Global analysis of seagrass restoration

the importance of a large scale

Roma 11 April 2018
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IN·DEI·NOMINE·FELICITER

Contents

- Global seagrass restoration, database
- Analysis
- Results
- Large scale
- Positive feedback
- Environmental variability
- Visualisation, take home message

Global analysis of seagrass restoration projects

17 nations
1786 trials

Journal of Applied Ecology

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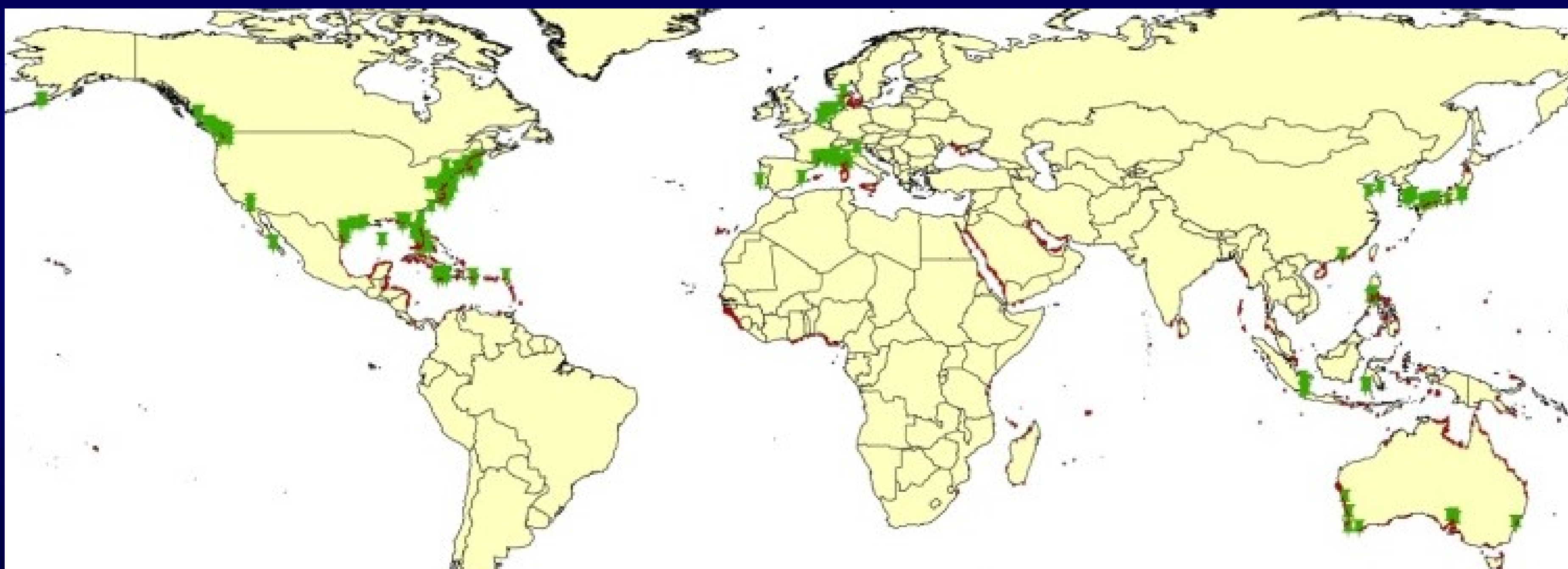
Global analysis of seagrass restoration: the importance of large-scale planting

Marieke M. van Katwijk[1]*, Anitra Thorhaug[2], Núria Marbà[3], Robert J. Orth[4], Carlos M. Duarte[3,5,6], Gary A. Kendrick[5], Inge H. J. Althuizen[1], Elena Balestri[7], Guillaume Bernard[8], Marion L. Cambridge[5], Alexandra Cunha[9], Cynthia Durance[10], Wim Giesen[1,11], Qiuying Han[12], Shinya Hosokawa[13], Wawan Kiswara[14], Teruhisa Komatsu[15], Claudio Lardicci[7], Kun-Seop Lee[16], Alexandre Meinesz[17], Masahiro Nakaoka[18], Katherine R. O'Brien[19], Erik I. Paling[20], Chris Pickerell[21], Aryan M. A. Ransijn[1] and Jennifer J. Verduin[22]

van Katwijk et al. J.Appl.Ecol. 2016

Global analysis of seagrass restoration projects

17 nations
1786 trials



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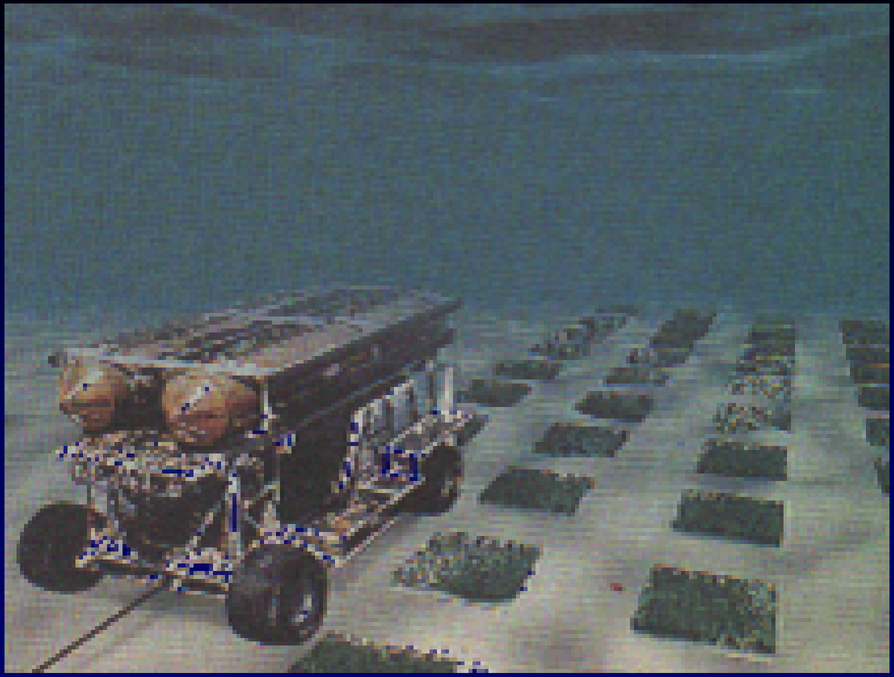
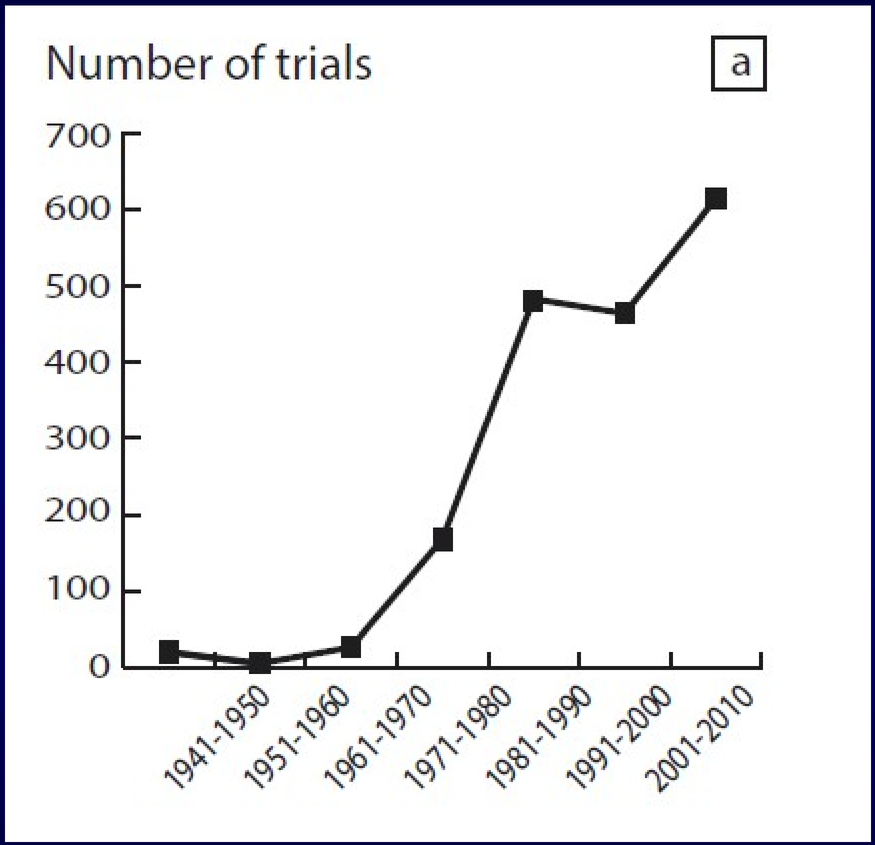
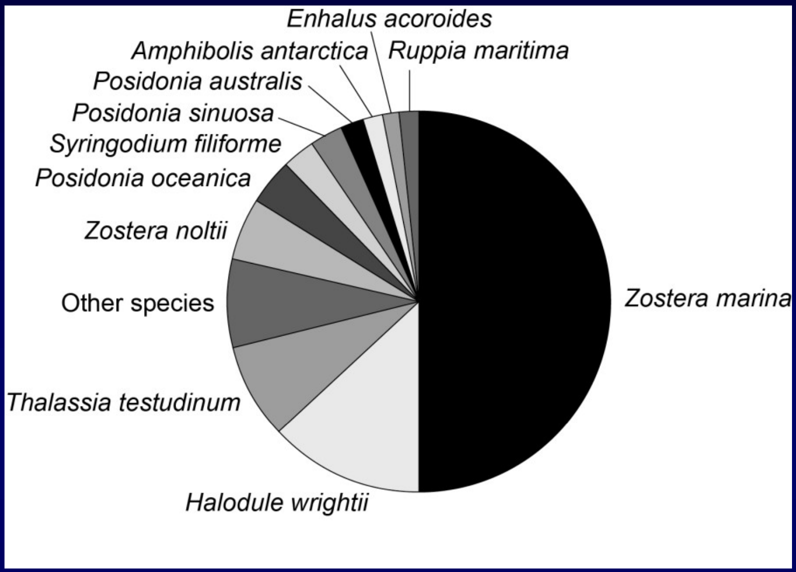


