International Workshop on Eutrophication: Synthesis of knowledge

Eutrophication trends in coastal lagoons in the Po river Delta and along the Northern Adriatic coast under river runoff influence

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Sacca di Goro and Po di Goro – Po River Delta (Photo by Amministrazione Provinciale di Ferrara)

Outline

- Recent evolution: eutrophication & macroalgal blooms; key role of benthic vegetation
- Causes of eutrophication: river runoff, nutrient loadings, lagoon (over)exploitation, tourism. An example from the Po river.
- The Venice lagoon: pressures and threats, macroalgal blooms, oligotrophication. The impact of urban areas in the lagoon.
- The Sacca di Goro lagoon: shellfish farming vs eutrophication. Macroalgae and clams: a labirynth of biogechemical and ecological interactions
- Perspectives: oligotrophication? More exploitation? Climate change?

EU projects on coastal lagoons in the North Adriatic coast

1. Studies of N- and P- cycles and eutrophication in the deltas of the rivers Ebro, Po and Rhone, EV4V (1989-92); coord. H. Golterman

2. Coastal lagoon eutrophication and anaerobic processes (CLEAN), EV5V (1993-94);coord. P. Caumette

3. Comparative studies into the mechanisms and dynamics of the impact of marine Eutrophication on benthic Macrophytes in different European coastal waters (EUMAC), MAS2 (1994-95); coord. W. Schramm

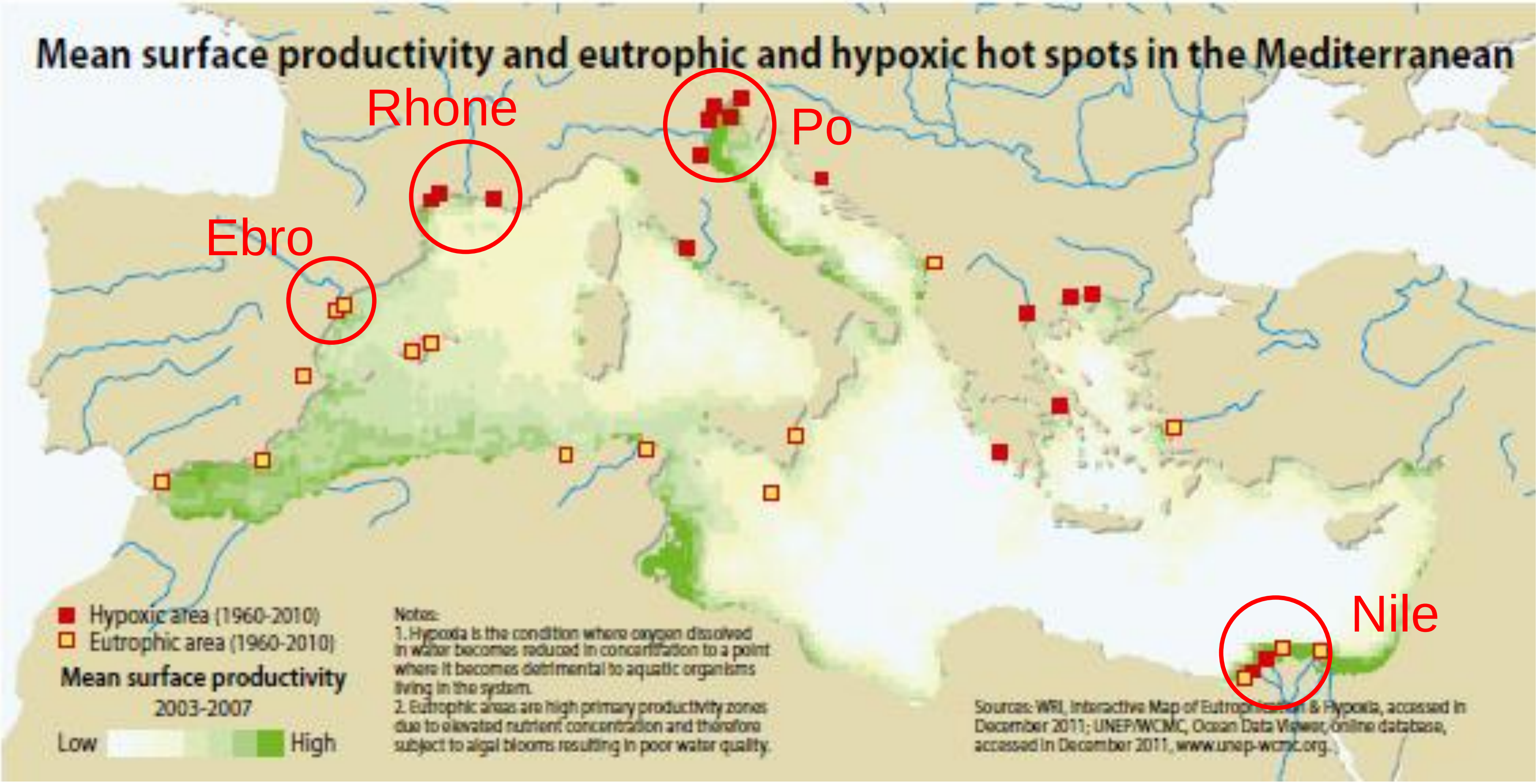
4. The role of buffering capacities in stabilising coastal lagoon ecosystems (ROBUST), ENV4 (1996-99); coord. R. de Wit

