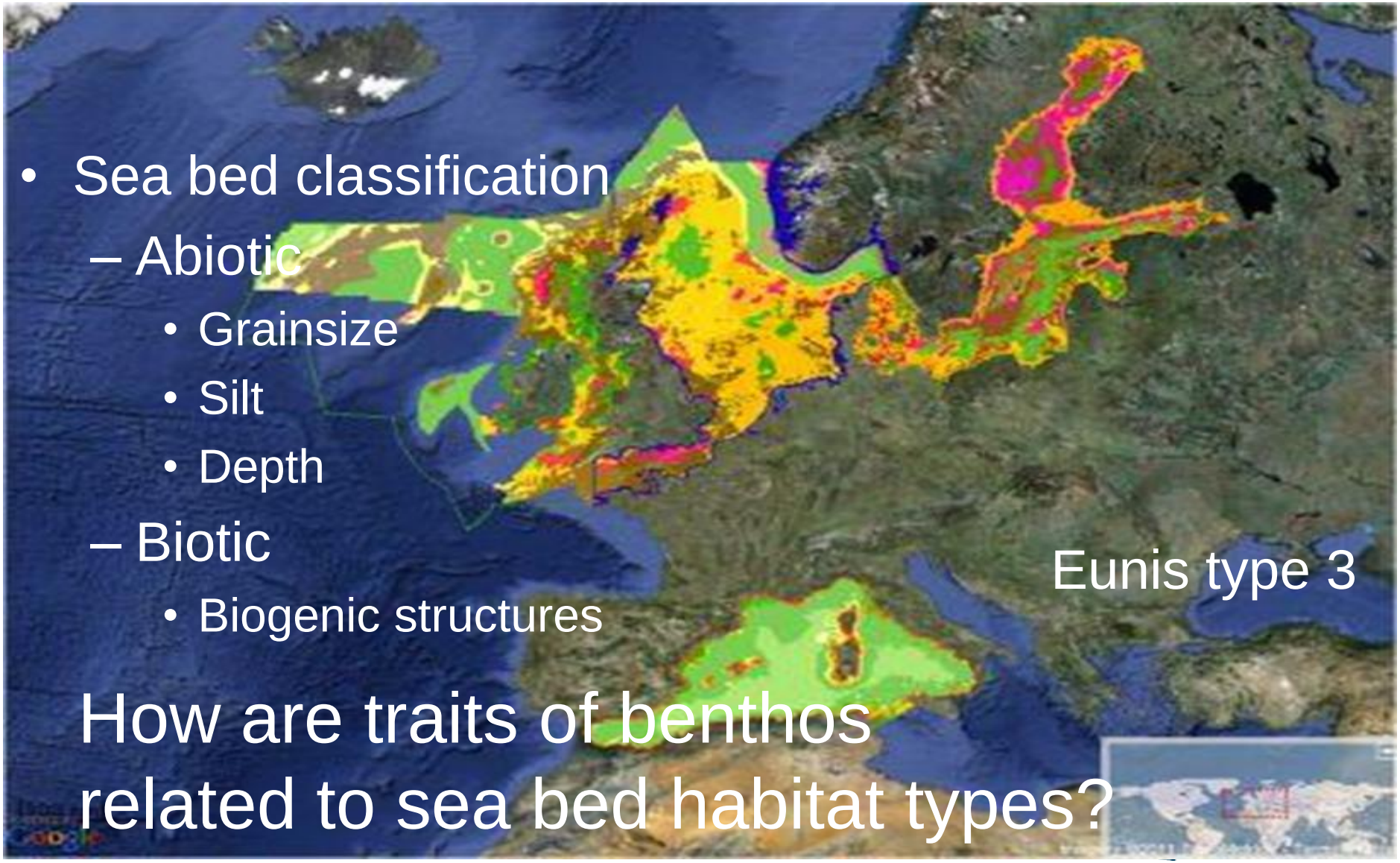
Bolam et al 2013; Presentation Kenny et al

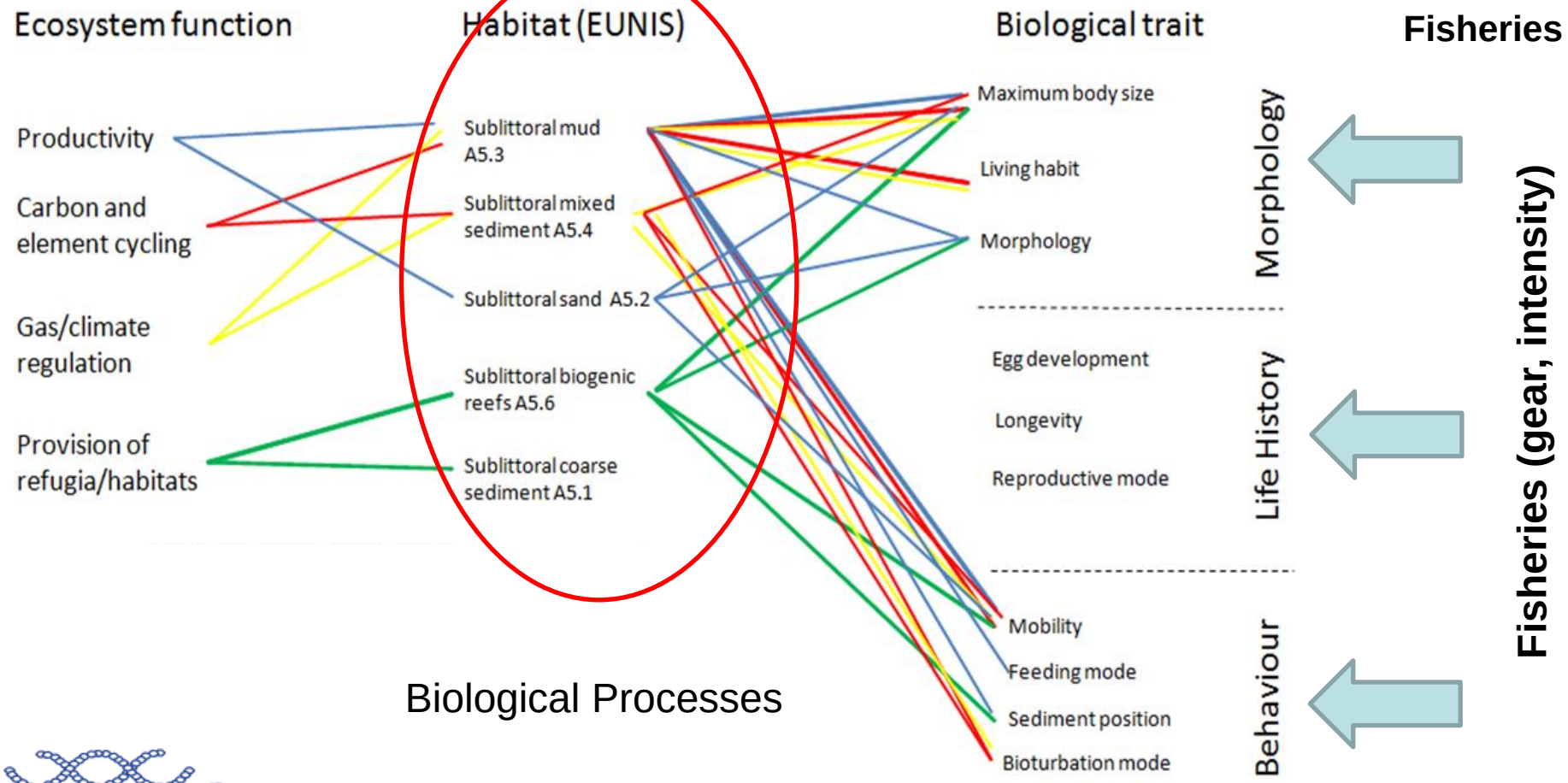
Benthic habitat map



- Sea bed classification
  - Abiotic
    - Grainsize
    - Silt
    - Depth
  - Biotic
    - Biogenic structures

How are traits of benthos related to sea bed habitat types?