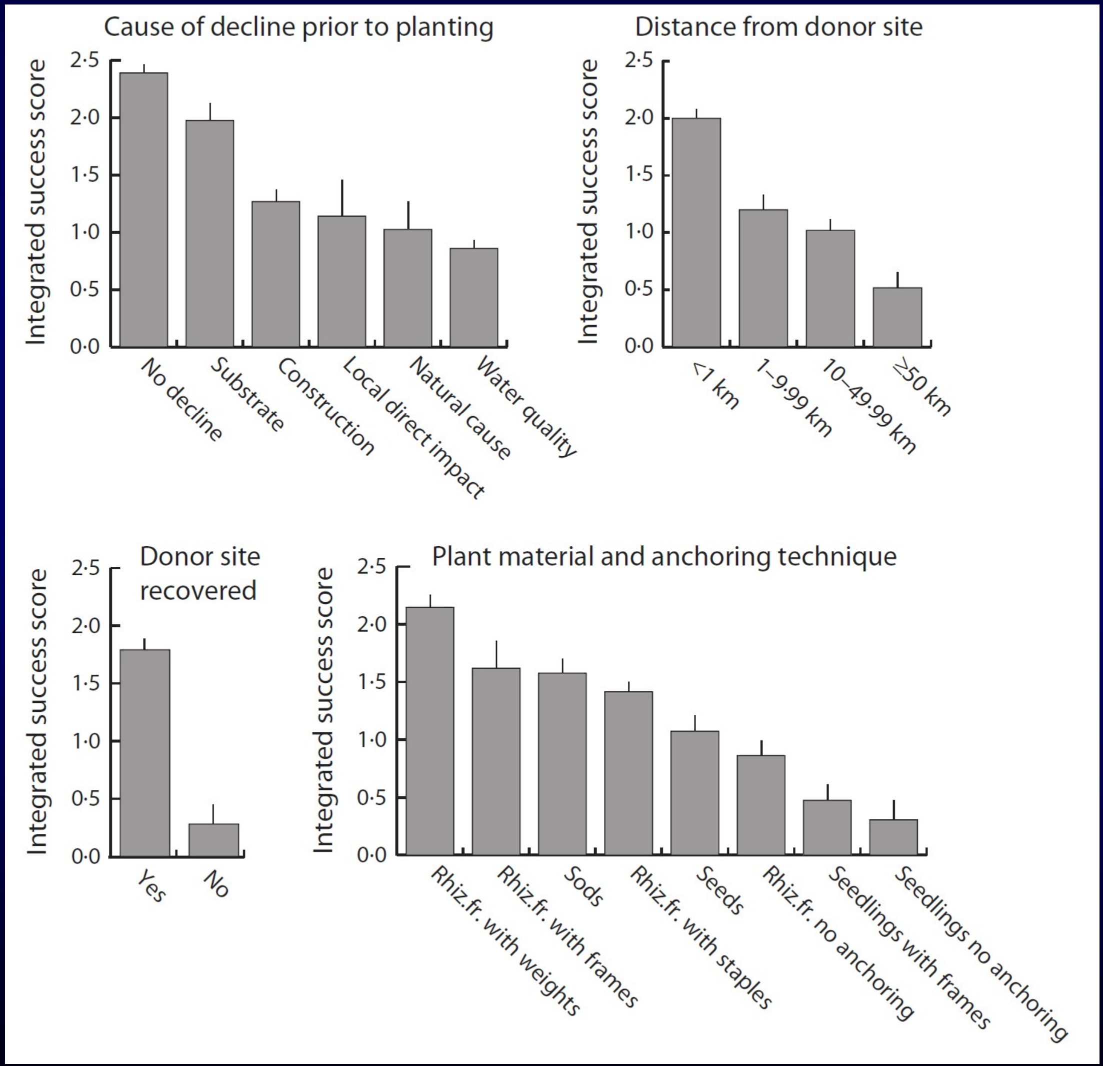
Global analysis: 1786 trials



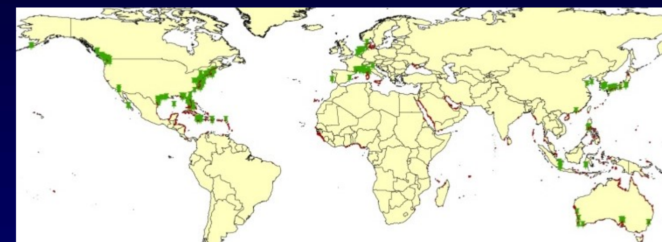


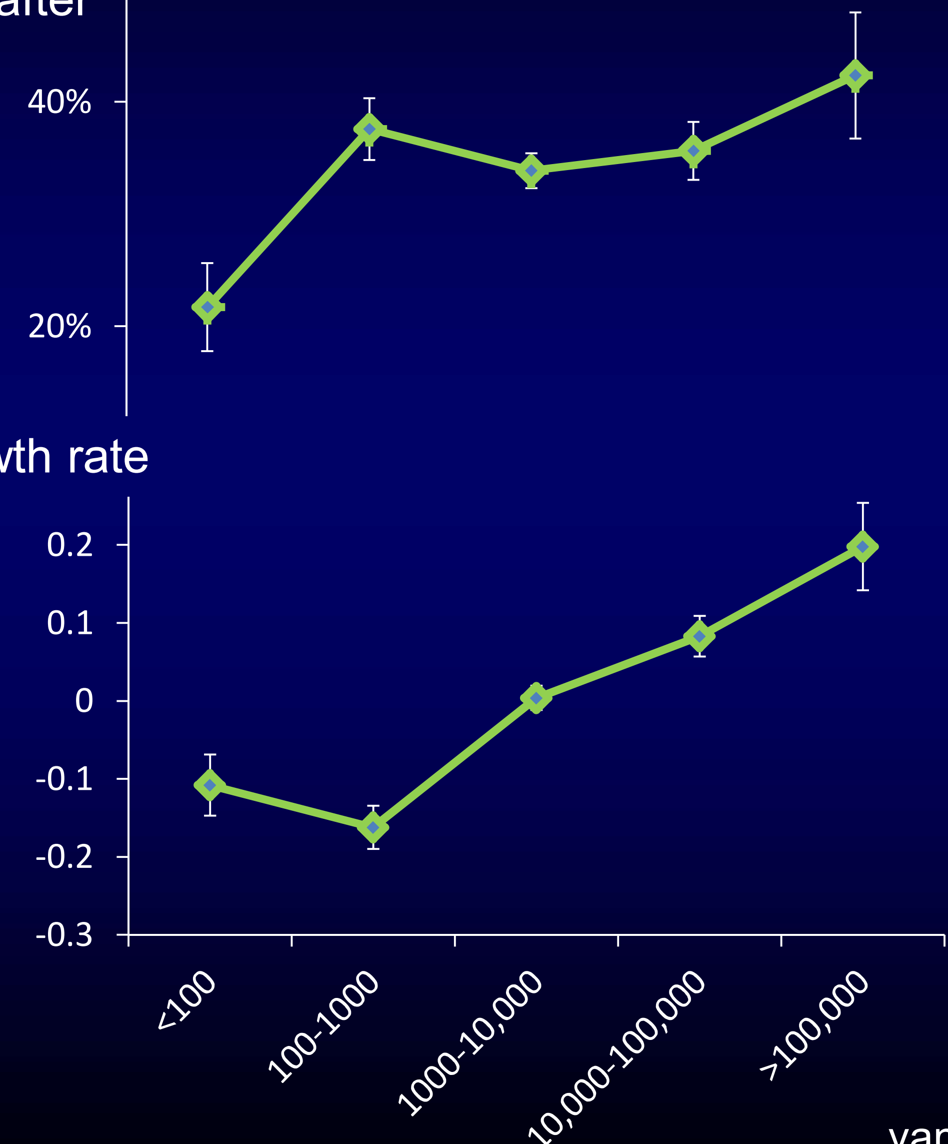
Species used in the trials

Global analysis



Global analysis: importance of scale





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Why?

1. Positive feedback
   requiring critical mass
2. Environmental variability
   requiring spreading of risks
   (to find a window of opportunity)

Or: extinction risk increases when population size is low (Allee-effects) and environmental variability is high (basic population dynamics theory)

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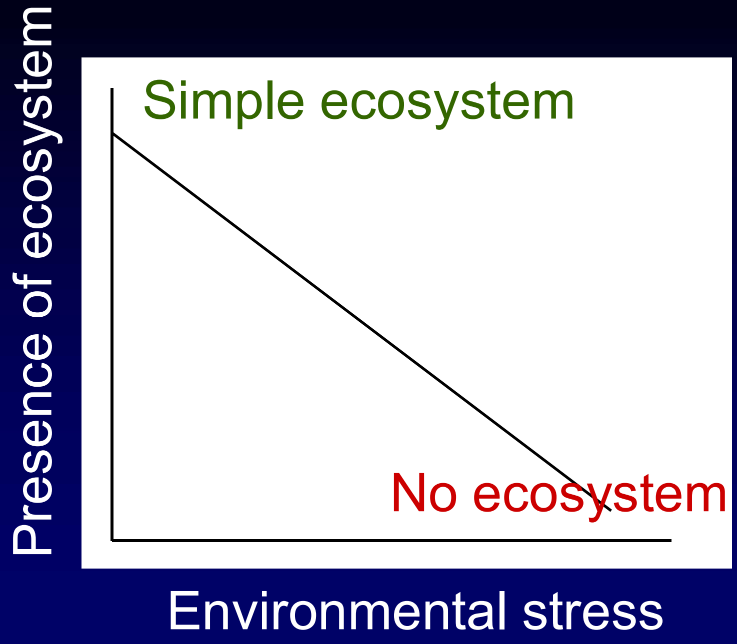
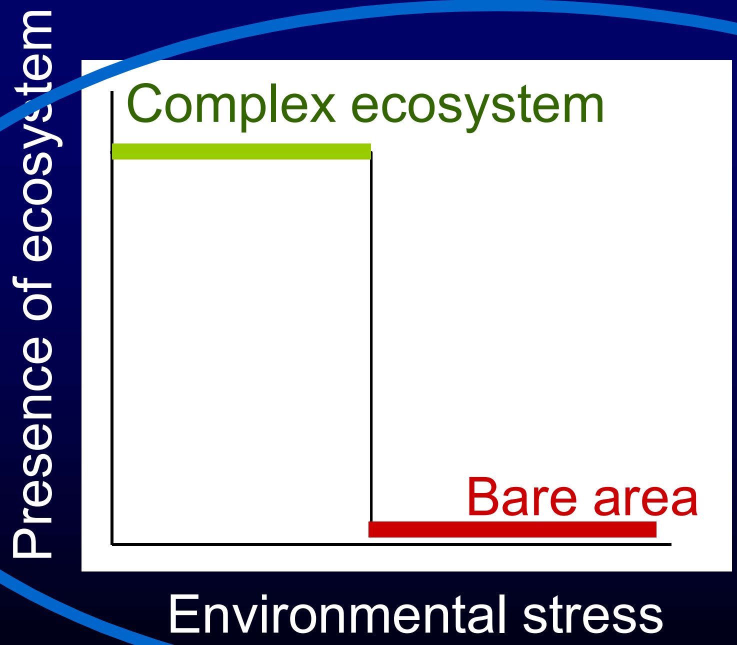
Saltmarshes
Mangroves
Coral reefs
Shallow lakes
Boreal forests
etc

Complex systems usually show non-linear dynamics



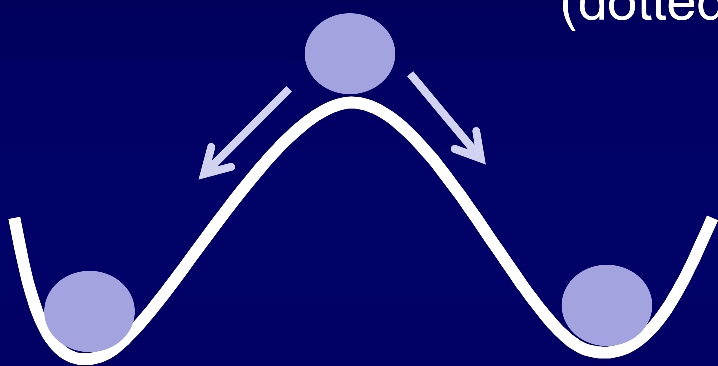


This is due to positive feedbacks

Bistability:

Two stable states under the same external circumstances

unstable state = threshold or tipping point (dotted line)



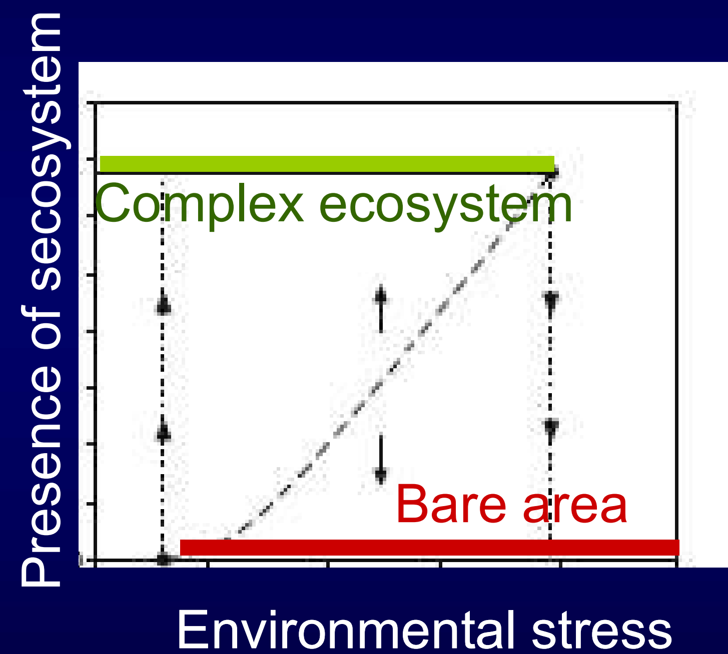
stable state 1

=Complex ecosystem

stable state 2

=Bare area

When the positive feedbacks are very strong, <u>bistability</u> may occur



Scheffer et al. Science 2001

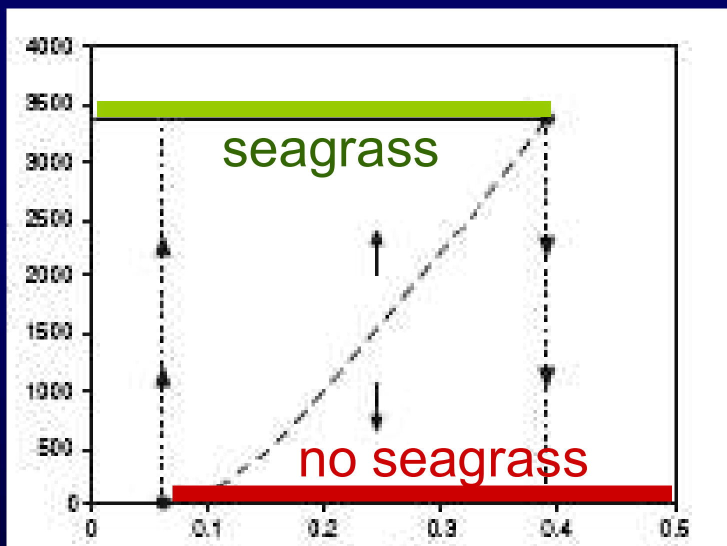
Seagrass example

Positive Feedbacks in Seagrass Ecosystems: Implications for Success in Conservation and Restoration
Ecosystems 2007

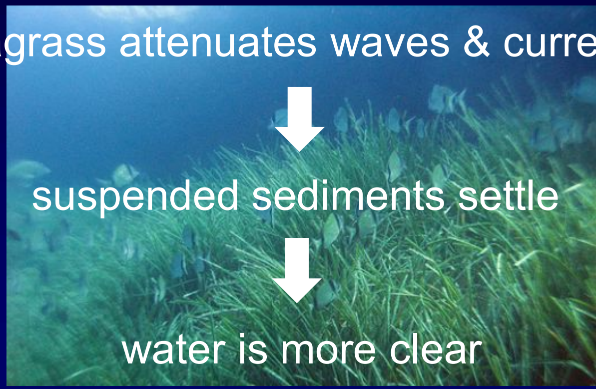
Tjisse van derHeide,[1,2,*] Egbert H. van Nes,[3] Gertjan W. Geerling,[4] Alfons J. P. Smolders,[2,5] Tjeerd J. Bouma,[6] and Marieke M. van Katwijk[1]

state 1: seagrass present and clear water
state 2: seagrass absent and turbid water
under the same external circumstances

Seagrass shoot density m-1



wave energy (max. orbital velocity m s^{-1})



Also Carr et al. 2010, 2012

Table 1. Feedback mechanisms known to occur in seagrass ecosystems (for further details see online Appendix S1). Green indicates self-amplifying feedbacks, whereby increase in seagrass density generates conditions which promote further increase in density, until carrying capacity is reached or poor environmental conditions overwhelm the feedback. Red indicates self-dampening feedbacks, whereby increase in seagrass presence creates conditions adverse to seagrass, such that seagrass subsequently declines. Yellow indicates feedbacks, which can be both self-amplifying and self-dampening.