5. Nitrogen cycling in coastal ecosystems (NICE), MAS3 (1996-99); coord. T. Dalsgard

6. Development of an Information Technology Tool for the Management of European Southern Lagoons under the influence of river-basin runoff (DITTY) FP6 (2003-2006); coord. T. Do Chi

7. AWARE: How to achieve sustainable water ecosystems management connecting research, people and policy makers in Europe – coordinated action, FP7 (2009-2012); coord. C. Sessa

8. Coastal lagoons were also key topics in the LOICZ (Land Ocean Interaction in Coastal Zone) programme, an IGBP initiative



Mean annual water discharge ($km^3\ y^{-1}$)	
Nile	89,2
Rhone	57,4
Po	46,7
Ebro	13,4

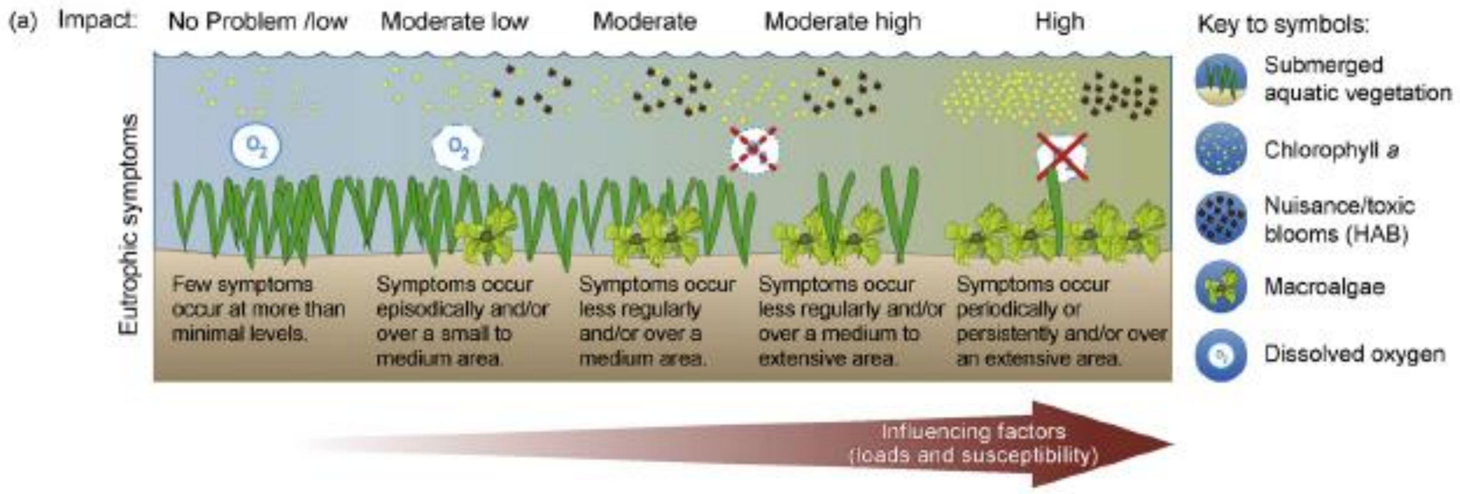
River runoff influence in the Mediterranean Sea