Link habitat – biological traits



Bolam, Kenny et al (2013)

Habitat – traits – trawling - relations

Changes in trait composition attributed to fishing pressure
(green traits are winners, red traits losers)

Habitat	Bioturbation	Egg devel.	Feeding mode	Larval devel.	Living habit	Longevity	Max. size	Mobility	Morphology	Sediment Pos.
A5.13	Upward conv	Direct dev Benthic eggs	Surface deposit Suspension Predators Scavengers	Planktonic	Tube-dwelling Free-living	<1yr	200-500mm <10mm 10-20mm	Sessile	Tunic Stalked	X
A5.14	X	X	X	X	X	X	X	*Sessile* *Crawlers*	X	X
A5.15	*Downward conv* *Upward conv*	X	X	Planktonic	*Tube-dwellers* *Crevice*	X	X	X	X	X
A5.23	X	Direct devel	Surface deposit Suspension Predators Scavengers	lecithotrophic	X	X	X	Swimmers	Stalked	X
A5.24	X	X	X	Planktonic Direct	X	X	X	Swimmers	Stalked	Surface-dweller
A5.25	X	X	X	*Lecithotrophic* *Direct dev*	X	X	X	X	X	X
A5.26	X	X	X	X	*Free living*	X	X	X	X	*Surface-dweller*
A5.27	X	X	X	X	Attached Free-living	X	X	*Swimmers*	X	X
A5.35	*Upward conv* *Non-bioturbator*	X	*Scavengers*	X	Epifaunal Attached	<1yr	X	Sessile Swimmers	Stalked Crustose	Surface-dweller 0-5cm 6-10cm

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Bolam, **Kenny**, et al (this conference)

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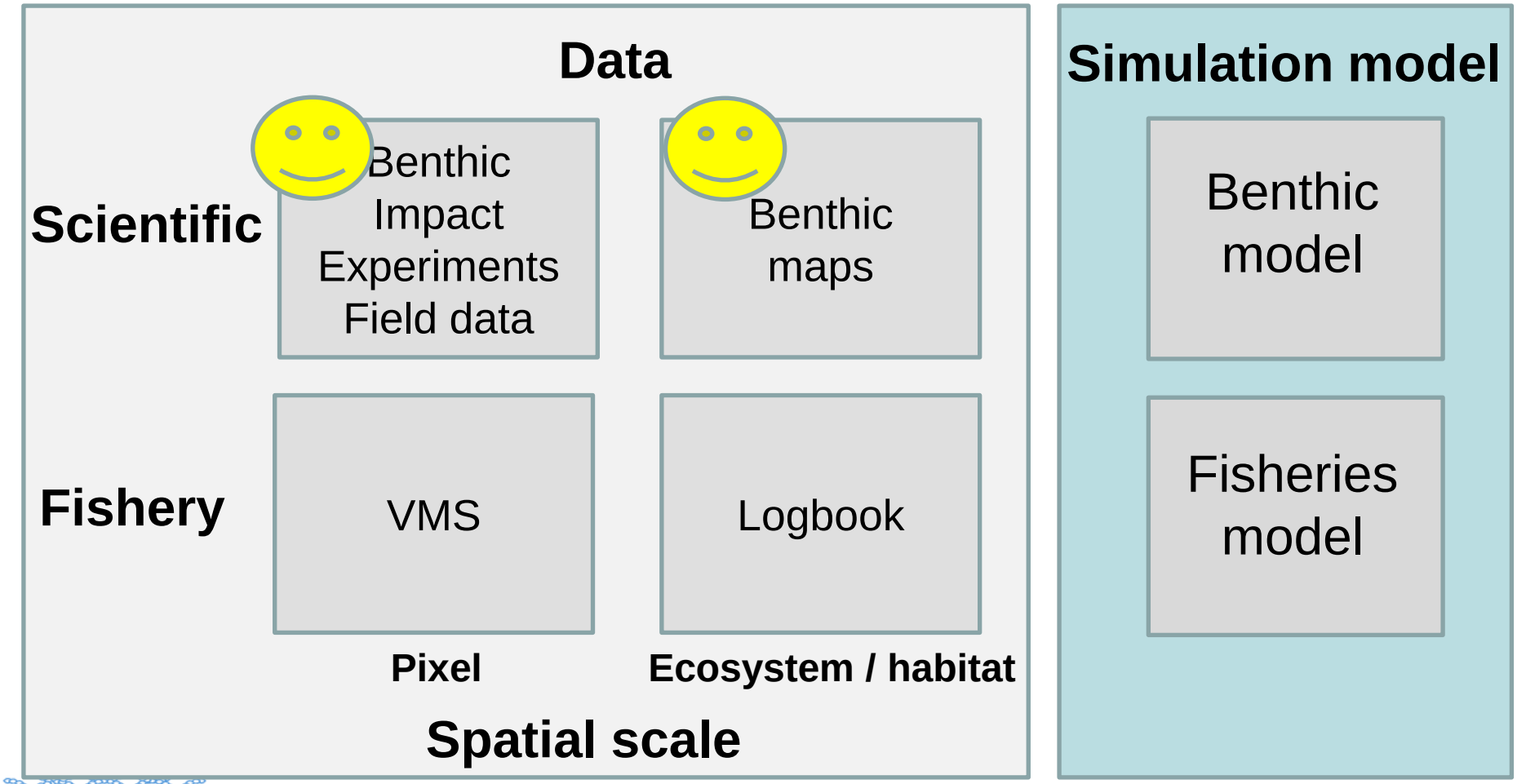
from pixel to management area level
from observations to predictions



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Hiddink et al 2006 CJFAS ; Ellis et al 2014 CJFAS

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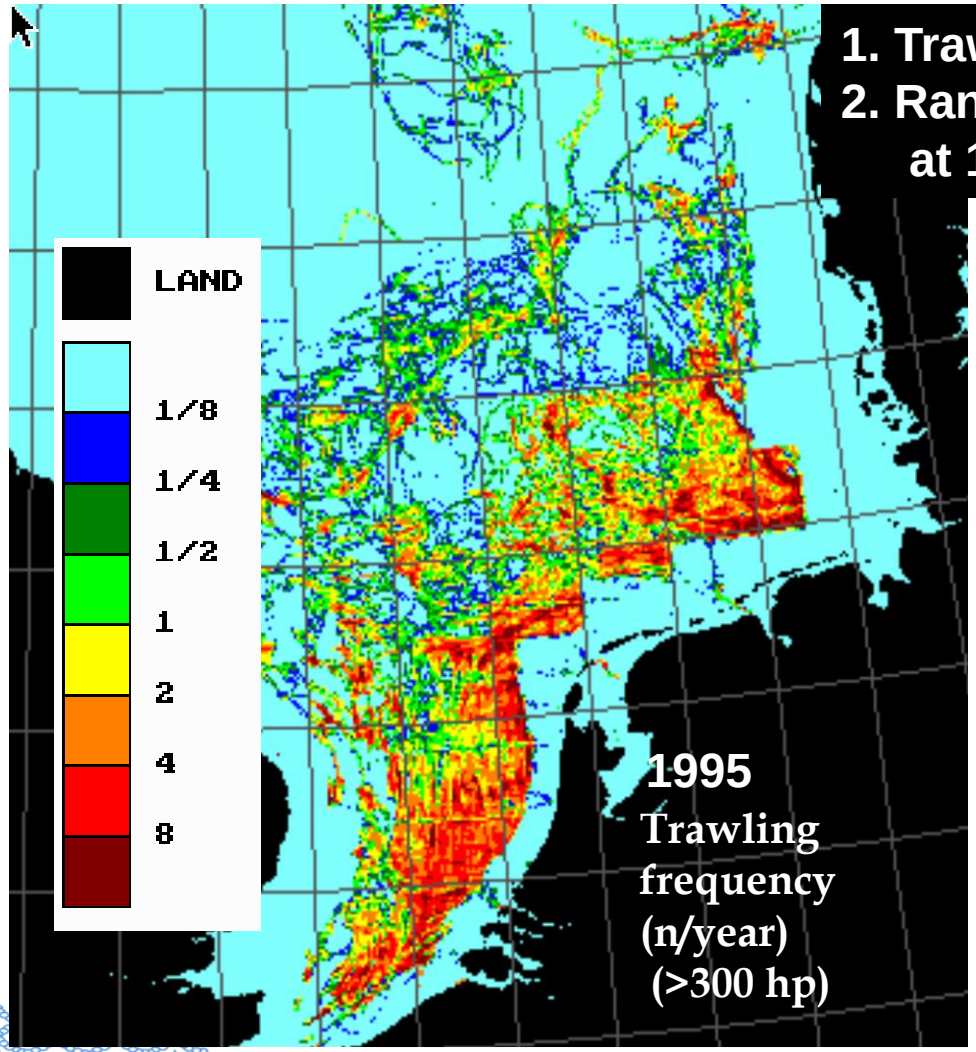
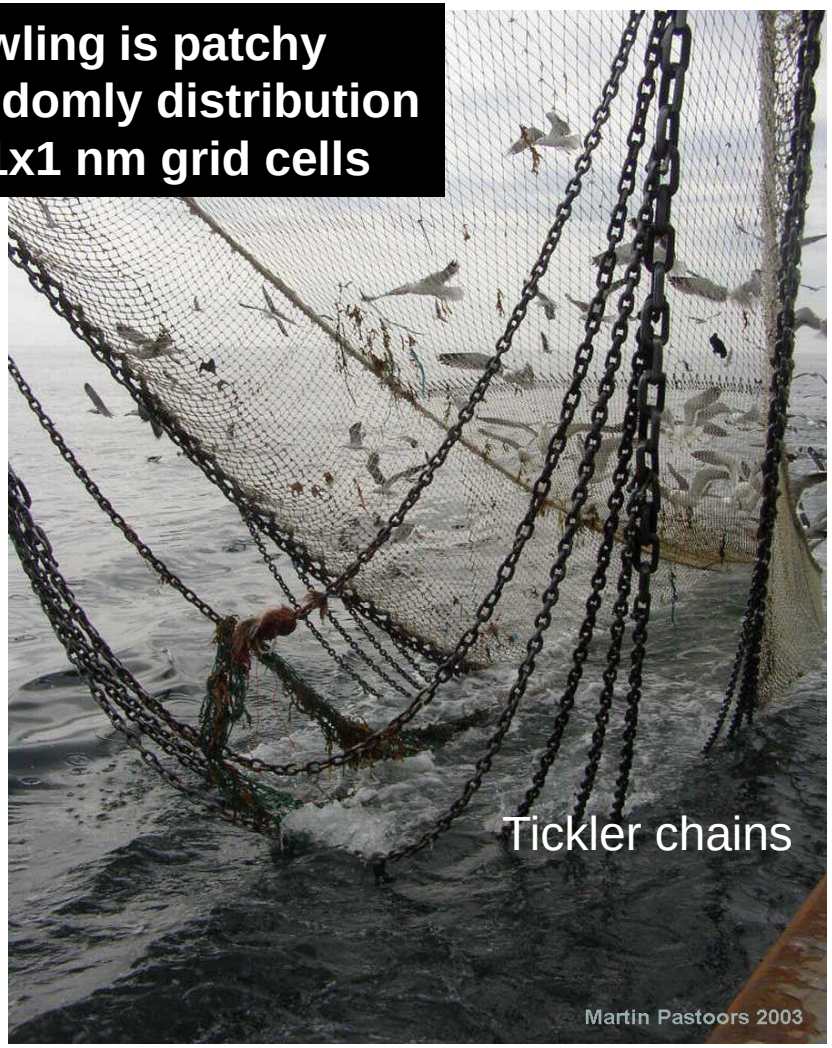
Fisheries data (VMS – Logbook)