	Feedback name	Feedback description	Operates under following conditions and scale:			
			Climate	Hydrodynamics	Nutrient state	Spatial scale
1	Sediment trapping	Seagrass traps water column sediment, improving water clarity, seagrass growth, and seagrass depth range (e.g. de Boer, 2007; Carr *et al.*, 2010, 2012*a*,*b*; Hansen & Reidenbach, 2012; Lawson *et al.*, 2012).	All	(Semi-)exposed	All	~1–>100 m
2	Erosion-facilitated spatial patterning	Interacting positive and negative feedbacks of erosion/sediment trapping acting at small and larger scales lead to self-organised pattern (e.g. van der Heide *et al.*, 2010*a*)	Observed in temperate ecosystems	Exposed	All	~1–~10 m
3	Reduced intertidal desiccation	High-density seagrass reduces desiccation in intertidal areas, creating more favourable seagrass growth conditions higher in intertidal zone (e.g. Fox, 1996; Tsai *et al.*, 2010)	All, but drought stress increases with temperature	All	All	~1–~10 m
4	Ammonium uptake	High-density seagrass takes up more ammonium, reducing toxicity, favouring seagrass growth (e.g. McGlathery *et al.*, 2007, 2012; van der Heide *et al.*, 2010*b*; Cole & McGlathery, 2012)	All	Sheltered	Eutrophic	~10–>100 m
5	Hydrodynamic disruption	High-density seagrass reduces near-bed water currents, reducing physical stress on seagrass plants and stabilising sediments. Small seagrass patches or meadow edges may increase turbulence locally resulting in erosion and scouring (e.g. Fonseca & Koehl, 2006; Bos & van Katwijk, 2007; Infantes *et al.*, 2009; van Katwijk *et al.*, 2010)	All	Exposed	All	<1–>100 m
6	Changing sediment size	High-density seagrass captures fine material, sediments become muddier. In small low-density patches, sediments can become more sandy (e.g. Bouma *et al.*, 2009; van Katwijk *et al.*, 2010; McGlathery *et al.*, 2012)	All	(Semi-)exposed	All	<1–>100 m
7	Sediment sulphide toxicity	High-density seagrass traps organic matter which decomposes, leading to sulphide toxicity which impairs seagrass growth (e.g. [illegible]lmer *et al.*, 2012; van der Heide *et al.*, 2012*b*)	All, but increases with temperature	Se[illegible]	[illegible]	[illegible]
8	Sediment oxygenation	[illegible]-density seagrass, or multiple seagrass species in mixed m[illegible]dows oxygenates sediments reducing sulphide [illegible]ncen[illegible]ion, thus improving sediment conditions for seagrass gro[illegible] (e.[illegible] Boru[illegible] *al.*, 2005; Mascaro *et al.*, 2009; Brodersen *et al.*, 201[illegible]	All, but increases with temperature	Se[illegible]	[illegible]	[illegible]
9	Lucinidae presence	Mutualistic fee[illegible]ck i[illegible] whic[illegible] lucinid bivalves alleviate negative feedback by cons[illegible]ing t[illegible]c s[illegible]lphide (see mechanism 6), while seagrass provides luc[illegible] [illegible] oxyg[illegible]n (van der Heide *et al.*, 2012*b*; de Fouw *et al.*, 201[illegible]	(Sub-)tropical	Se[illegible]	[illegible]	[illegible]
10	pH toxicity	Photosynthesis leads to elevated p[illegible] w[illegible]ch inh[illegible]its [illegible]grass growth (e.g. Beer *et al.*, 2006)	All	Sh[illegible]	[illegible]	[illegible]
11	Carbonate dissolution	High density of seagrass generates CO_2 by enhan[illegible]ing aerobic organic matter mineralisation, incr[illegible]sing levels of calcium carbonates and phosphates, and increasing P availability and thus increases seagrass growth (Marbà *et al.*, 2006; Burdige, Zimmerman & Hu, 2008; Long *et al.*, 2008)	(Sub-)tropical	Se[illegible]	[illegible]	[illegible]
12	Genetic diversity	Meadows with high genetic diversity and connectivity between regions show increased community-level persistence against disturbance (e.g. Williams & Heck, 2001; Hughes & Stachowicz, 2004; Procaccini, Olsen & Reusch, 2007; Reynolds, Waycott & McGlathery, 2013)	All	All	All	>1 km
13	Mesograzer habitat	Seagrass shelters mesograzers from predation, increasing epiphyte grazing, improving light availability and seagrass growth (e.g. Schanz & Asmus, 2003; Valentine & Duffy, 2006; Duffy *et al.*, 2015)	All	Semi-exp[illegible]ed to sheltered	M[illegible]otrophic to eu[illegible]ophic	~1–>100 m
14	Juvenile predator habitat	Seagrass shelters juveniles of large predators which as adults control smaller predator density, leading to more mesograzers (e.g. Valentine & Duffy, 2006; Eriksson *et al.*, 2011)	All	Semi-exposed to sheltered	Mes[illegible]o[illegible] to eutrop[illegible]ic	~1–>100 m
15	Megaherbivore-induced nutrient tolerance	High seagrass biomass attracts megagrazers (e.g. turtles, dugongs) whose grazing activities alleviate the negative effects of eutrophication by stimulating seagrass production (e.g. Christianen *et al.*, 2012)	(Sub-)tropical	Semi-exposed to sheltered	Mesotrophic to eutrophic	~1–>100 m
16	Megaherbivores overgrazing	Overgrazing by megaherbivores drives adverse feedbacks and prevents seagrass recovery. Seagrass decline increases grazing pressure on remaining meadows (e.g. Christianen *et al.*, 2014)	(Sub-)tropical	(Semi-)exposed	All	~1–>100 m
17	Sea urchins: grazing	Overgrazing of seagrass by sea urchins reduces seagrass aboveground biomass which leads to increased predation pressure on sea urchins, through the loss of shelter, leading to reduced urchins and recovery of seagrass density (e.g. Heck & Valentine, 1995)	(Sub-)tropical	All	All	~1–>100 m

17 feedbacks identified

BIOLOGICAL REVIEWS

Cambridge Philosophical Society

Biol. Rev. (2017), **92**, pp. 1521–1538. 1521

doi: 10.1111/brv.12294

The fundamental role of ecological feedback mechanisms for the adaptive management of seagrass ecosystems – a review

Paul S. Maxwell[1,†,*], Johan S. Eklöf[2], Marieke M. van Katwijk[3], Katherine R. O'Brien[1], Maricela de la Torre-Castro[4], Christoffer Boström[5], Tjeerd J. Bouma[6], Dorte Krause-Jensen[7,8], Richard K. F. Unsworth[9], Brigitta I. van Tussenbroek[3,10] and Tjisse van der Heide[11]

The feedback can be positive for seagrass

(=self-facilitation, or self-sustaining, or self-amplifying)

The feedback can be negative for seagrass

(=self-inhibiting, self-dampening)

Or both, depending on the conditions

Maxwell et al. 2017

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Dynamics

Large variability of results *Zostera noltii* transplantation in dynamic environment

Oosterschelde, The Netherlands, transplantations 2007-2012, monitoring ongoing

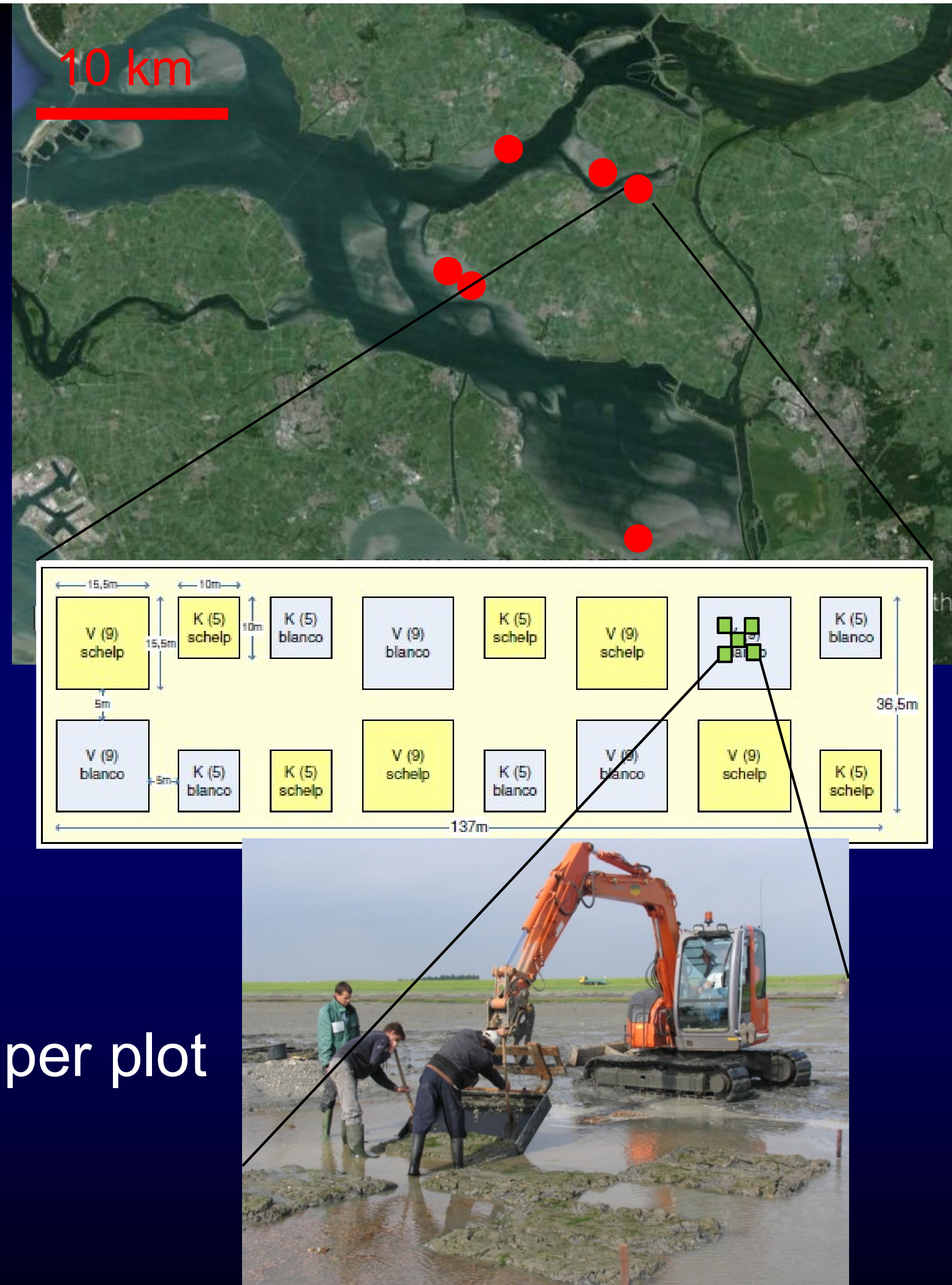
Foto's: Wim Giesen

Projectbureau Zeeweringen, Rijkswaterstaat, Radboud University Nijmegen, NIOZ-Yerseke