UNEP-MAP, 2012. State of the Mediterranean marine and coastal environment.

benthic vegetation is a key biological element

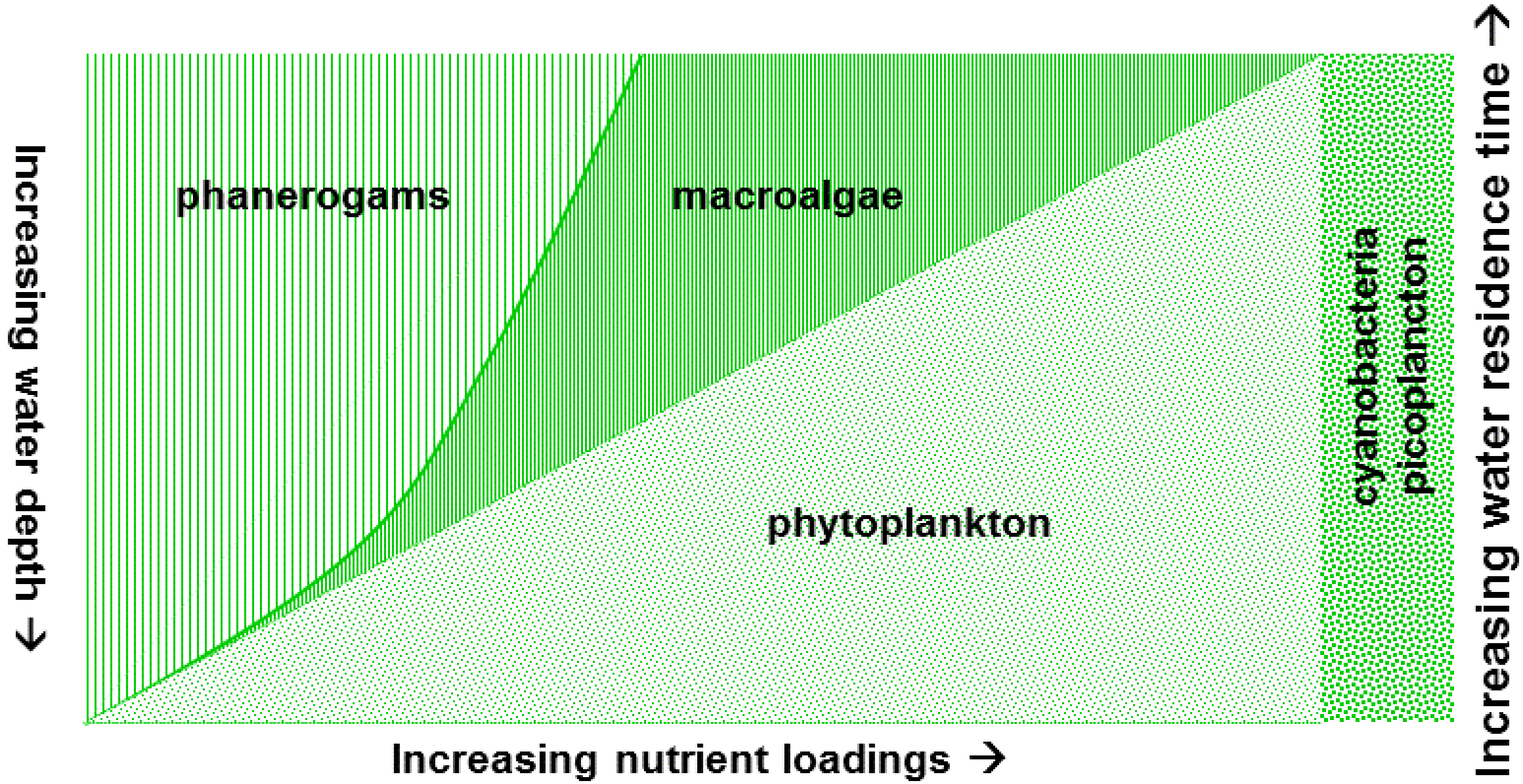
Conceptual representation of the succession of aquatic vegetation along an increasing eutrophication gradient according to 1: Nienhuis, 1992, Vie et Milieu; 2: Valiela et al., (1997) L&O; Dahlgreen and Kautsky, 2004, Hydrobiologia; 3: Schramm (1999), Aquatic Botany; 4: Viaroli et al. (2008), Aquatic Conservation