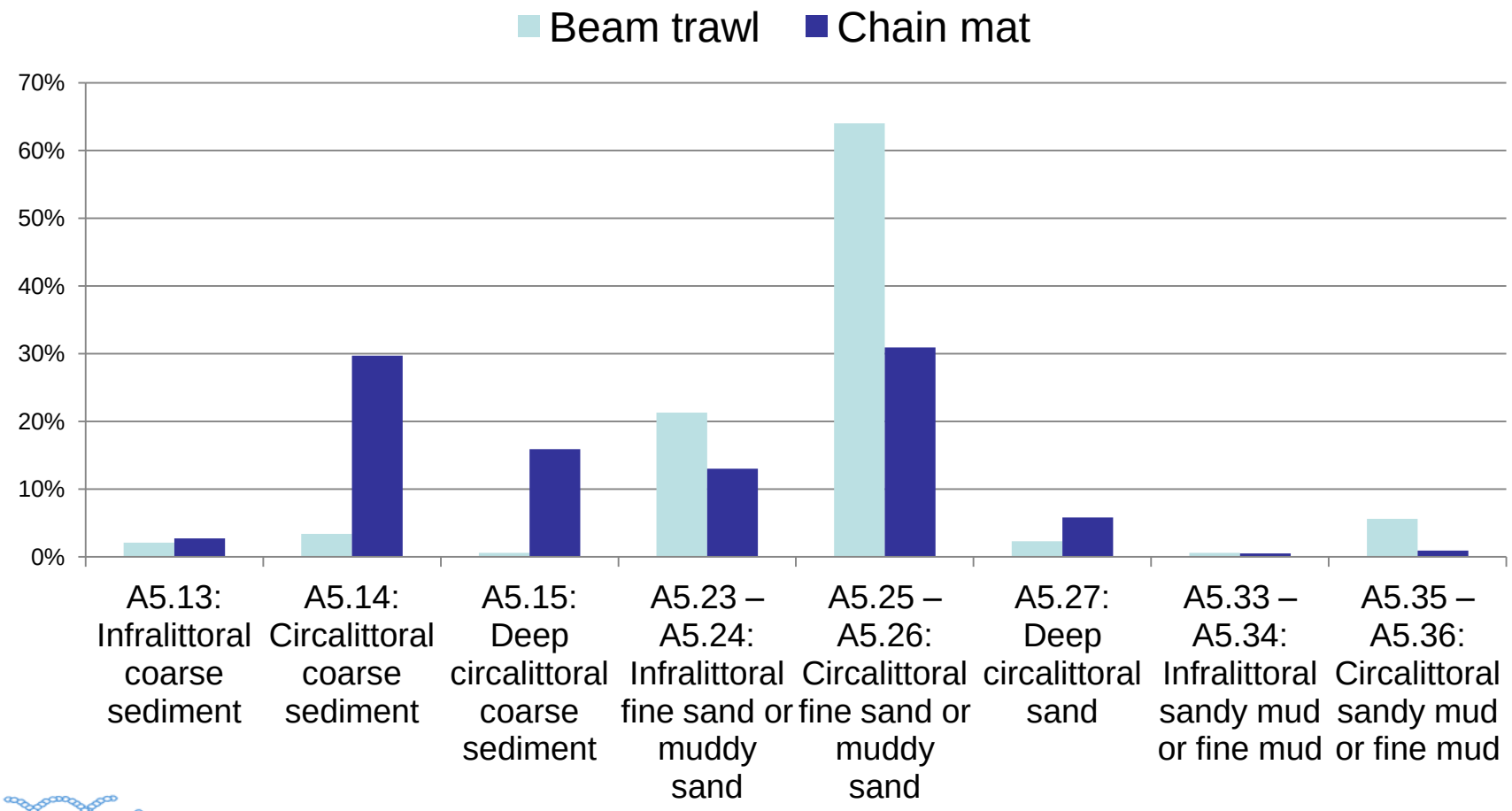
1. Trawling is patchy
2. Randomly distribution at 1x1 nm grid cells



BENTHIS

Rijnsdorp et al. (1998) ICES J Mar Sci 55: 403-419

Trawling effort by habitat



Coarse → **Fine**

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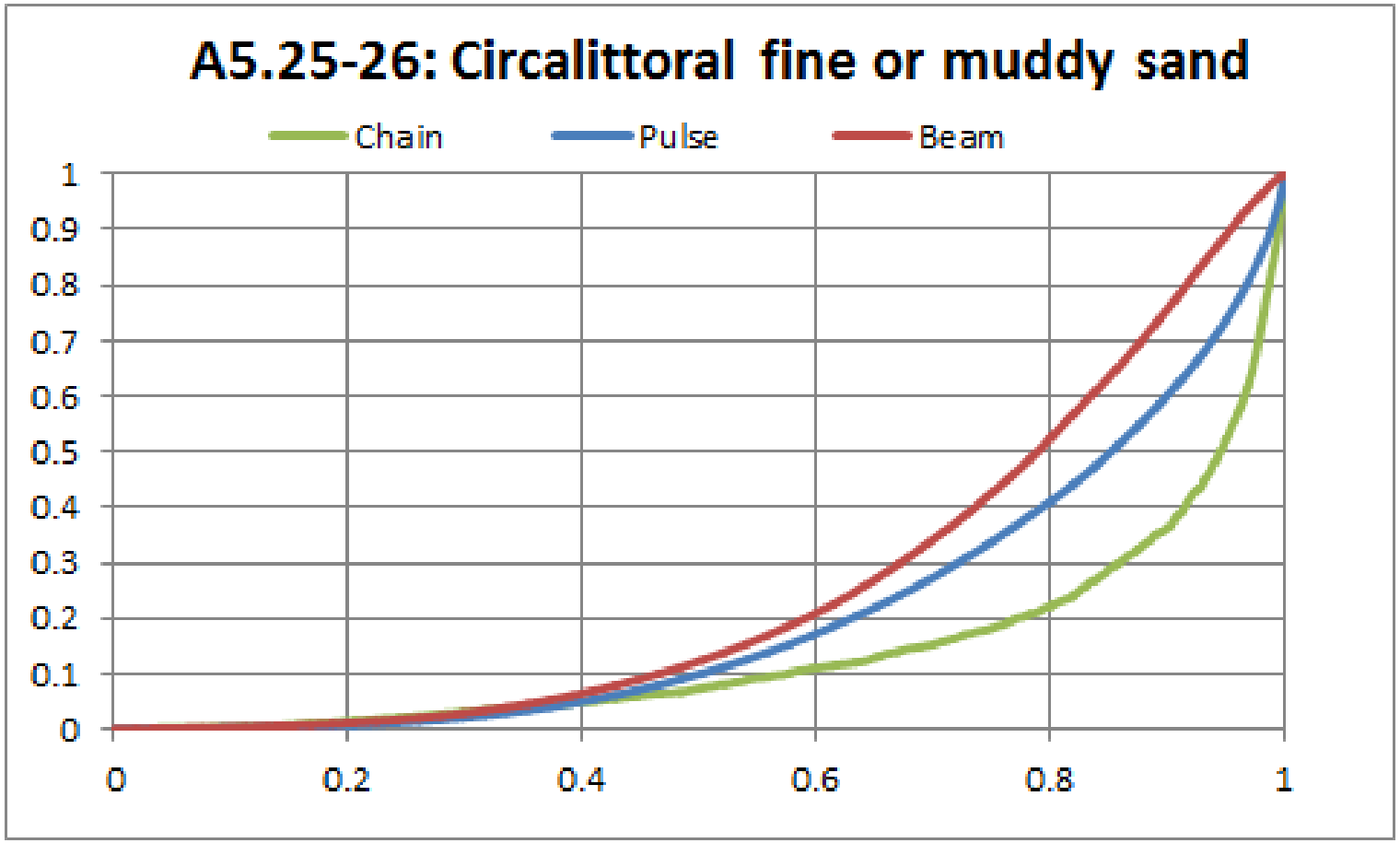
Heterogeneous distribution within habitat