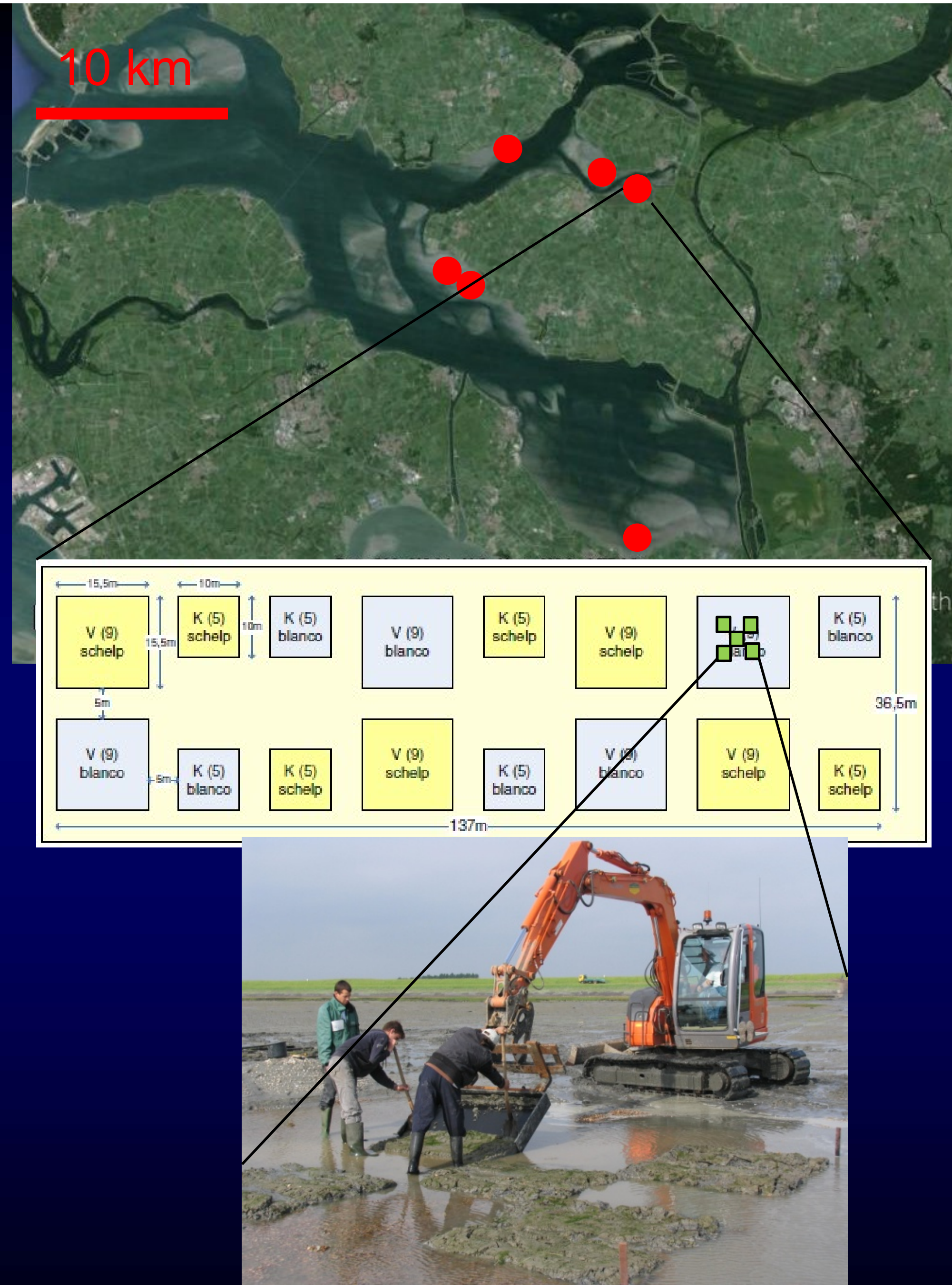
6 tidal flats

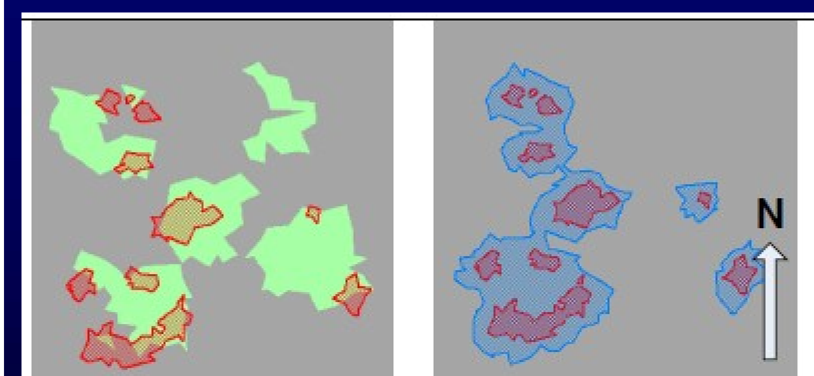
12-24 plots per tidal flat

5-9 patches per plot



Suykerbuyk, Govers, Bouma, van Katwijk et al. J.Appl.Ecol. 2016

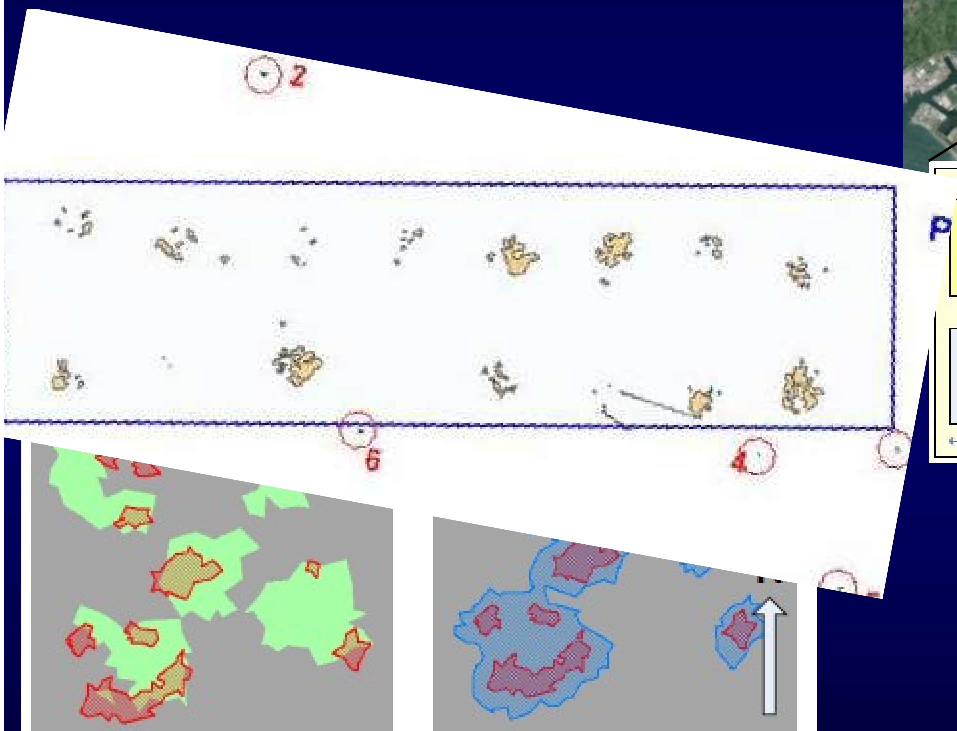


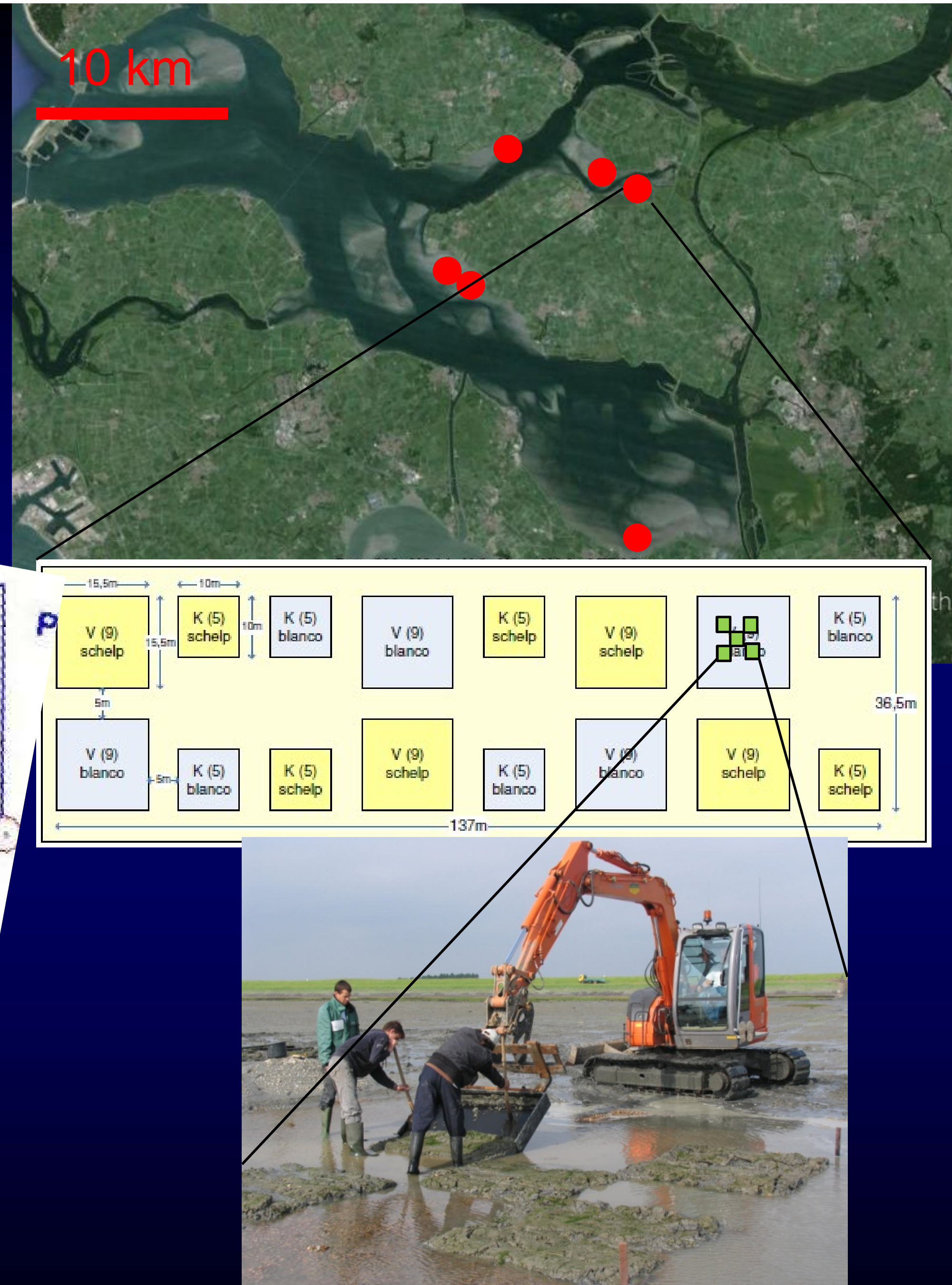


Aug08 – June09
(winter)

June09 – Aug09
(next summer)

Suykerbuyk, Govers, Bouma, van Katwijk et al. J.Appl.Ecol. 2016



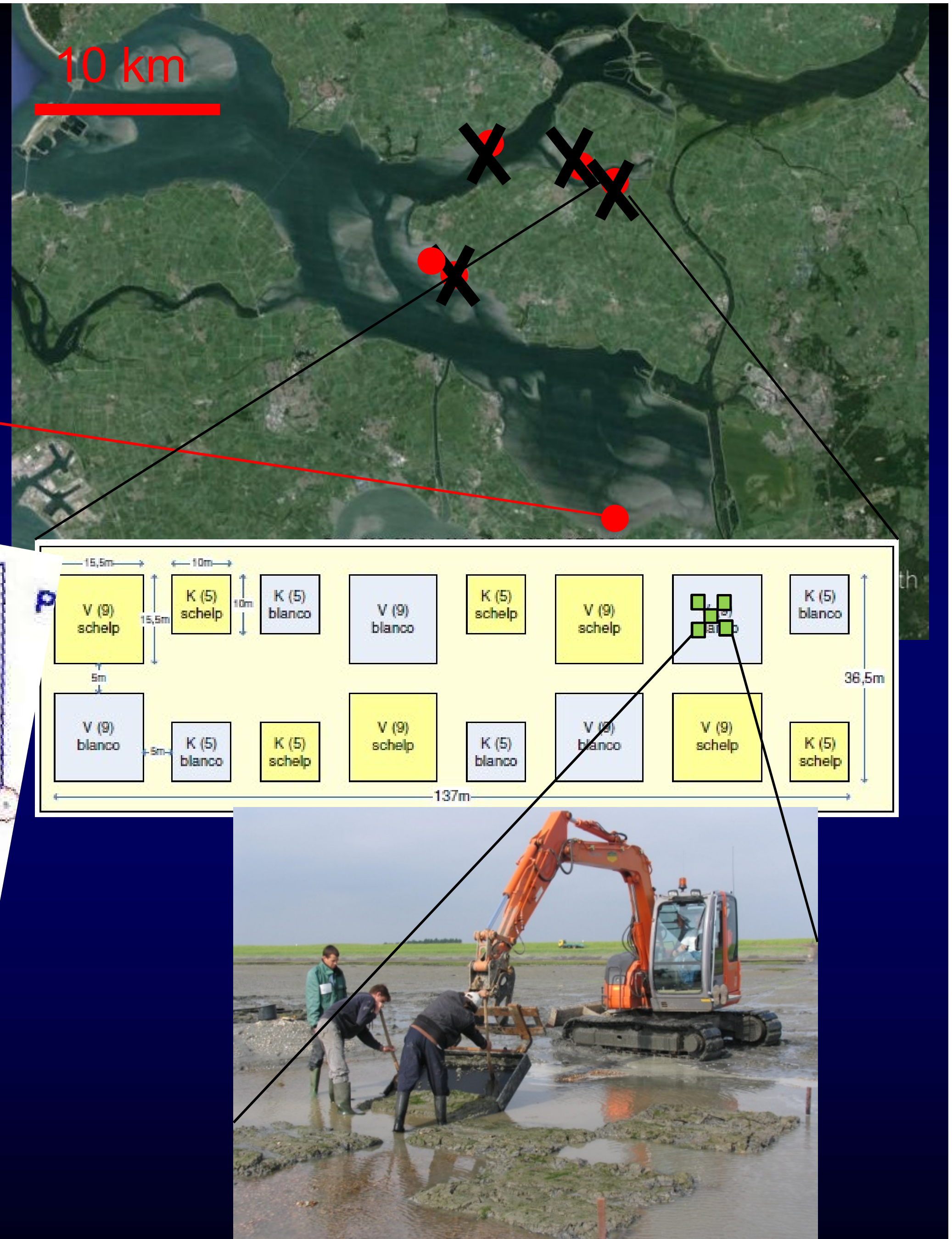


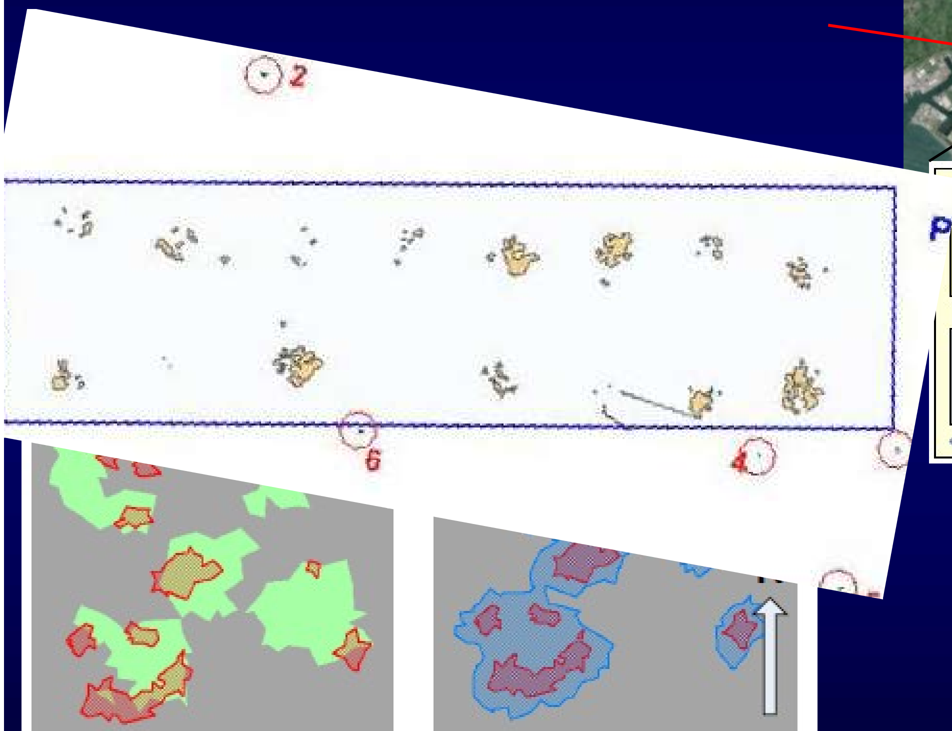
Aug08 – June09
(winter)

June09 – Aug09
(next summer)

Suykerbuyk, Govers, Bouma, van Katwijk et al. J.Appl.Ecol. 2016

2017: 1 location big success,
1 location intermediate
4 locations failure





Aug08 – June09
(winter)

June09 – Aug09
(next summer)

Suykerbuyk, Govers, Bouma, van Katwijk et al. J.Appl.Ecol. 2016

In this case, key variables to the success were: sediment dynamics (lower depth) and desiccation (upper depth)

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser
33–143, 2012
54/meps09532
Published March 8

OPEN ACCESS

Resilience of *Zostera noltii* to burial or erosion disturbances

Qiuying Han[1,2,*], Tjeerd J. Bouma[2], Fernando G. Brun[3], Wouter Suyker
Marieke M. van Katwijk[4]

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Ecosystems (2016) 19: 296–310
DOI: 10.1007/s10021-015-9932-3

ECOSYSTEMS CrossMark

Surviving in Changing Seascapes: Sediment Dynamics as Bottleneck for Long-Term Seagrass Presence

Wouter Suykerbuyk,[1,2*] Tjeerd J. Bouma,[2] Laura L. Govers,[1] Kris Giesen,[1,2] Dick J. de Jong,[3] Peter Herman,[1,2] Jan Hendriks,[1] and Marieke M. van Katwijk[1]

Submitted: Living in the intertidal; desiccation and shading reduce seagrass growth, but high salinity or population of origin have no additional effect

Wouter Suykerbuyk[1,2], Laura L. Govers [1,3,4], W. G. van Oven[1], Kris Giesen[1,2], Wim B.J.T. Giesen[1,5], Dick J. de Jong[6], Tjeerd J. Bouma[2], Marieke M. van Katwijk[1,2]

Ecological Applications, 22(4), 2012, pp. 1224–1231

Suppressing antagonistic bioengineering feedbacks doubles restoration success

Wouter Suykerbuyk,[1,2,6] Tjeerd J. Bouma,[2] Tjisse van der Heide,[3] Cornelia Faust,[2] Laura L. Govers,[1] Wim B. J. T. Giesen,[1,4] Dick J. de Jong,[5] and Marieke M. van Katwijk[1]

In this case, key variables to the success were: sediment dynamics (lower depth) and desiccation (upper depth)

Sediment dynamics and desiccation are partly unpredictable (stochastics of the wheather). These natural dynamics also make seagrass restoration success unpredictable to a certain extent…
This likely applies to many seagrass restorations worldwide!