Succession phases and conditions (pristine → altered)				Ref
phanerogams	phanerogams+epiphytes	macroalgae+phytoplankton		1
seagrasses		macroalgae	phytoplankton	2, 3
perennial benthic macrophytes	macrophytes+ fast growing epiphytes	free floating macroalgae+phytoplankton	Phytoplankton	4



Bricker et al., 2008, Harmful Algae 8: 21-32

The system is multivariate with non-liner behaviour



In nutrient poor, well-flushed and shallow waters phanerogams take advantage of nutrient supply from sediment. Long water residence times favour macroalgae and phytoplankton. Given a certain water residence time, the succession from perennial benthic species to macroalgae and phytoplankton seems mainly caused by nutrient loadings (modified from Valiela et al., 1997, L&O 42; Dahlgreen & Kautsky, 2004, Hydrobiologia 514).

Main community traits and biogeochemical features of different primary producer communities

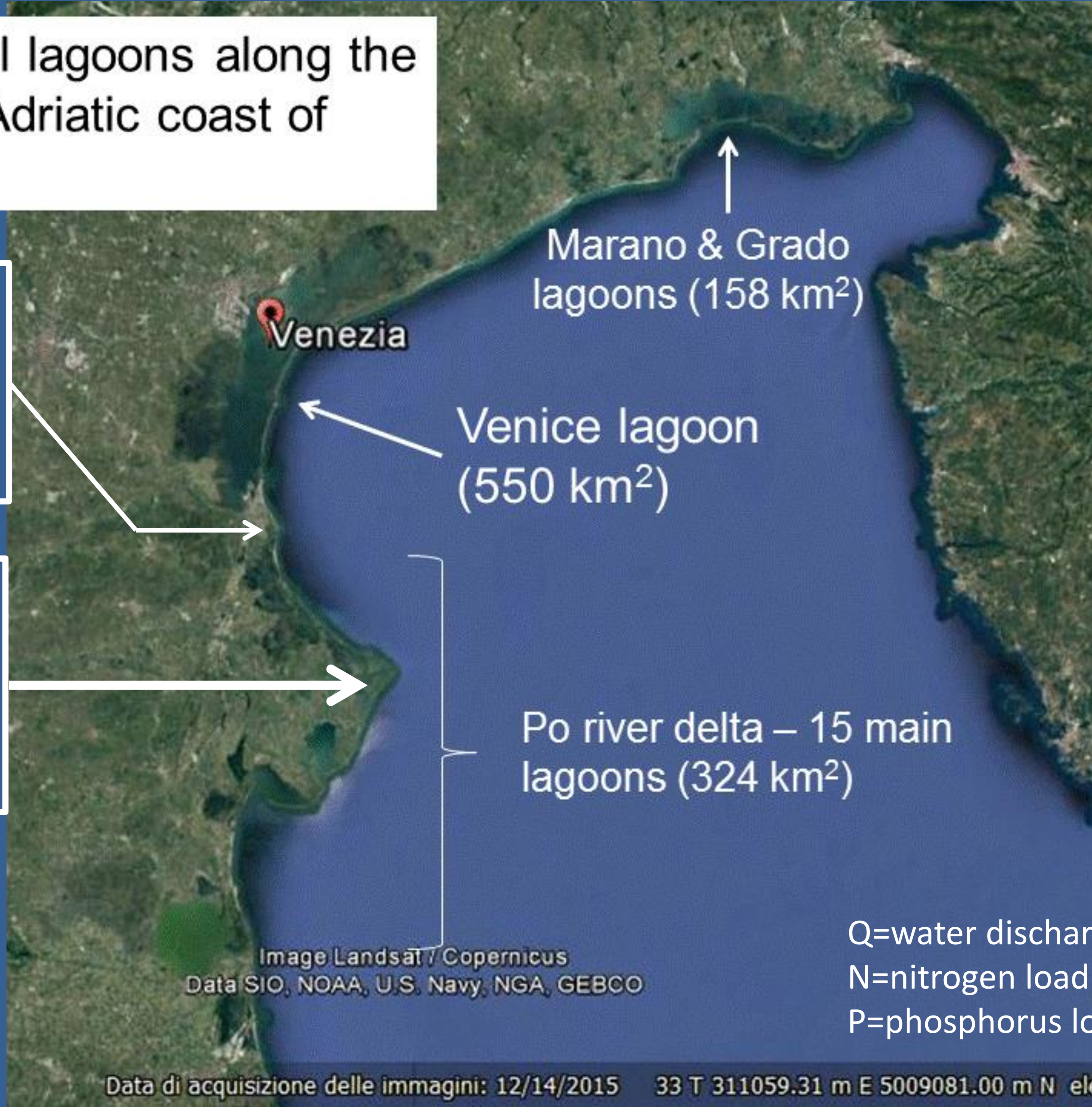
	Seagrass meadow	**Macroalgae (bloom forming)**	**Phytoplankton Microphytobenthos**
Biomass bulk	High/persistent	High/ephemeral «boom and bust»	Low/transient
Growth rate	Low	High/very High	High
Biomass degradability	Refractory	Labile	Labile/refractory
Oxygen	Balanced	Unbalanced dystrophy	Variable
Sulphide in pore water/bottom water	Absent to low	High	Absent to low
Nitrogen	Retention Low concentration	Pulsing; Low to high concentrations	variable