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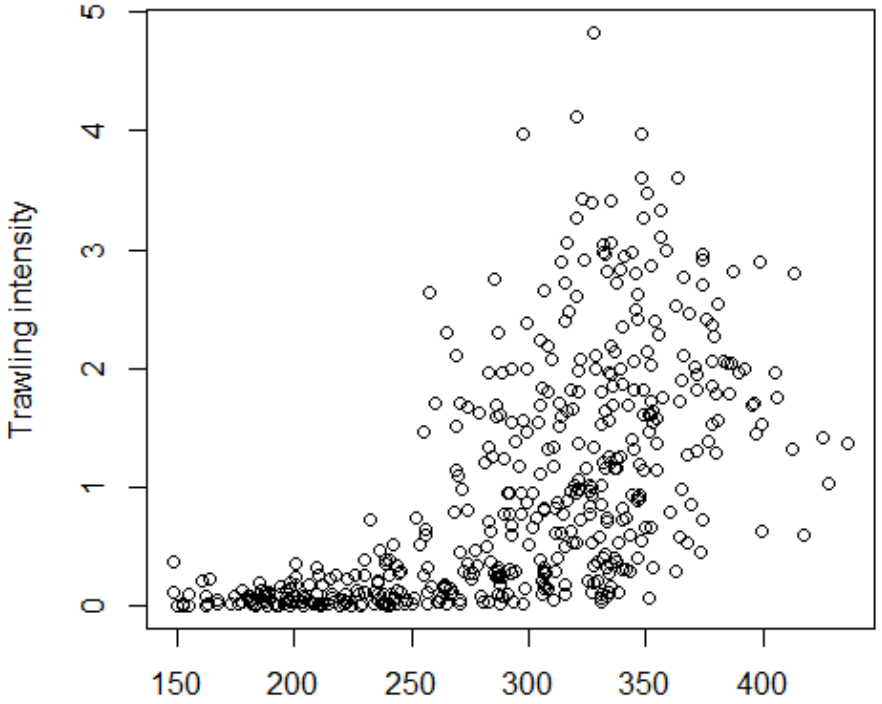
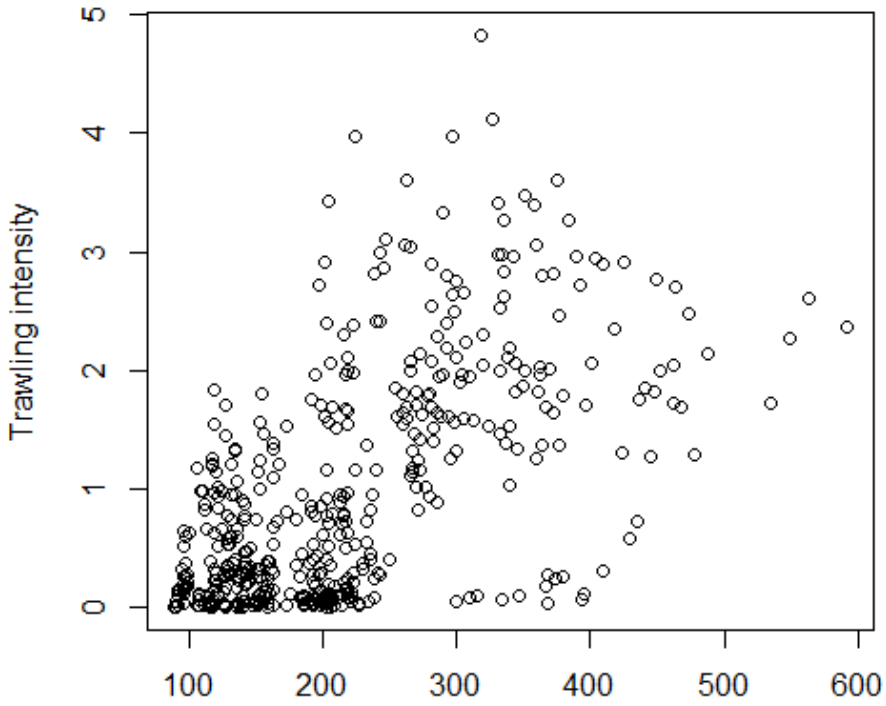
Trawling related to Primary Production

	Correlation coefficient	P-value
Depth	-0.562	<0.001
Grain size	0.614	<0.001
Primary production	0.613	<0.001