Journal of Applied Ecology

British Ecological Society

Journal of Applied Ecology 2016, 53, 774–784 doi: 10.1111/1365-2664.12614

Unpredictability in seagrass restoration: analysing the role of positive feedback and environmental stress on *Zostera noltii* transplants

Wouter Suykerbuyk[1,2,*], Laura L. Govers[1], Tjeerd J. Bouma[2], Wim B. J. T. Giesen[1,3], Dick J. de Jong[4], Roy van de Voort[4], Kris Giesen[1], Paul T. Giesen[1] and Marieke M. van Katwijk[1]

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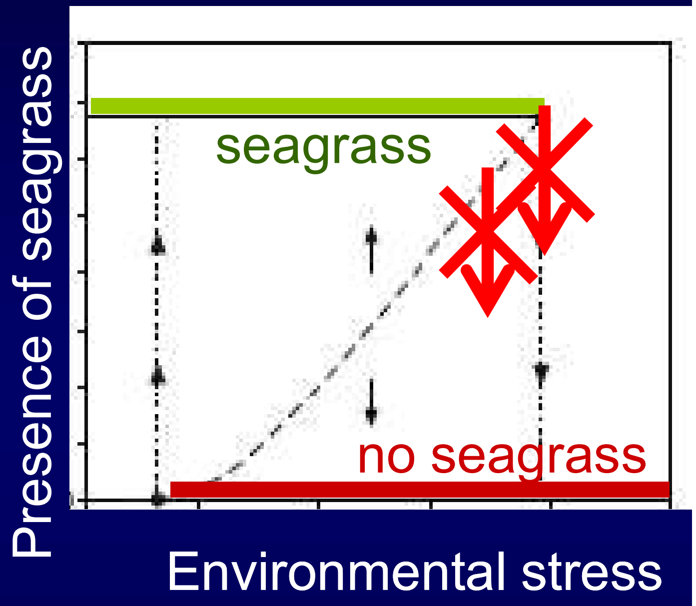
visualisation

Tipping points

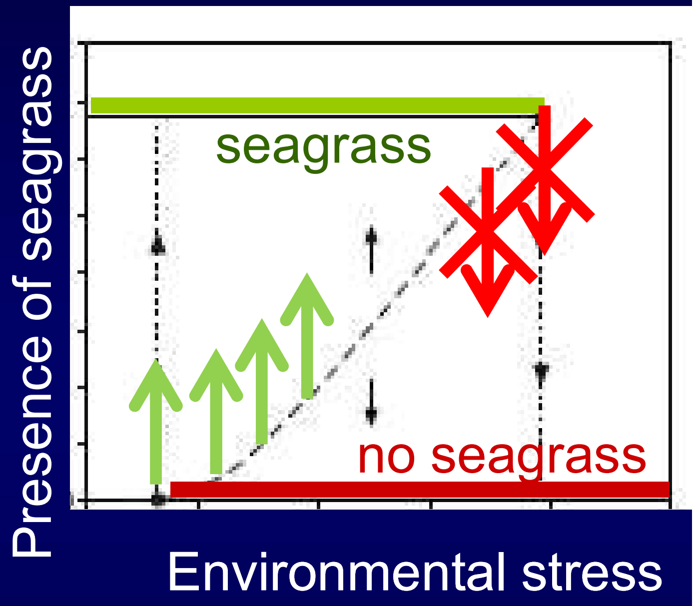
Conservation: don’t cross



Tipping points

Conservation: don't cross

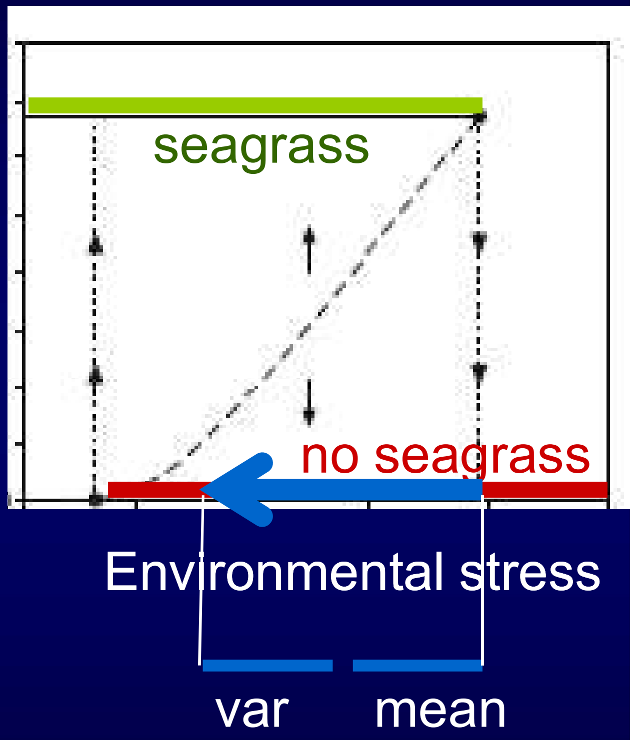
Restoration: cross



Restore: cross tipping point

Reduce environmental stress

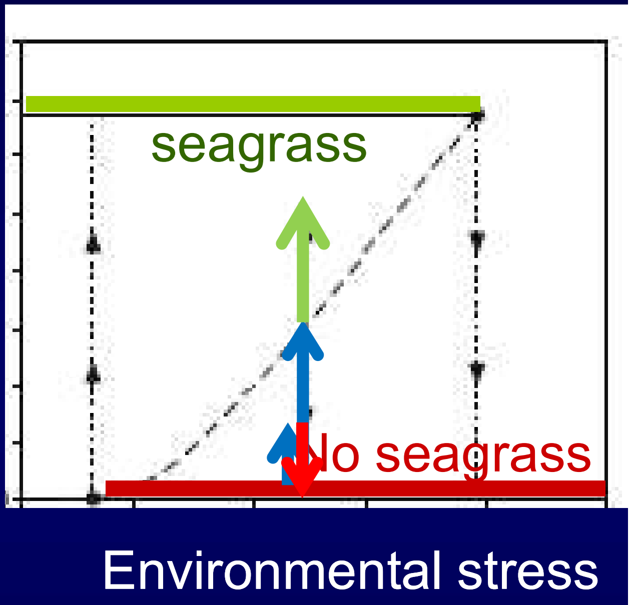
Encounter a window of opportunity in space or time



Restore: cross tipping point

Reintroduce seagrass

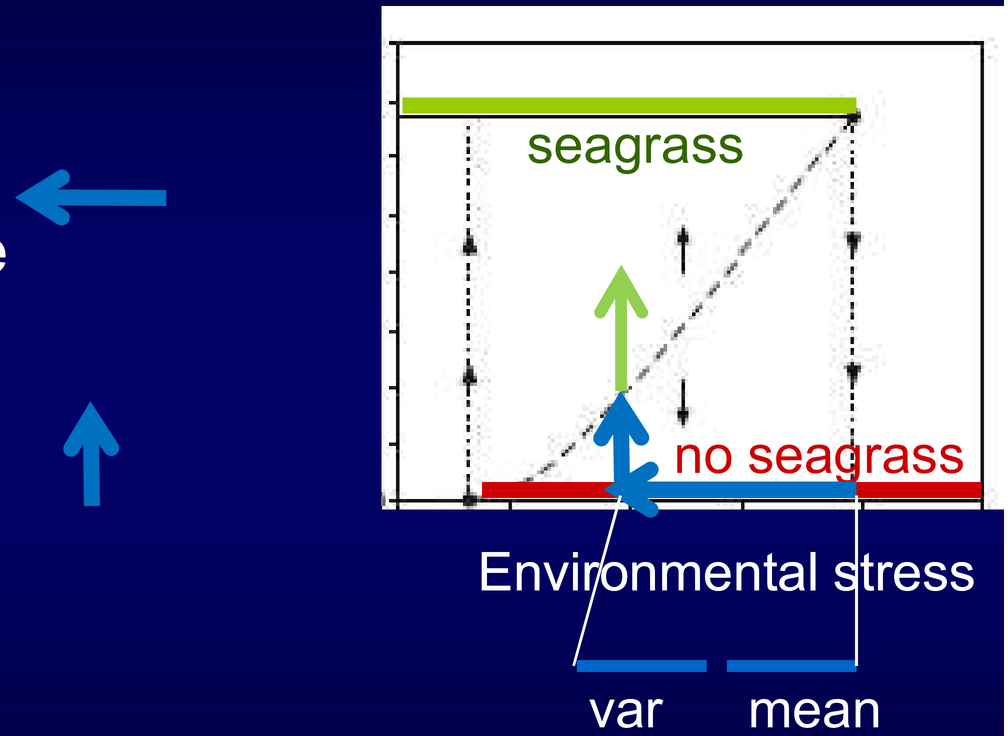
- Reach critical threshold to initiate self-sustaining processes



Restore: scale is important

Larger scale increases the likelyhood to:

1. Encounter a window of opportunity in space or time (spread risks)
2. Reach critical threshold to initiate self-sustaining processes



van Katwijk et al. 2009

Take home message 1 (2):

For restoration

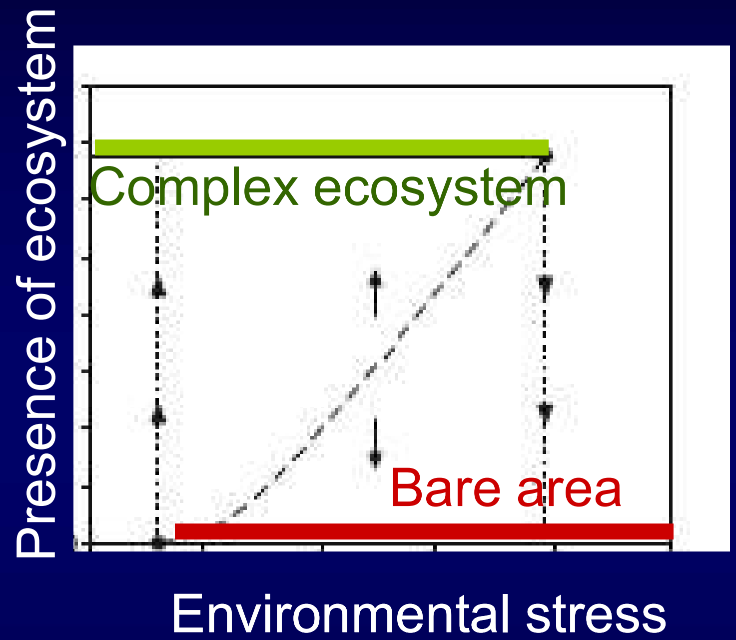
Use large scale and take time, BUT:

- Causes of loss prior to restoration should be (largely) recovered
- Chances should be maximized (e.g., additional temporal or local stress reduction)

…because if a large scale restoration fails, you lose more donor material, finances and goodwill

Take home message 2 (2):

Non-linear dynamics: if a complex ecosystem collapses, it may be very difficult to restore it!



Conservation is more efficient

Questions?