Viaroli et al., 2008, Aquatic Conservation

What has determined changes?

- Pressures from watersheds
- Resource exploitation, e.g. shellfish farming
- Manipulation of lagoons
- Wastewaters from urban areas in the lagoon (Venice)

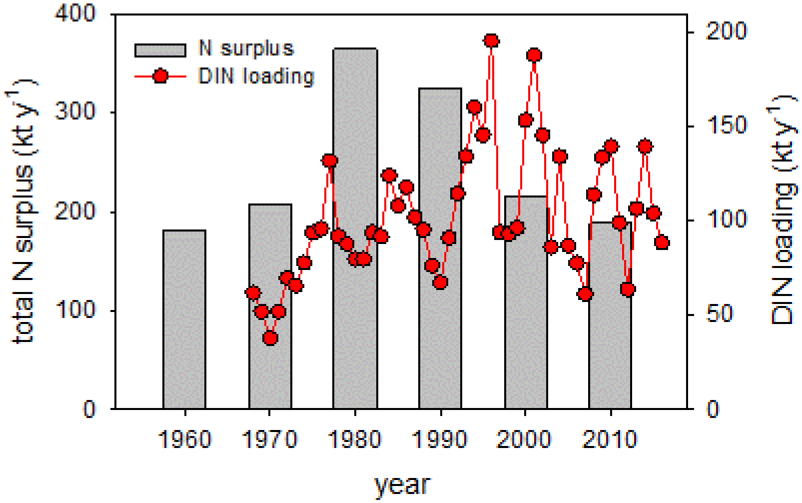
Coastal lagoons along the North Adriatic coast of Italy