Primary production



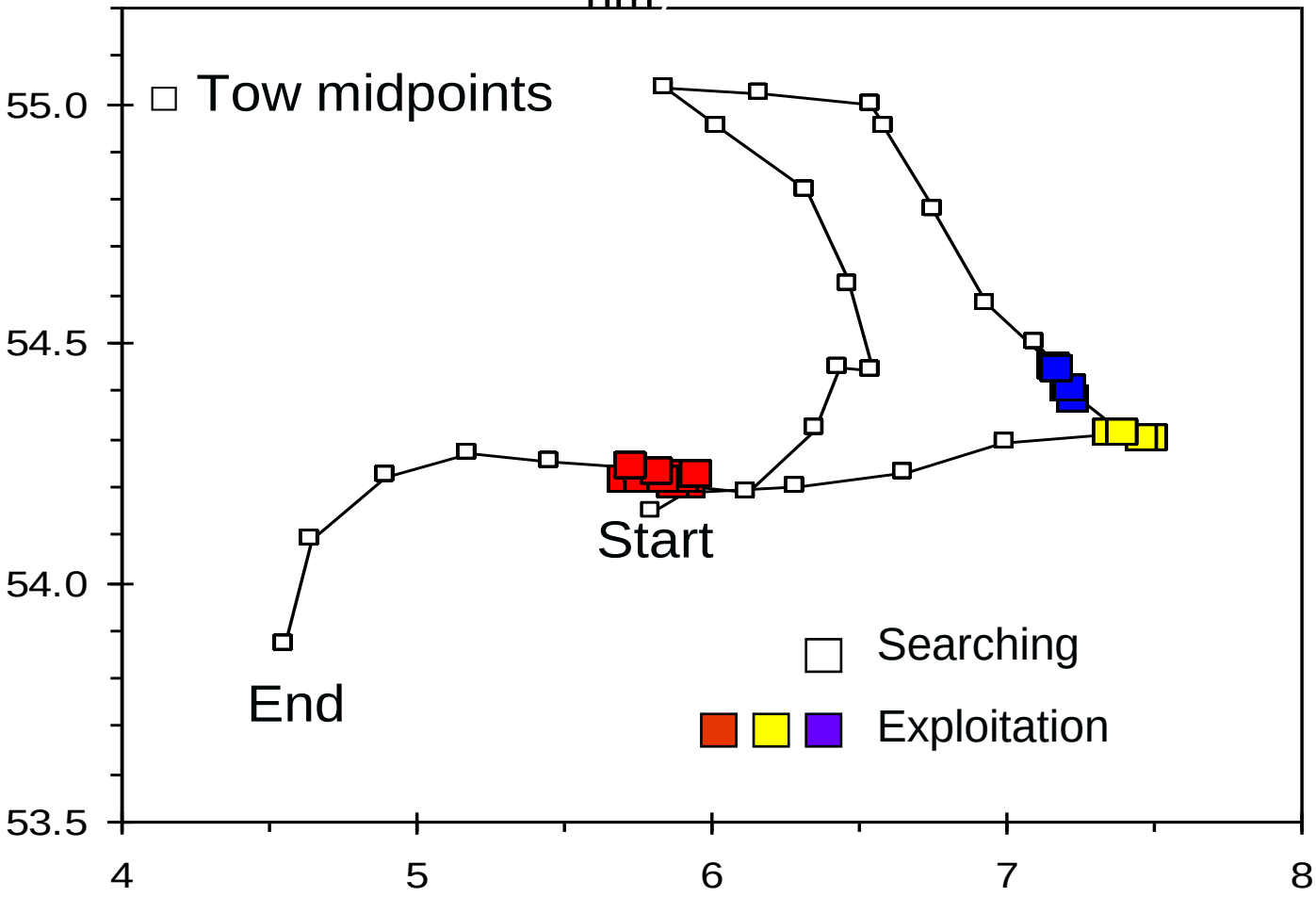
Grain size

Van Denderen et al (2014) Ecosystems in press

Understanding fishing aggregations

Fishing patterns within a trip

3 fishing grounds using cluster analysis (single linkage: d=4 nm



Rijnsdorp et al (2011) Can J Fish Aquat Sci 68: 1064-1076

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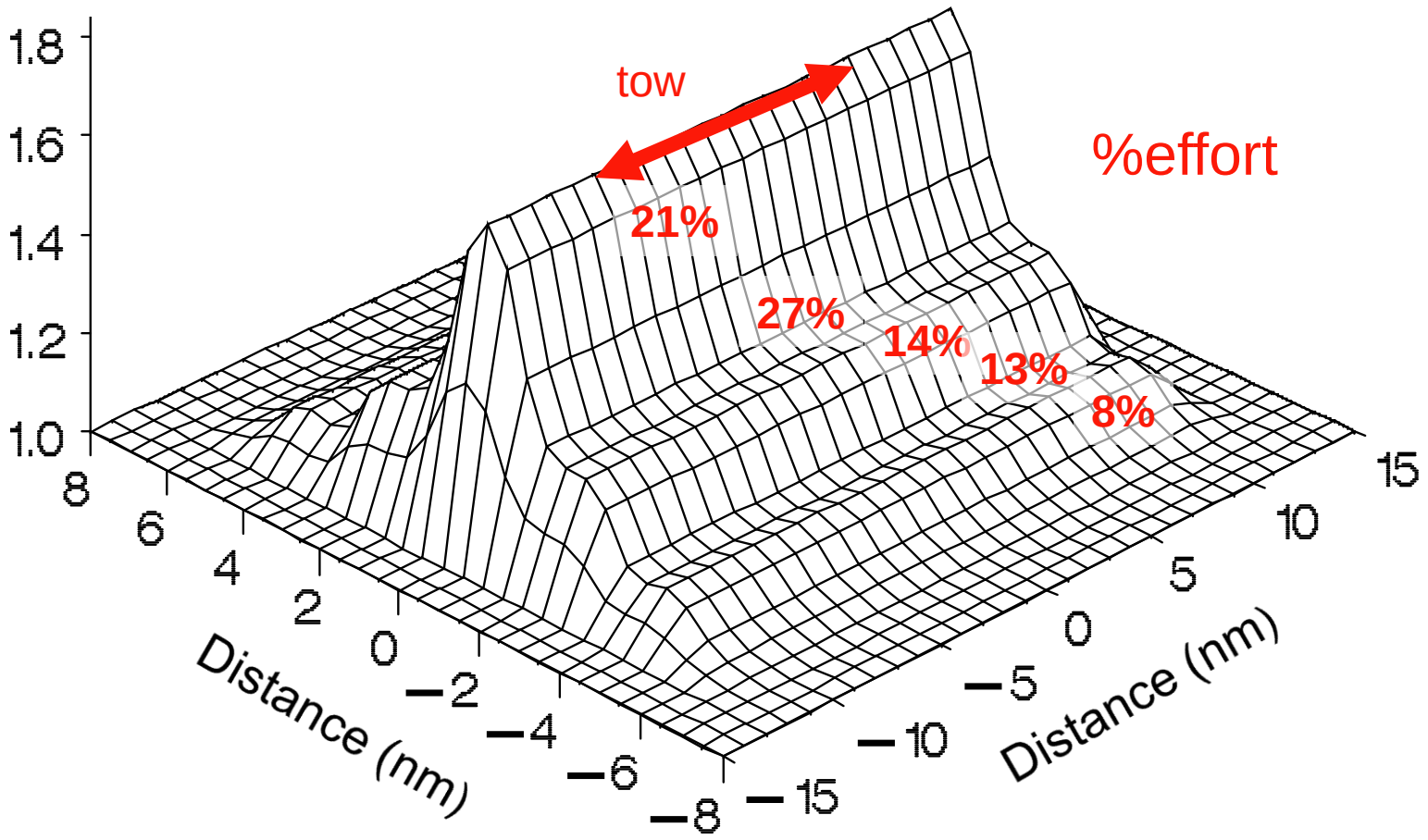
Catch rate and dimensions fishing hot spot

Catch rate



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Rijnsdorp et al (2011) CJFAS Poos et al (2007) JSR

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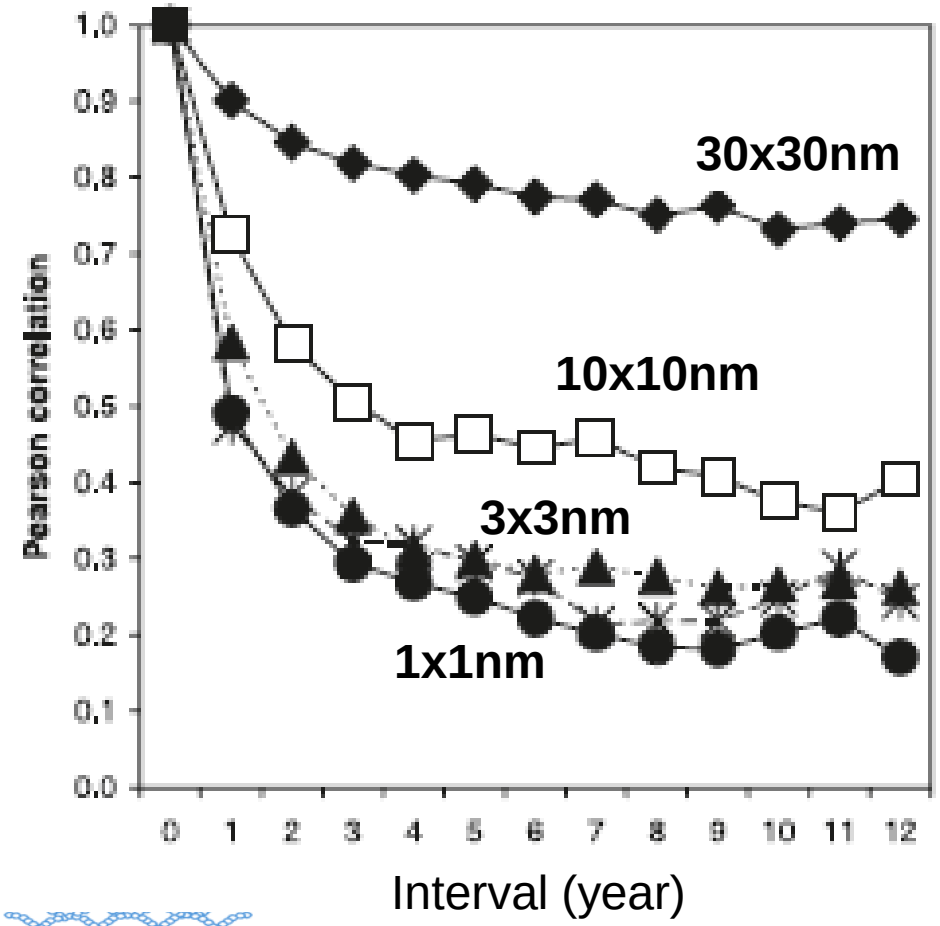
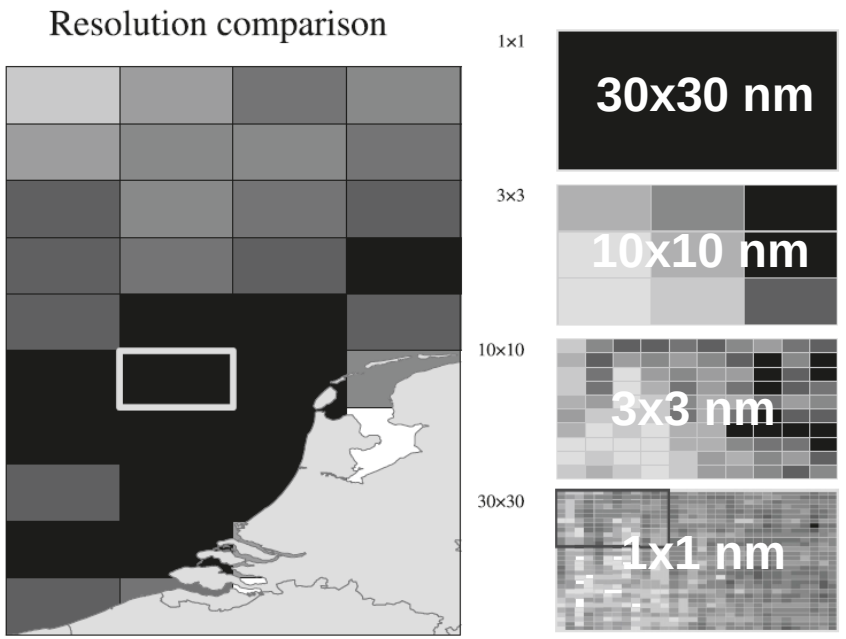
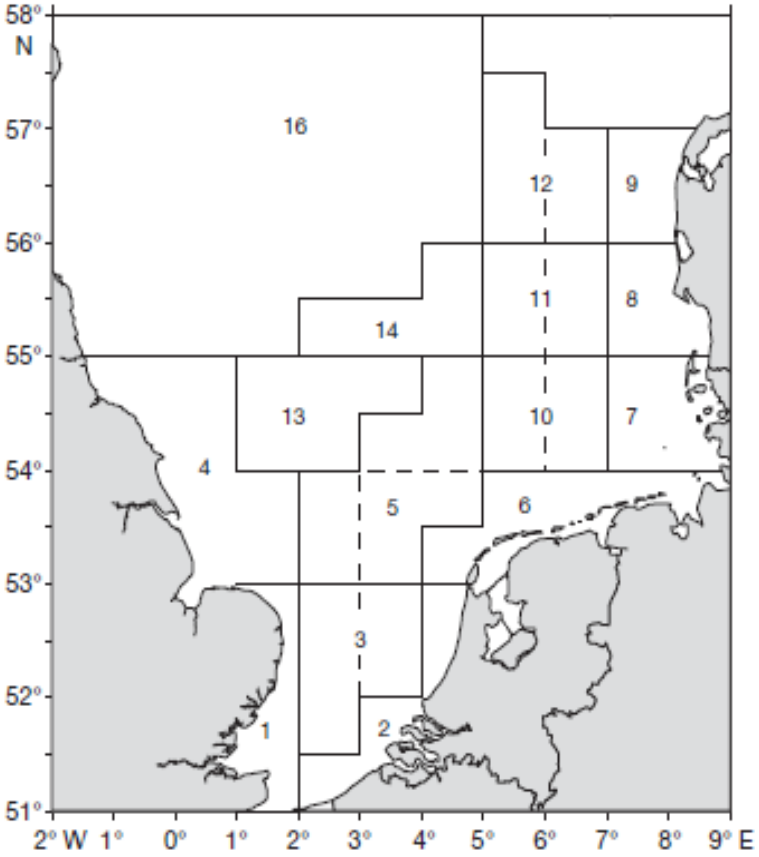
Spatial consistency in trawling hot spots