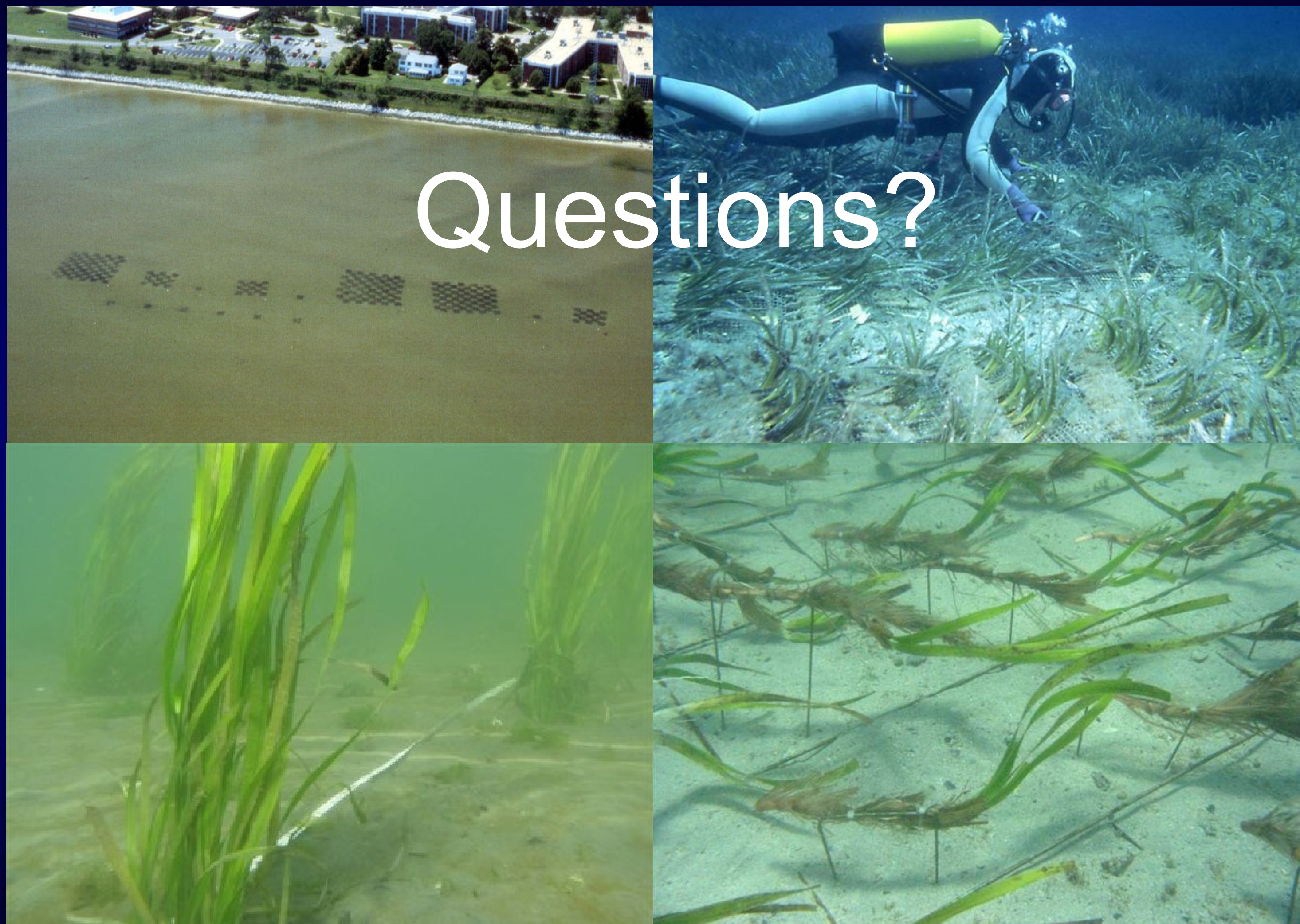
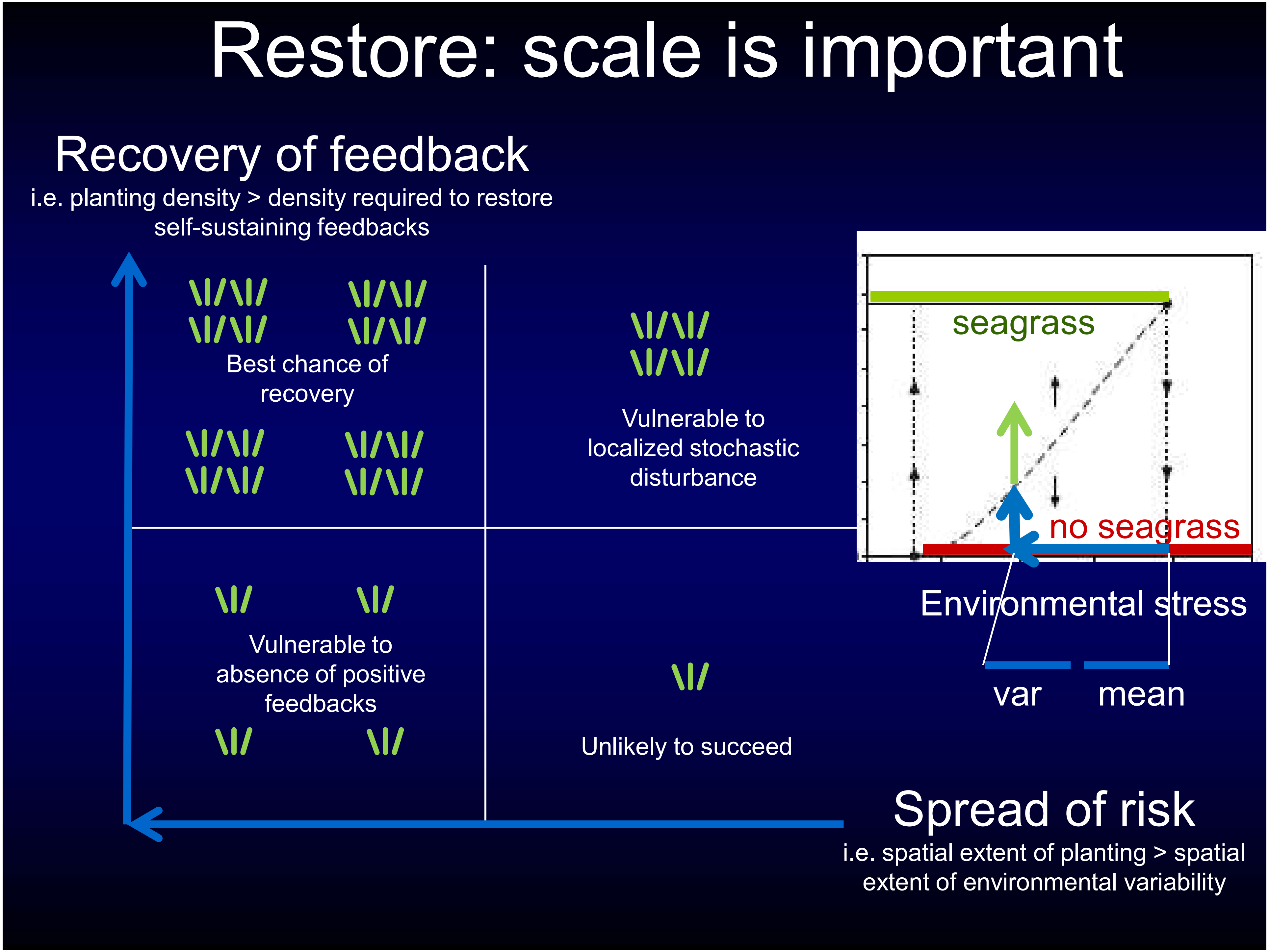
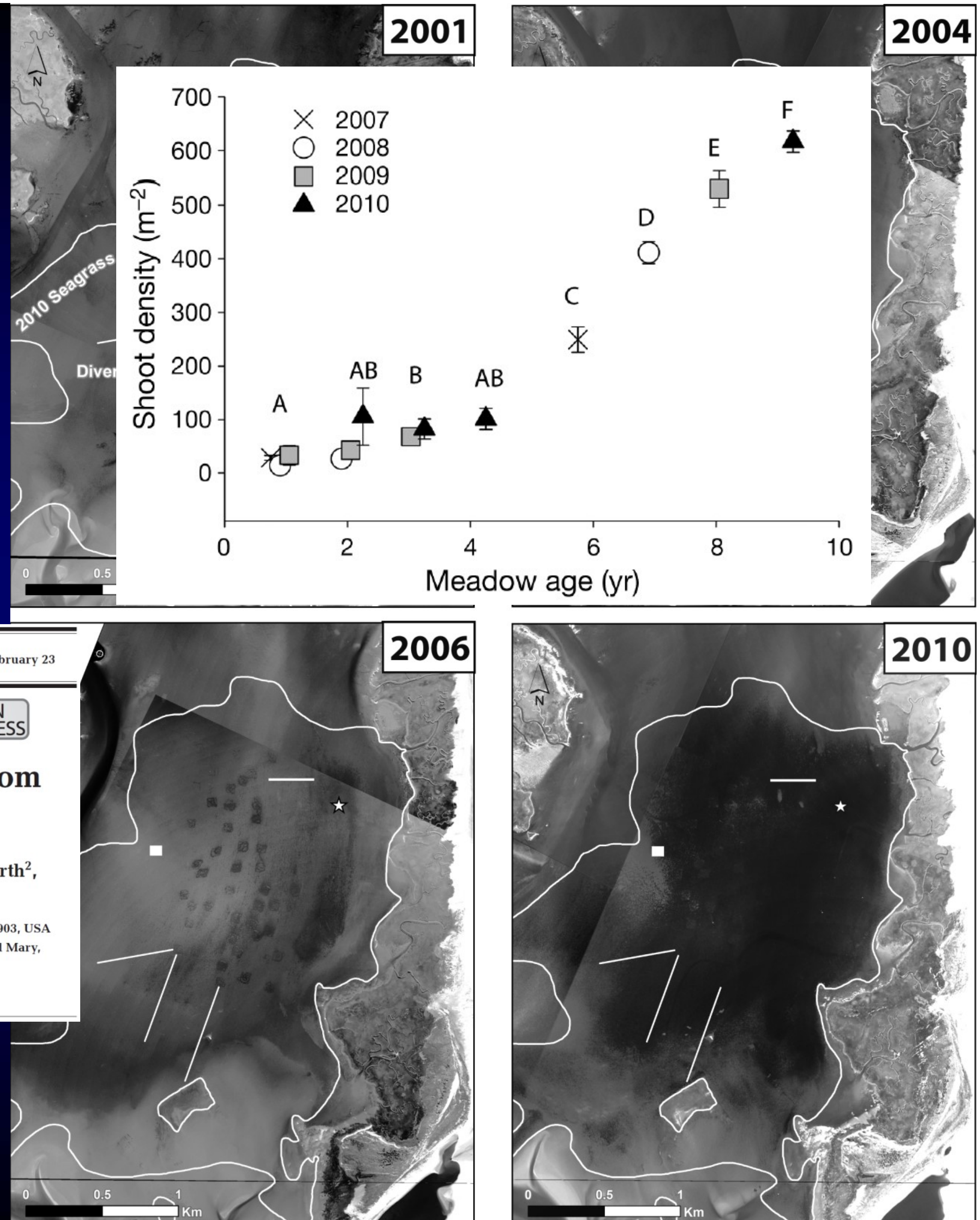


Photo courtesy, clockwise: Bob Orth, Alexandre Meinesz, Jennifer Verduin, Cynthia Durance


Restore: scale is important
Recovery of feedback
i.e. planting density > density required to restore self-sustaining feedbacks
Best chance of recovery
Vulnerable to localized stochastic disturbance
Vulnerable to absence of positive feedbacks
Unlikely to succeed
seagrass
no seagrass
Environmental stress
var
mean
Spread of risk
i.e. spatial extent of planting > spatial extent of environmental variability

Density-related expansion (*Z. marina*)



Vol. 448: 209–221, 2012
doi: 10.3354/meps09574

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published February 23

Contribution to the Theme Section 'Eelgrass recovery'

OPEN ACCESS

Recovery trajectories during state change from bare sediment to eelgrass dominance

Karen J. McGlathery[1,*], Laura K. Reynolds[1], Luke W. Cole[1], Robert J. Orth[2], Scott R. Marion[2], Arthur Schwarzschild[1]

[1]Department of Environmental Sciences, University of Virginia, PO Box 400123, Charlottesville, Virginia 22903, USA

[2]Virginia Institute of Marine Science, School of Marine Science, 1208 Greate Road, College of William and Mary, Gloucester Point, Virginia 23062, USA

Orth et al. 2012

Variation in feedback processes across environmental gradients

A. nutrients

B. hydrodynamics

C. depth

BIOLOGICAL REVIEWS

Cambridge Philosophical Society

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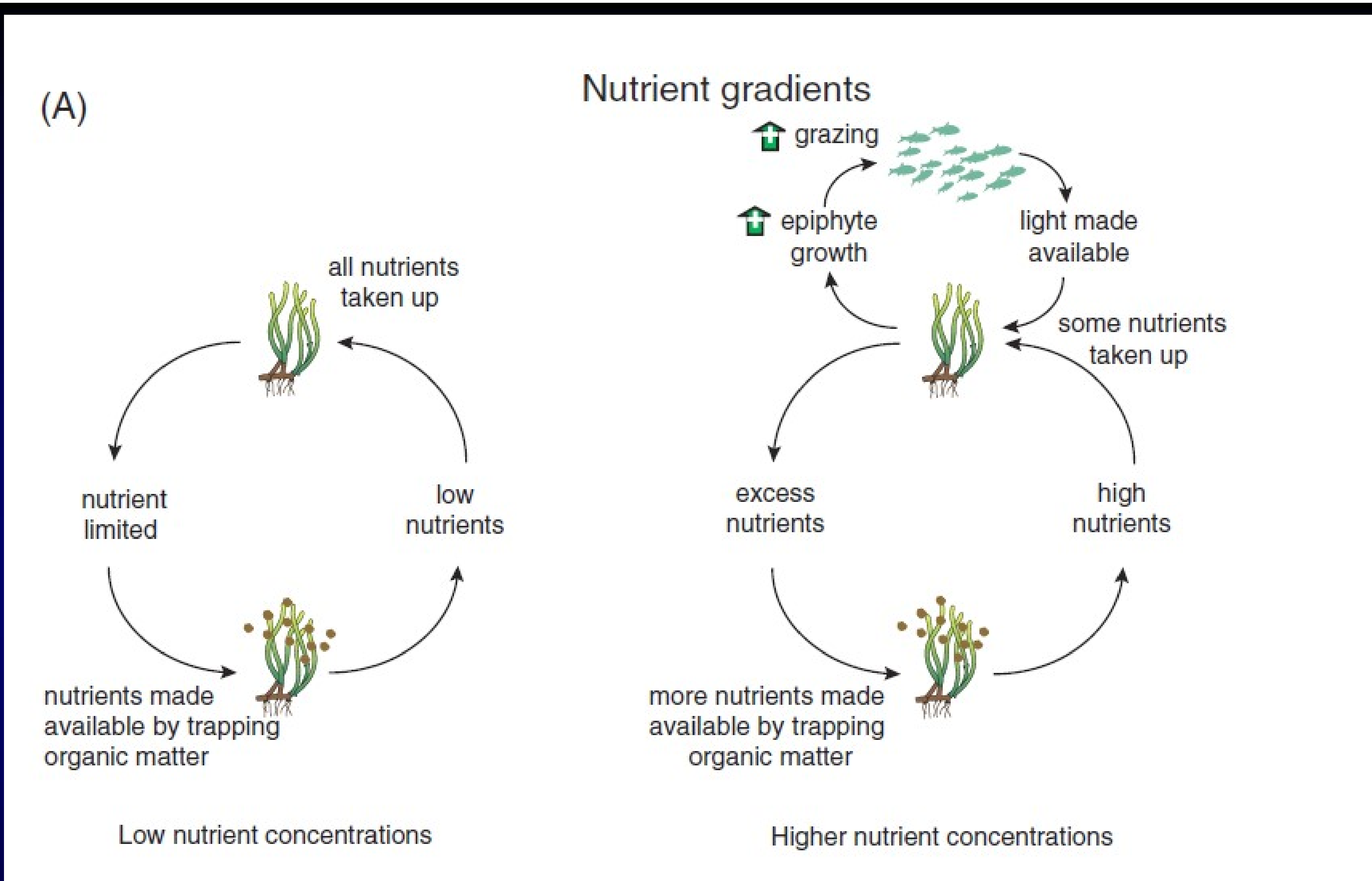
doi: 10.1111/brv.12294

The fundamental role of ecological feedback mechanisms for the adaptive management of seagrass ecosystems – a review

Paul S. Maxwell[1,†,*], Johan S. Eklöf[2], Marieke M. van Katwijk[3], Katherine R. O'Brien[1], Maricela de la Torre-Castro[4], Christoffer Boström[5], Tjeerd J. Bouma[6], Dorte Krause-Jensen[7,8], Richard K. F. Unsworth[9], Brigitta I. van Tussenbroek[3,10] and Tjisse van der Heide[11]



When nutrient limited, seagrass meadows quickly sequester any nutrients from the water column, lowering their availability to seagrass competitors. When the system is eutrophied, more nutrients are available for algal growth. Excess algal growth is controlled by algal grazers, which in turn have a positive effect on seagrass growth.