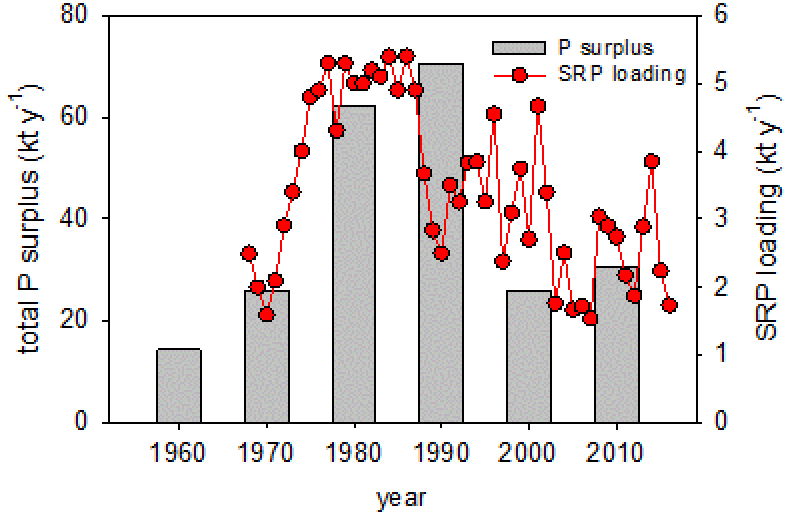


LOADINGS FROM PO RIVER

Red lines: decadal trends of dissolved inorganic nitrogen (DIN = $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$) and soluble reactive phosphorus (SRP) delivered by the Po river to the Northern Adriatic Sea

Grey bars: N and P surplus generated by agriculture and livestock (Soil System Budget) and urban wastewaters



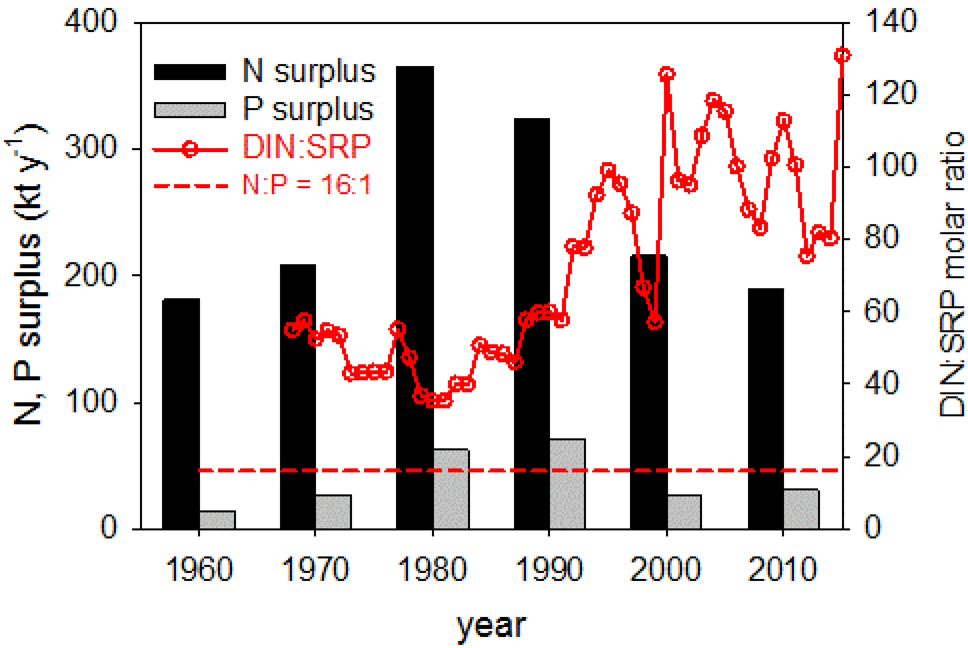


years	DIN	SRP
1965-1974	60±17	2.4±1.1
1975-1984	94±15	5.0±0.3
1985-2000	116±33	3.7±1.0
2000-2016	106±27	2.4±0.6

SRP loadings overlap P surplus

DIN loadings are delayed by ~2 decades from N surplus peaks (possible groundwater feedback loop)

RITMARE flagship project– deliverable SP3_ LI5_WP1_UO8_D01



years	DIN:SRP
1968-1989	48±8
1990-1999	77±16
2000-2016	102±16

year	DSi	DSi:DIN
	kt Si y^{-1}	
1968-70	114-134	1,06
1981-84	156-178	0,70
2004	172	0,64
2005-07	77-102	0,58-0,62
2015	81	0,39
2016	50	0,28