Piet & Quirijns (2009) CJFAS

Modelling Distribution Fishing Effort



Effort allocation at scale of (fishing areas >30x30 nm)

- RUM models (e.g. Hutton et al 2004 ICES JMS 61: 1443-1452)
- DSVM (e.g. Poos et al 2010 ICES JMS 67: 323-333)

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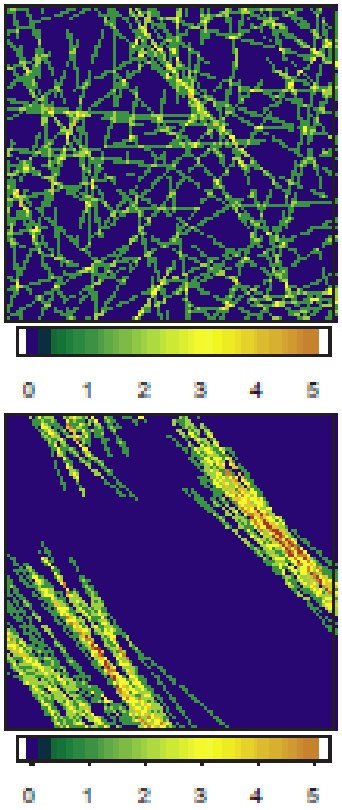
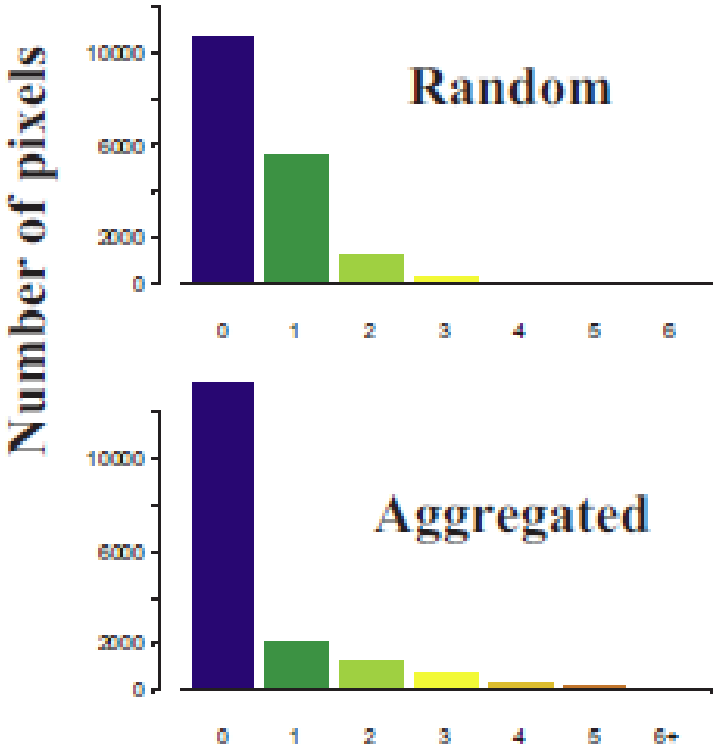
Modelling Distribution Fishing Effort

- Effort allocation at pixel scale
  - Ellis et al 2014 Can J Fish Aquat Sci: 71(5)





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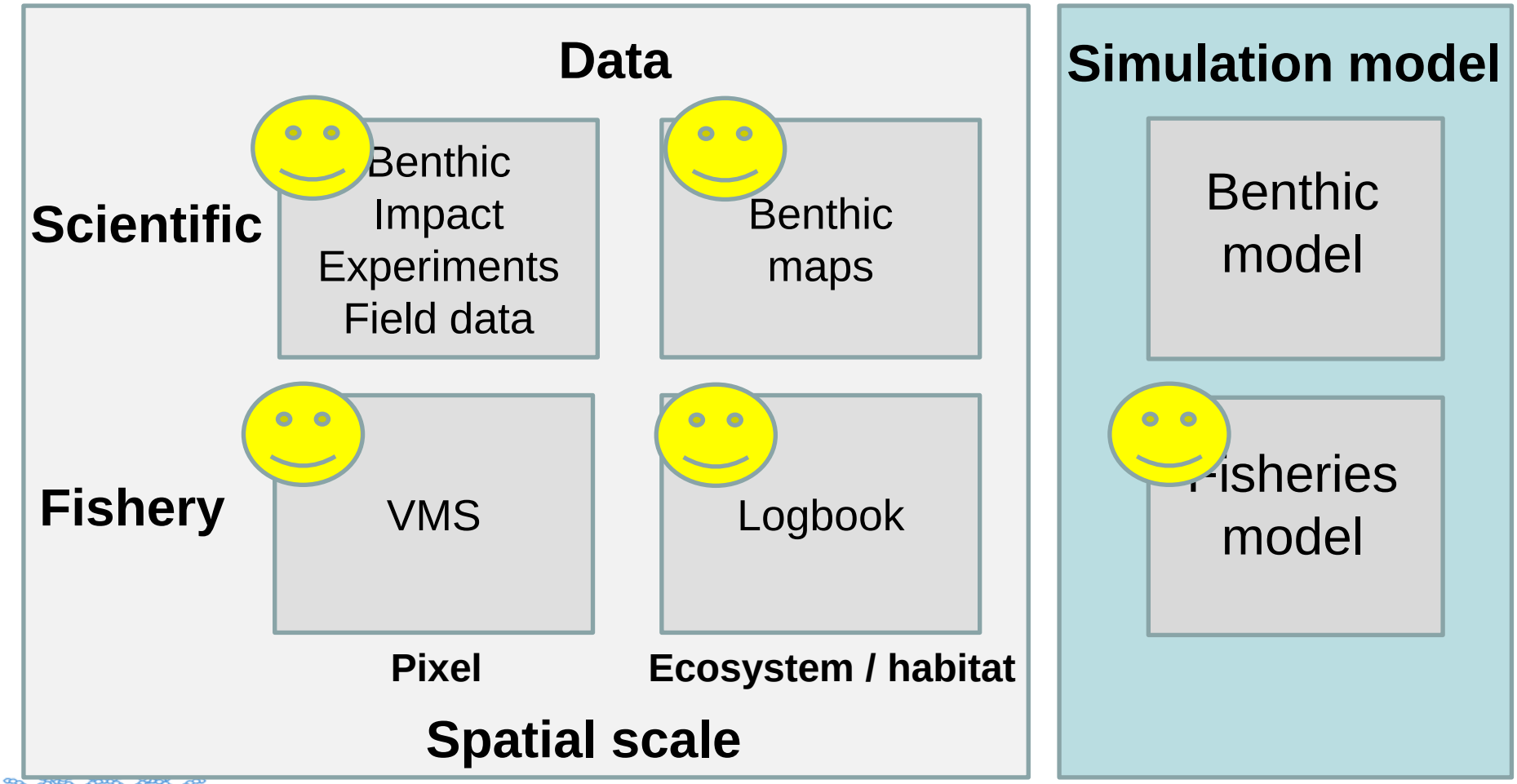
from pixel to management area level
from observations to predictions



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Hiddink et al 2006 CJFAS ; Ellis et al 2014 CJFAS

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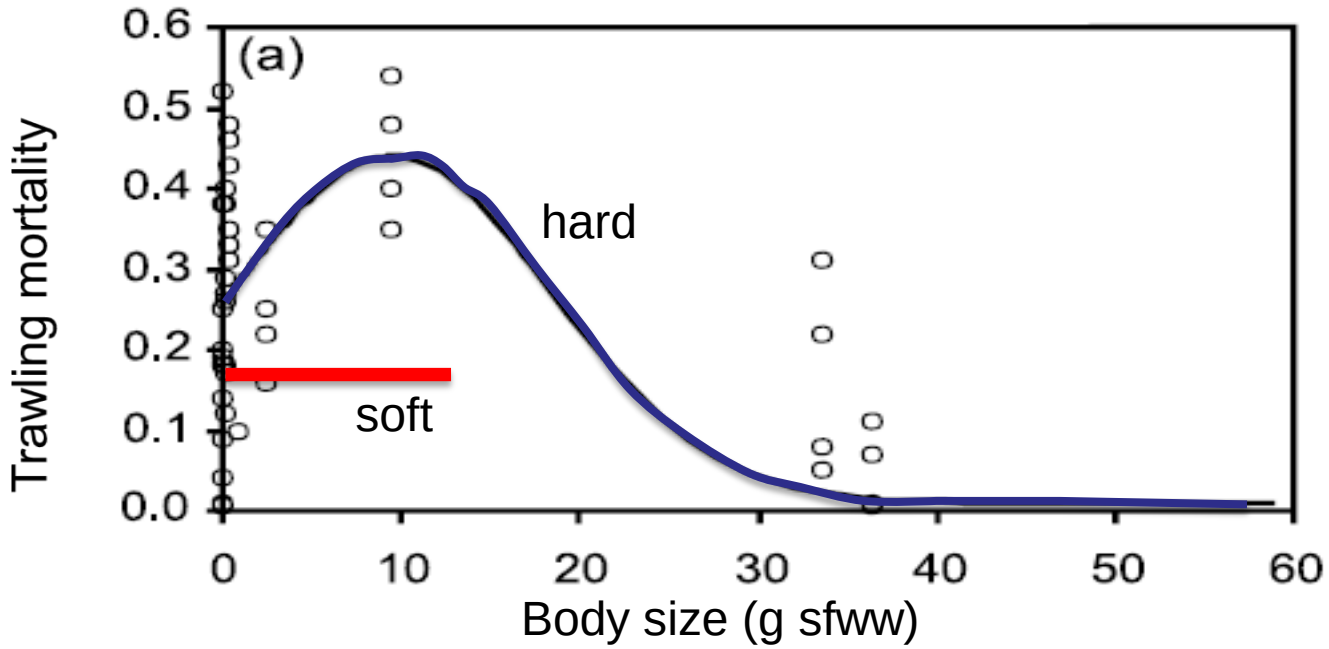
Modelling trawling impact benthos