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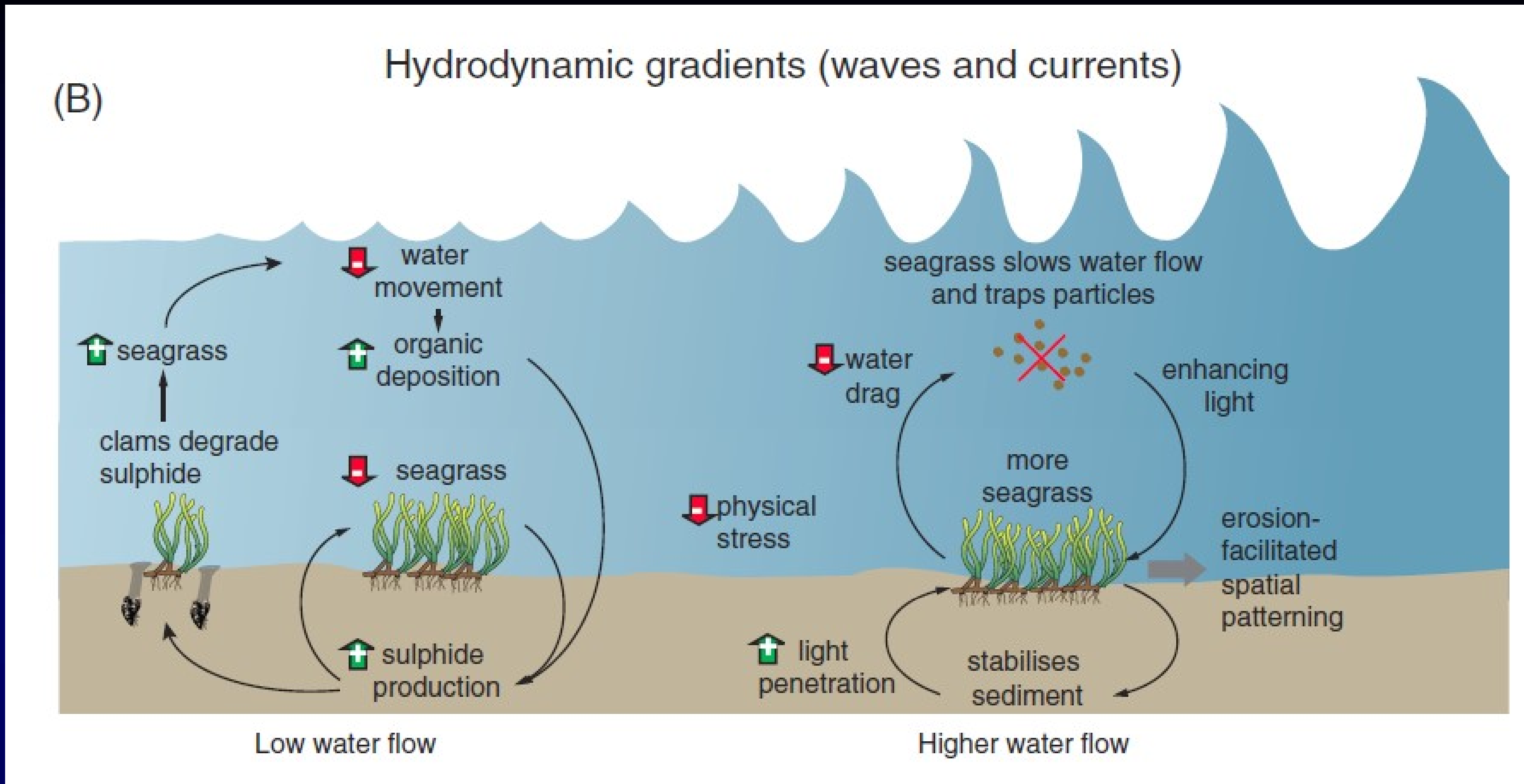

Changes to the hydrodynamics of the meadow can affect sediment toxicity and stability, which in turn affects seagrass persistence. + (Green) symbols indicate an increase and − (red) symbols indicate a decrease in levels.

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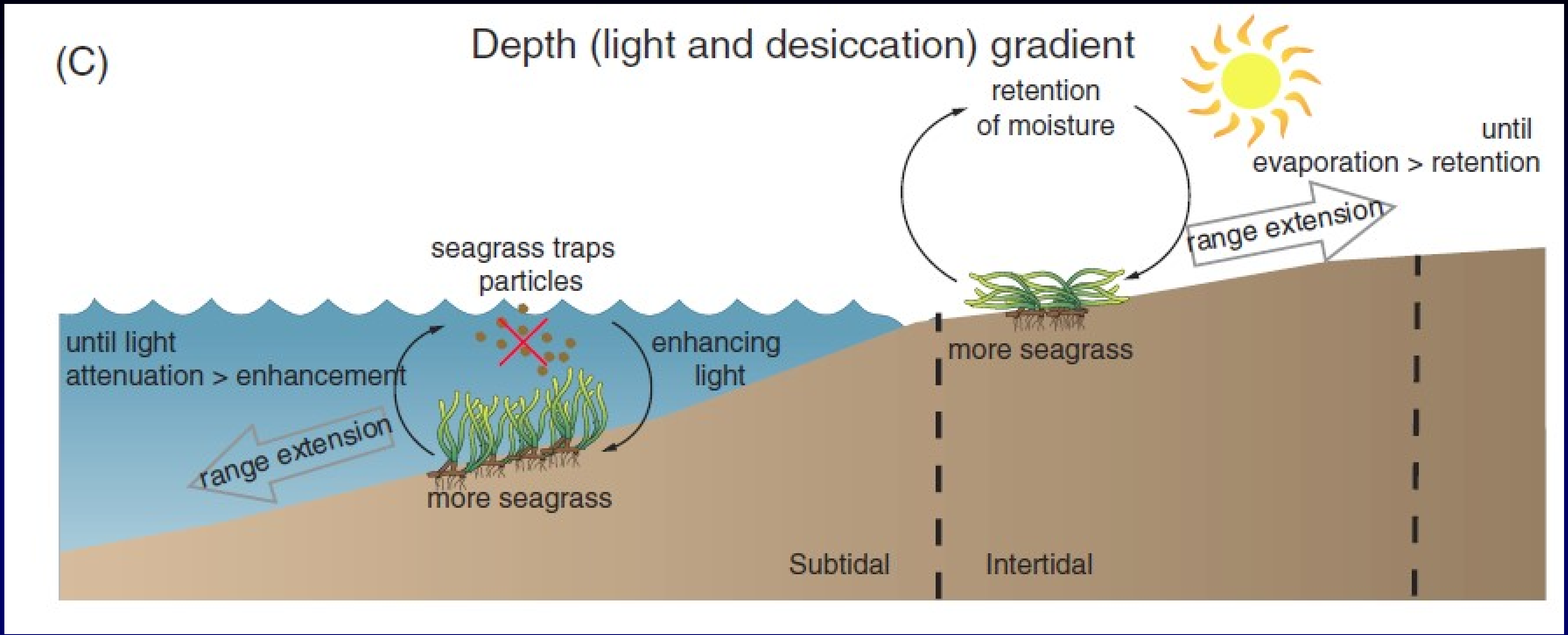

The ability of seagrass meadows to trap particles and improve light varies along the depth gradient.

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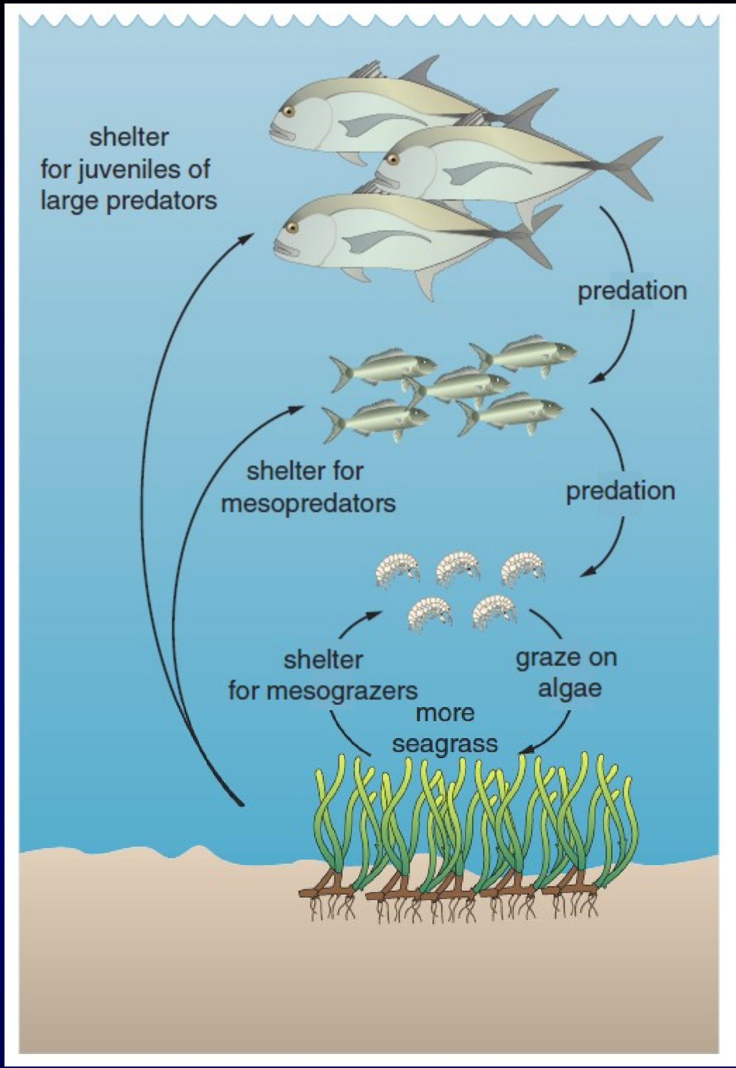

Interacting trophic cascades and non-trophic interactions causing two intertwined feedbacks.

In the first feedback, seagrass is facilitated by mesograzers through grazing of macroalgae and/or epiphytes growing on the seagrass leaves, while seagrass facilitates mesograzers by providing shelter. A second positive feedback occurs when large predatory fish indirectly facilitate seagrasses through mesopredator control, while seagrass facilitates large predatory fish by providing shelter (e.g. nursery habitat). In the trophic cascade, smaller predatory fish are predated by the larger fish, alleviating predation pressure on mesograzers, indirectly facilitating seagrasses through enhanced grazing on macroalgae and epiphytes.

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Table 1. Feedback mechanisms known to occur in seagrass ecosystems (for further details see online Appendix S1). Green indicates self-amplifying feedbacks, whereby increase in seagrass density generates conditions which promote further increase in density, until carrying capacity is reached or poor environmental conditions overwhelm the feedback. Red indicates self-dampening feedbacks, whereby increase in seagrass presence creates conditions adverse to seagrass, such that seagrass subsequently declines. Yellow indicates feedbacks, which can be both self-amplifying and self-dampening.

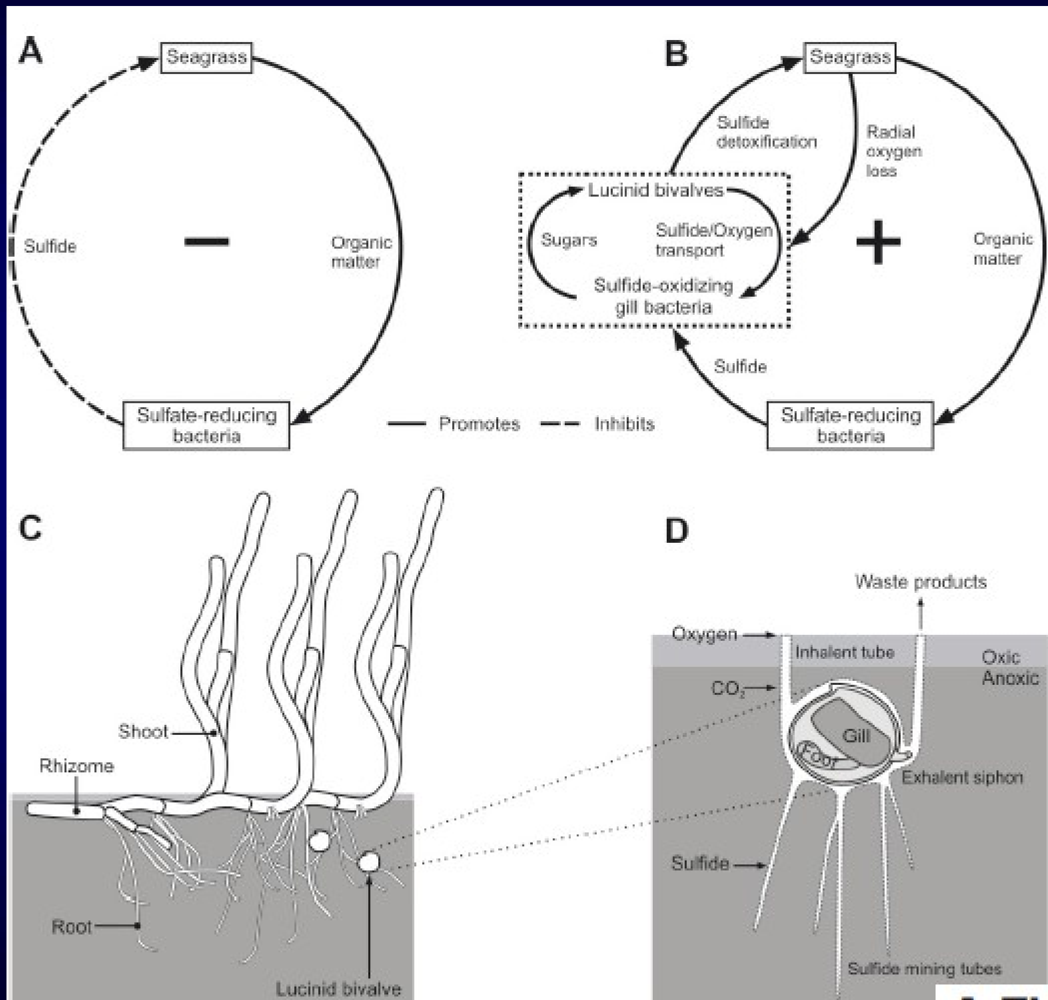
	Feedback name	Feedback description	Operates under following conditions and scale:			
			Climate	Hydrodynamics	Nutrient state	Spatial scale
1	Sediment trapping	Seagrass traps water column sediment, improving water clarity, seagrass growth, and seagrass depth range (e.g. de Boer, 2007; Carr *et al.*, 2010, 2012*a*,*b*; Hansen & Reidenbach, 2012; Lawson *et al.*, 2012).	All	(Semi-)exposed	All	∼1–>100 m
2	Erosion-facilitated spatial patterning	Interacting positive and negative feedbacks of erosion/sediment trapping acting at small and larger scales lead to self-organised pattern (e.g. van der Heide *et al.*, 2010*a*)	Observed in temperate ecosystems	Exposed	All	∼1–∼10 m
3	Reduced intertidal desiccation	High-density seagrass reduces desiccation in intertidal areas, creating more favourable seagrass growth conditions higher in intertidal zone (e.g. Fox, 1996; Tsai *et al.*, 2010)	All, but drought stress increases with temperature	All	All	∼1–∼10 m
4	Ammonium uptake	High-density seagrass takes up more ammonium, reducing toxicity, favouring seagrass growth (e.g. McGlathery *et al.*, 2007, 2012; van der Heide *et al.*, 2010*b*; Cole & McGlathery, 2012)	All	Sheltered	Eutrophic	∼10–>100 m
5	Hydrodynamic disruption	High-density seagrass reduces near-bed water currents, reducing physical stress on seagrass plants and stabilising sediments. Small seagrass patches or meadow edges may increase turbulence locally resulting in erosion and scouring (e.g. Fonseca & Koehl, 2006; Bos & van Katwijk, 2007; Infantes *et al.*, 2009; van Katwijk *et al.*, 2010)	All	Exposed	All	<1–>100 m
6	Changing sediment size	High-density seagrass captures fine material, sediments become muddier. In small low-density patches, sediments can become more sandy (e.g. Bouma *et al.*, 2009; van Katwijk *et al.*, 2010; McGlathery *et al.*, 2012)	All	(Semi-)exposed	All	<1–>100 m
7	Sediment sulphide toxicity	High-density seagrass traps organic matter which decomposes, leading to sulphide toxicity which impairs seagrass growth (e.g. Folmer *et al.*, 2012; van der Heide *et al.*, 2012*b*)	All, but increases with temperature	Semi-exposed to sheltered	Mesotrophic to eutrophic	∼1–10 mm
8	Sediment oxygenation	High-density seagrass, or multiple seagrass species in mixed meadows, oxygenates sediments reducing sulphide concentration, thus improving sediment conditions for seagrass growth (e.g. Borum *et al.*, 2005; Mascaro *et al.*, 2009; Brodersen *et al.*, 2014)	All, but increases with temperature	Semi-exposed to sheltered	Mesotrophic to eutrophic	∼1–10 mm
9	Lucinidae presence	Mutualistic feedback in which lucinid bivalves alleviate negative feedback by consuming toxic sulphide (see mechanism 6), while seagrass provides lucinids with oxygen (van der Heide *et al.*, 2012*b*; de Fouw *et al.*, 2016)	(Sub-)tropical	Semi-exposed to sheltered	Mesotrophic to eutrophic	∼1–10 mm
10	pH toxicity	Photosynthesis leads to elevated pH which inhibits seagrass growth (e.g. Beer *et al.*, 2006)	All	Sheltered	All	∼1–>100 m