Unbalanced N:P ratios (less P-more N)
Unbalanced N:Si ratios (less Si-more N)

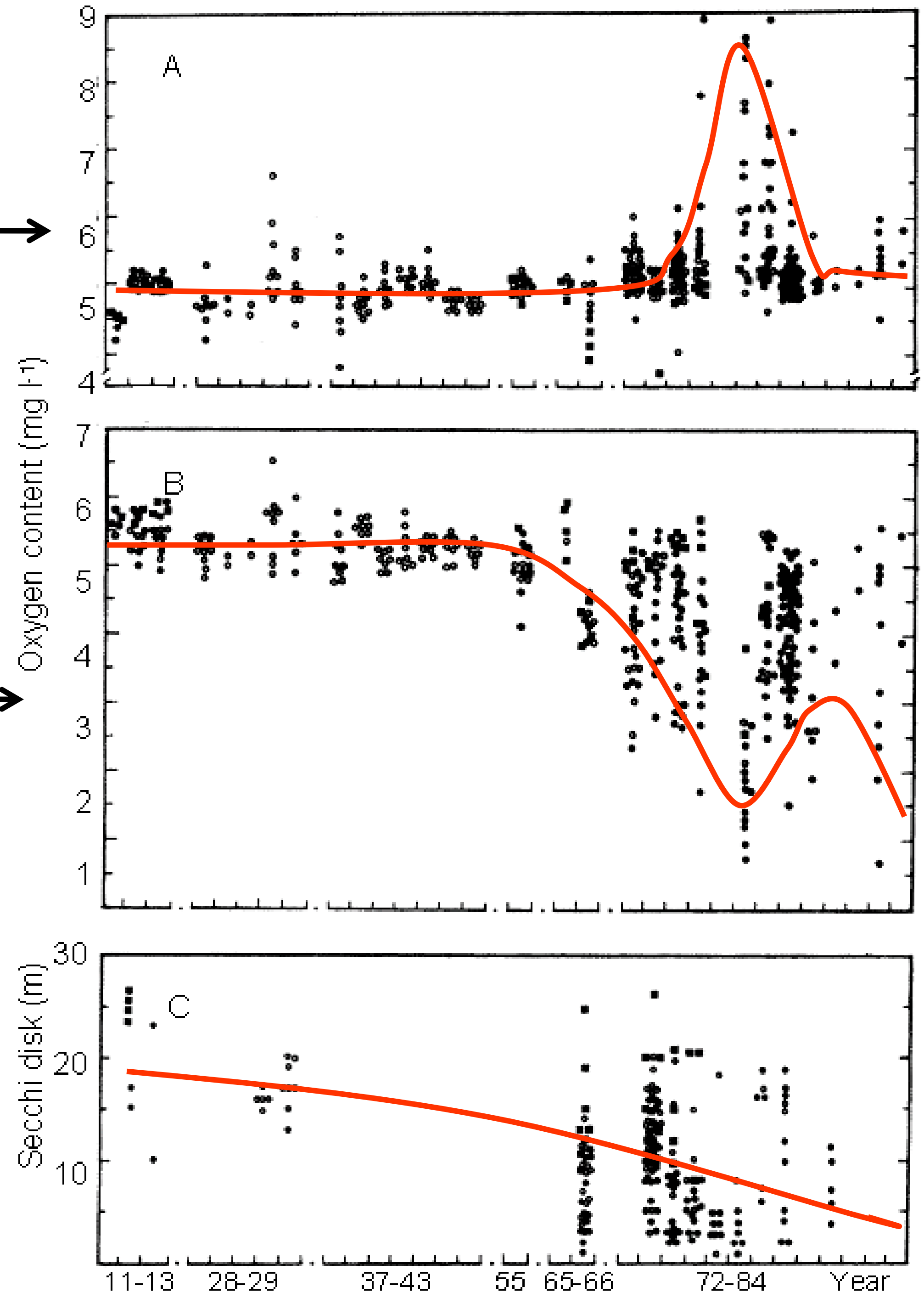
Nitrophilous macroalgae can take competitive advantages
Harmful Algal Blooms