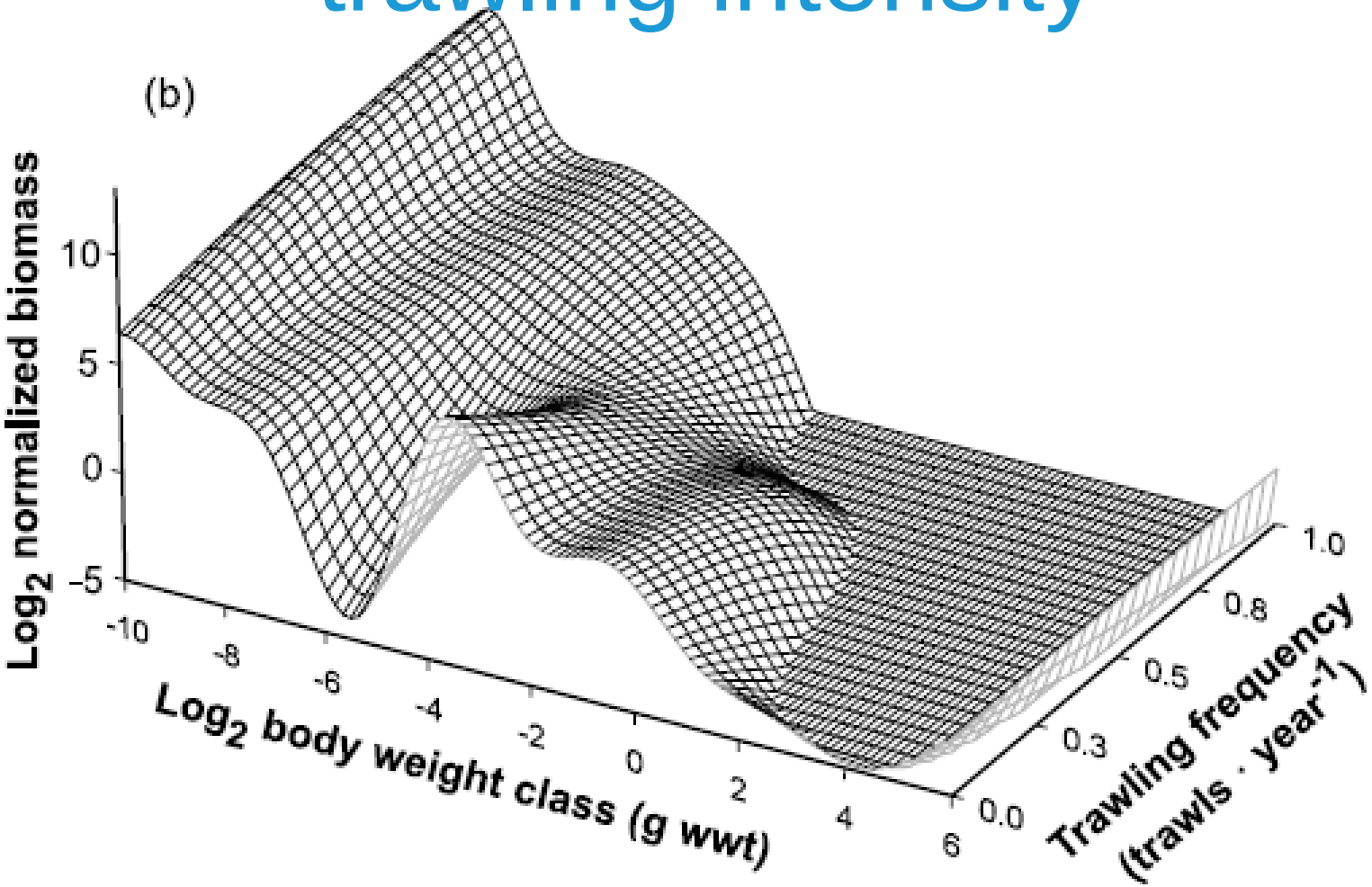
- Three groups (**meio, soft** & hard species)
- Size structured
- Lotka-Volterra dynamics
- Food competition (α)

$$\frac{dB_i}{dt} = B_i r_i \left(\frac{C_i - B_i - \alpha_{ij} B_j}{C_i} \right) - B_i \, \mathrm{Mort}_i$$



Duplisea et al (2002) CJFAS 59: 1785-1795

Biomass size spectrum – trawling intensity



Duplisea et al (2002) CJFAS 59: 1785-1795

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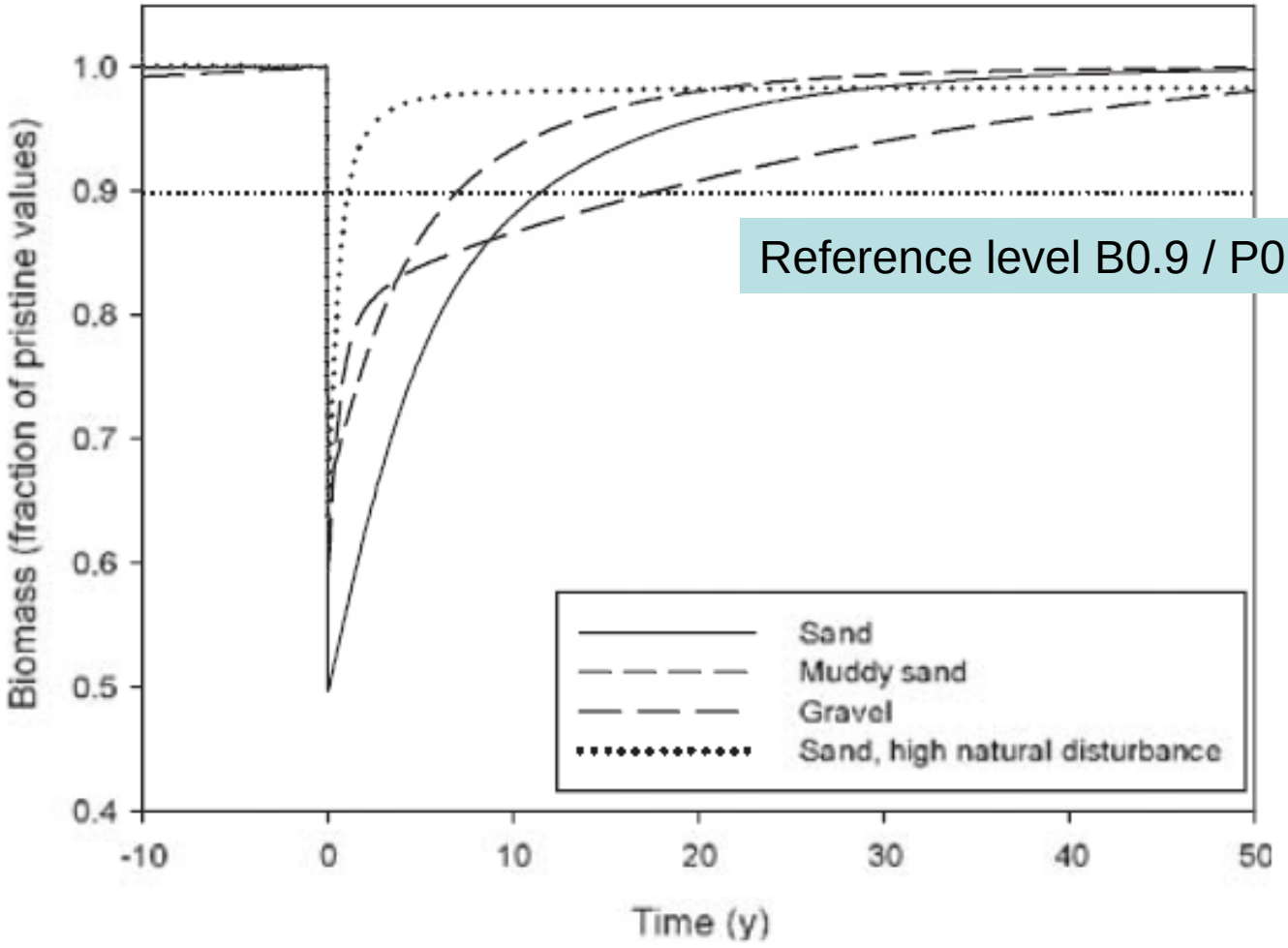
Modelled production recovery (years) after a single trawling event