Table 1. continued

	Feedback name	Feedback description	Operates under following conditions and scale:			
			Climate	Hydrodynamics	Nutrient state	Spatial scale
11	Carbonate dissolution	High density of seagrass generates CO_2 by enhancing aerobic organic matter mineralisation, increasing levels of calcium carbonates and phosphates, and increasing P availability and thus increases seagrass growth (Marbà *et al.*, 2006; Burdige, Zimmerman & Hu, 2008; Long *et al.*, 2008)	(Sub-)tropical	Semi-exposed to sheltered	Oligotrophic	~1–10 mm
12	Genetic diversity	Meadows with high genetic diversity and connectivity between regions show increased community-level persistence against disturbance (e.g. Williams & Heck, 2001; Hughes & Stachowicz, 2004; Procaccini, Olsen & Reusch, 2007; Reynolds, Waycott & McGlathery, 2013)	All	All	All	>1 km
13	Mesograzer habitat	Seagrass shelters mesograzers from predation, increasing epiphyte grazing, improving light availability and seagrass growth (e.g. Schanz & Asmus, 2003; Valentine & Duffy, 2006; Duffy *et al.*, 2015)	All	Semi-exposed to sheltered	Mesotrophic to eutrophic	~1–>100 m
14	Juvenile predator habitat	Seagrass shelters juveniles of large predators which as adults control smaller predator density, leading to more mesograzers (e.g. Valentine & Duffy, 2006; Eriksson *et al.*, 2011)	All	Semi-exposed to sheltered	Mesotrophic to eutrophic	~1–>100 m
15	Megaherbivore-induced nutrient tolerance	High seagrass biomass attracts megagrazers (e.g. turtles, dugongs) whose grazing activities alleviate the negative effects of eutrophication by stimulating seagrass production (e.g. Christianen *et al.*, 2012)	(Sub-)tropical	Semi-exposed to sheltered	Mesotrophic to eutrophic	~1–>100 m
16	Megaherbivores overgrazing	Overgrazing by megaherbivores drives adverse feedbacks and prevents seagrass recovery. Seagrass decline increases grazing pressure on remaining meadows (e.g. Christianen *et al.*, 2014)	(Sub-)tropical	(Semi-)exposed	All	~1–>100 m
17	Sea urchins: grazing	Overgrazing of seagrass by sea urchins reduces seagrass aboveground biomass which leads to increased predation pressure on sea urchins, through the loss of shelter, leading to reduced urchins and recovery of seagrass density (e.g. Heck & Valentine, 1995)	(Sub-)tropical	All	All	~1–>100 m

Feedback Lucinidae clams

three-stage symbiosis



Hidden workers. Tiny clams living in the roots of seagrass help keep the sediment a healthy environment.

Science 2012

A Three-Stage Symbiosis Forms the Foundation of Seagrass Ecosystems

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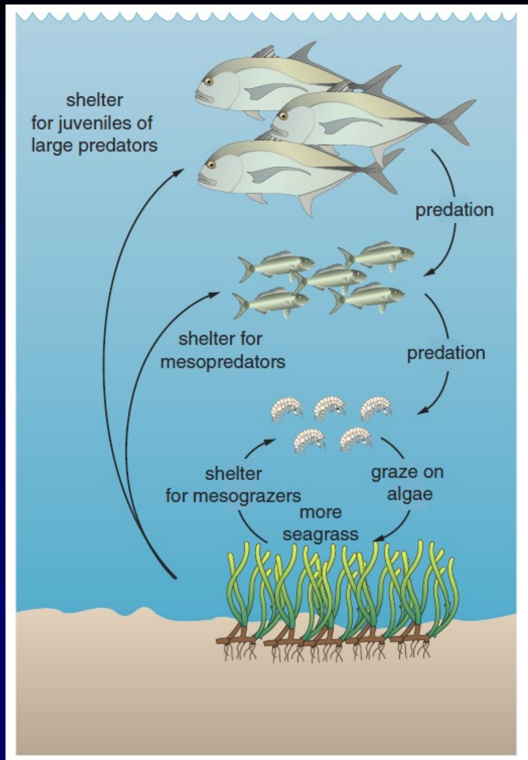

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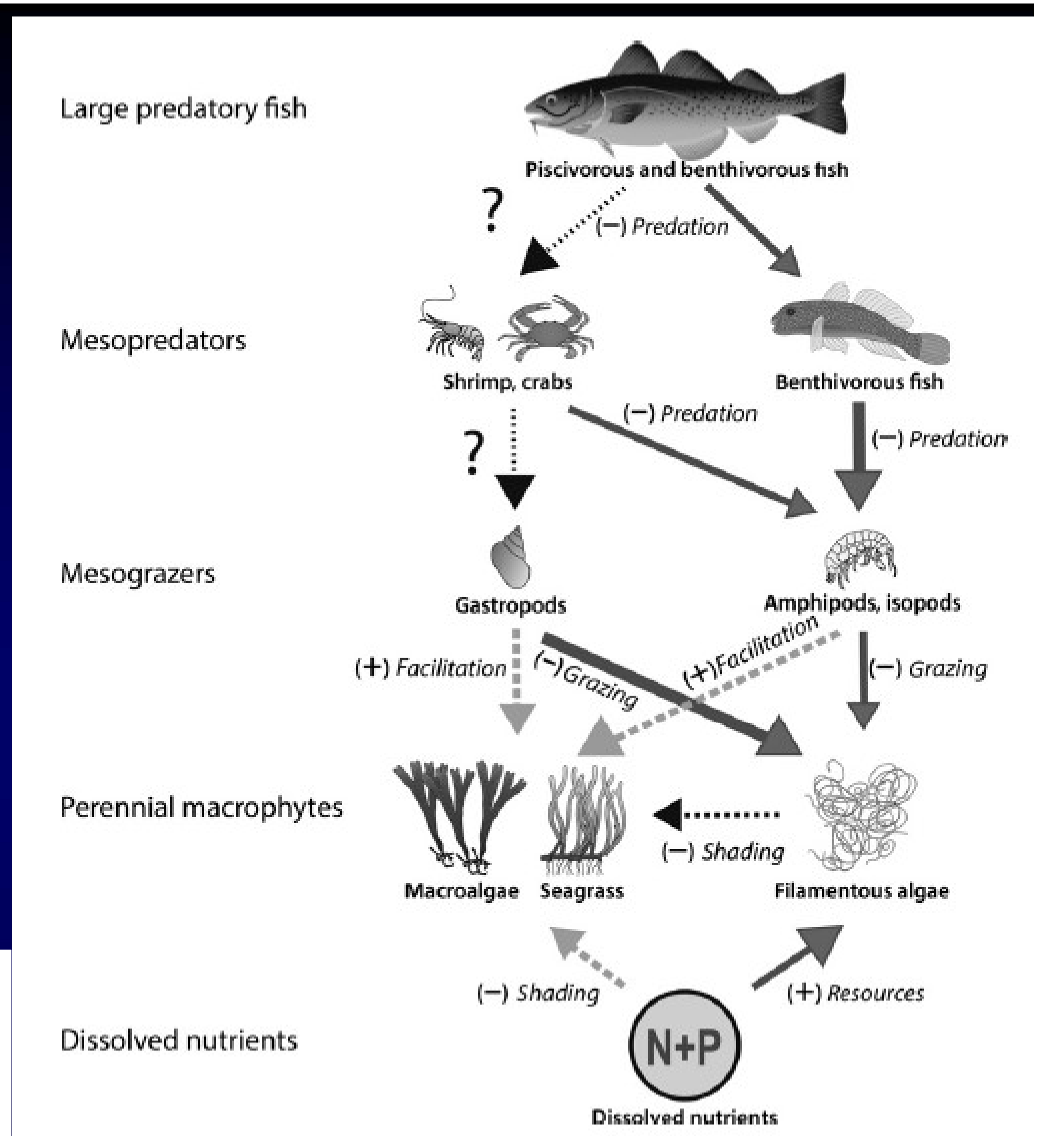
Nutrients

Fig. 5. Conceptualized figure of food web interactions in coastal *Fucus*/*Zostera* food webs. The thickness of the arrow is proportional to interaction strength (*LRR*). Darker solid grey arrows indicate direct effects, and hatched lighter arrows indicate indirect effects. Dotted black arrows indicate missing estimates of the interaction strength. Text in italics describes the type of interaction (e.g. predation), and (+/−) the sign of the effect on the receiving functional group. Symbols courtesy of the Integration and Application Network (IAN).



Example of temperate seagrass and brown macroalgae

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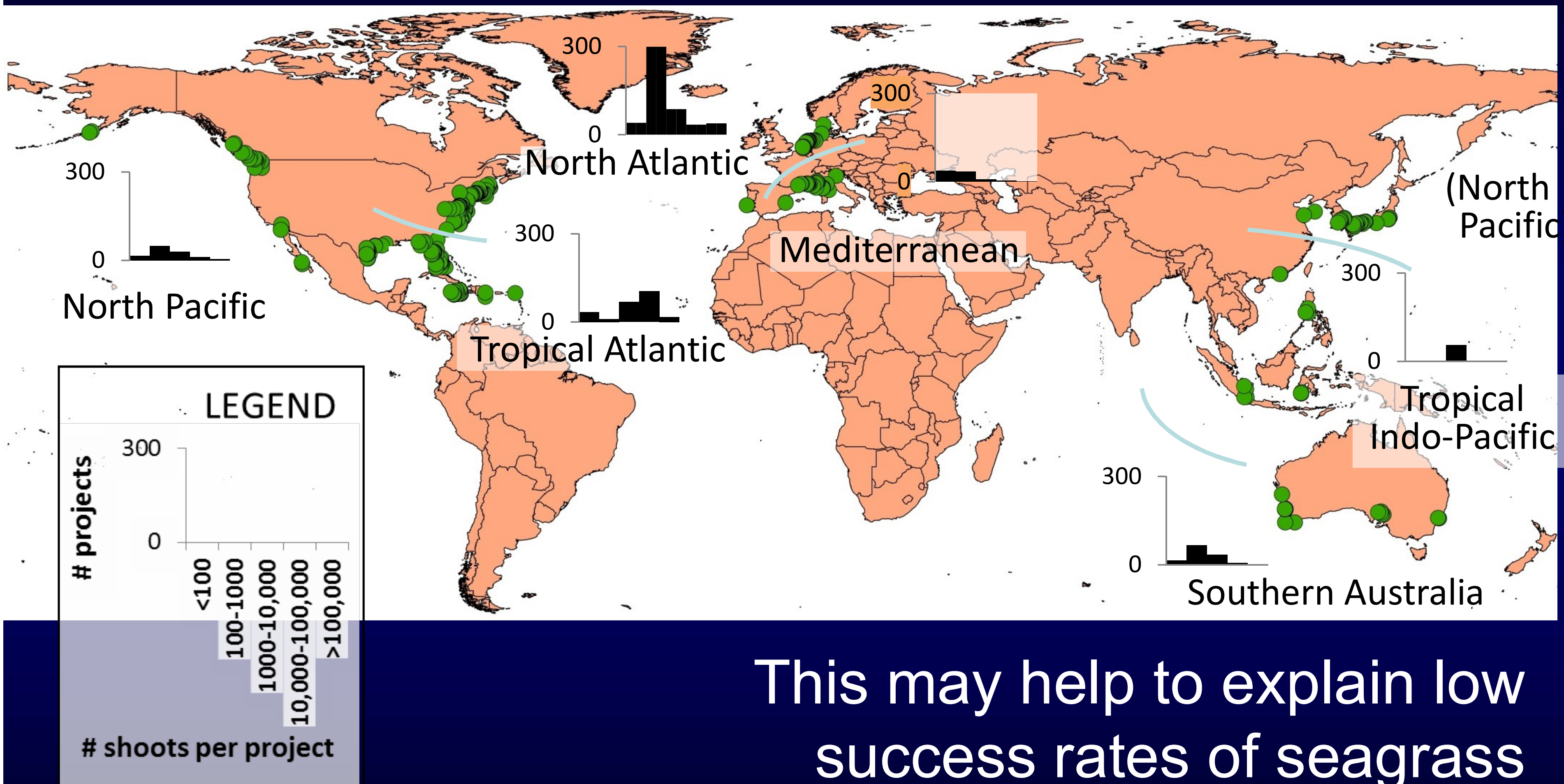
Initial planting scales employed



This may help to explain low success rates of seagrass restoration