Reference level B0.9 / P0.9

Hiddink et al (2006) Ecosystems

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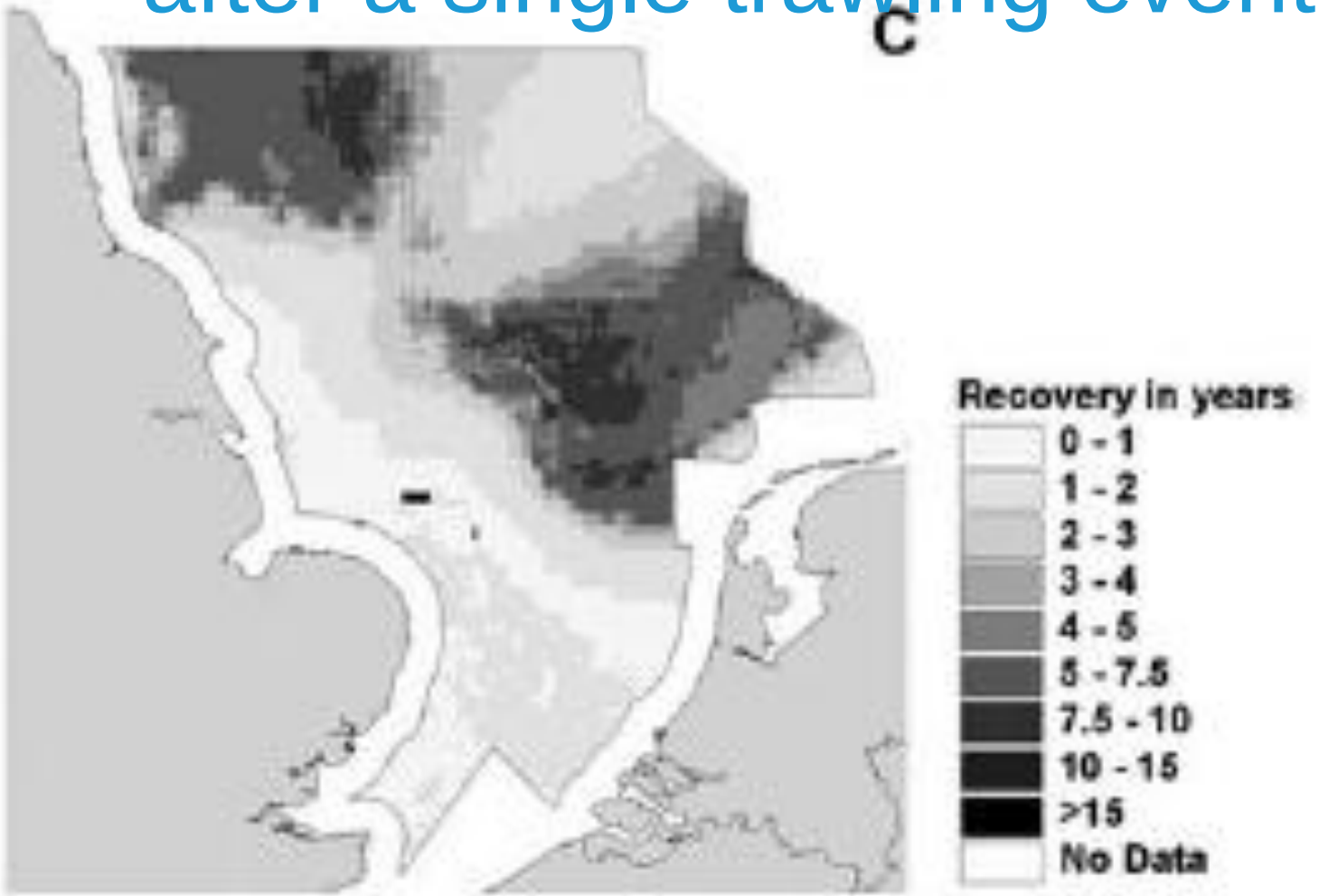
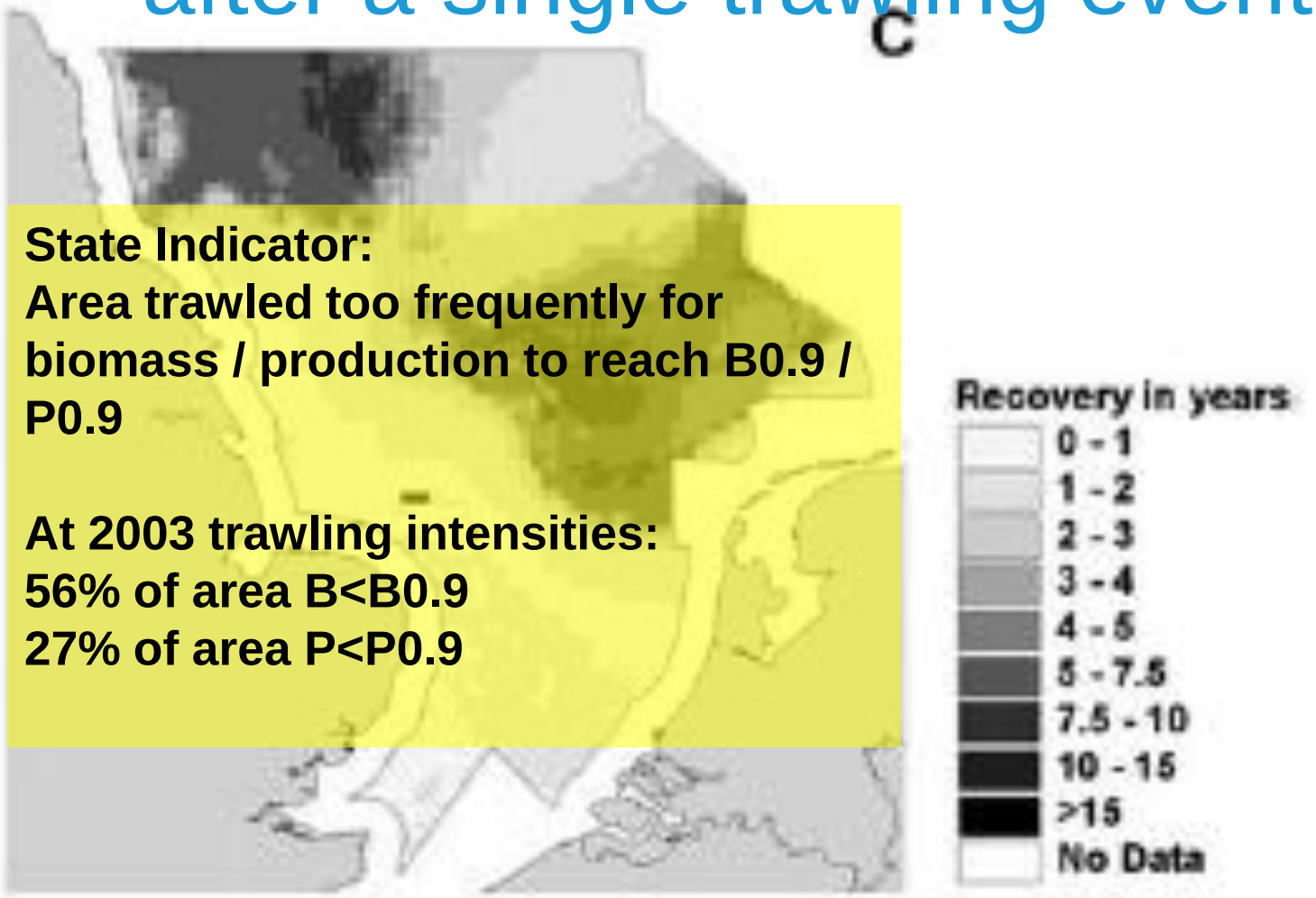
Modelled production recovery (years) after a single trawling event



Hiddink et al (2006) Ecosystems

Modelled production recovery (years) after a single trawling event



State Indicator:
Area trawled too frequently for biomass / production to reach B0.9 / P0.9

At 2003 trawling intensities:
56% of area B<B0.9
27% of area P<P0.9

Hiddink et al (2006) Ecosystems

Conclusion

Predicting trawling impacts benthic ecosystem

- **Biodiversity conservation**
  - ✓ **Species richness**
  - ✓ **Benthic biomass**
  - Habitat complexity
- Loss of ecosystem services
  - Essential fish habitat (a place to live)
  - Fish production (food for fish)
  - Benthic – pelagic coupling
  - Nutrient regeneration

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Conclusions

Impact trawling on structure and function (analysis):

- Gear traits→ Biota/Habitat traits → Indicators Benthic State

Benthic processes (modelling)

- role of species interactions (fish predation on benthos)
- Spatial dynamics of perturbation and recovery (growth, recruitment, immigration)

Fisheries

- Mechanisms underpinning the temporal consistency of small scale aggregations
- Historic reconstruction of trawling impact (shadow of the past?

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Acknowledgement

- BENTHIS colleagues: Stefan Bolam and Andrew Kenny (CEFAS), Jan Geert Hiddink (Bangor), Ana Ivanovich (Aberdeen), Barry O'Neill (Marine Scotland), Ole Eigaard (DTU-Aqua), Antonello Sala (CNR), Daniel van Denderen and Tobias van Kooten (IMARES)

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BANGOR
UNIVERSITY

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