Northern Adriatic Sea

Phytoplankton Biomass ($mm^3\ m^{-3}$) →

Dissolved oxygen in bottom waters ($mg\ L^{-1}$) →

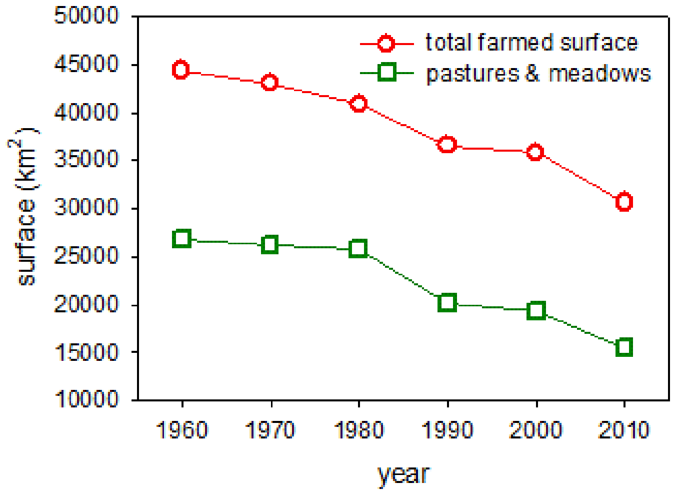
Secchi depth (m) →



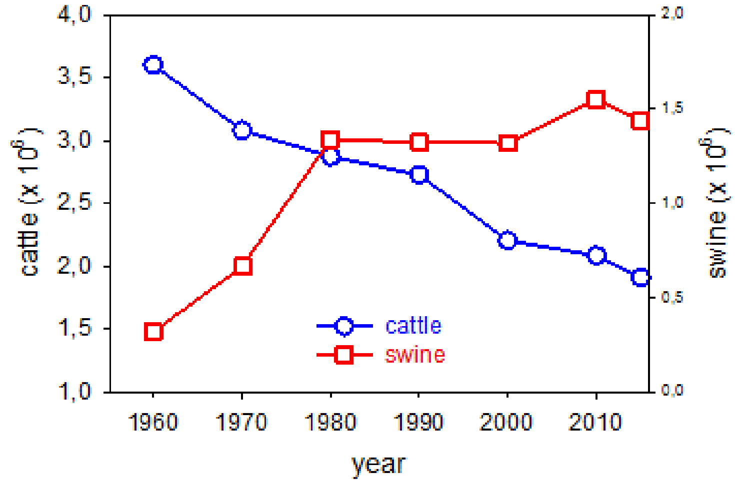
Justić et al. 1987

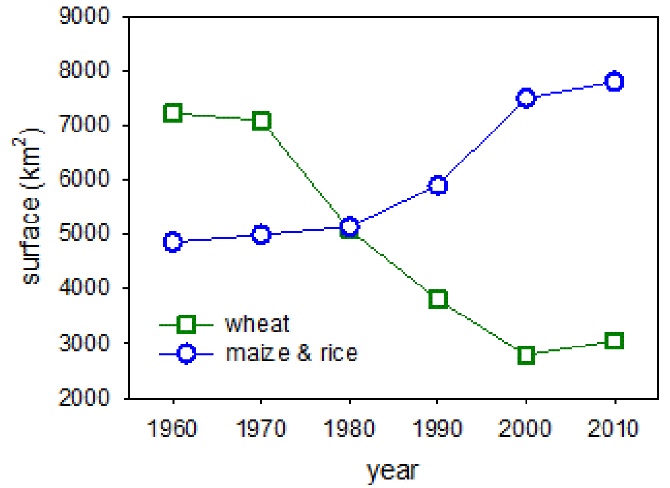
Example of major pressures from agriculture and livestock in Po River basin

total farmed area and main crops



livestock units (cattle equivalent)





	changes (%) 1960-2010	expected impacts
total farmed area	-31	urban sprawl
pastures and meadows	-42	increasing runoff and nutrient loss
wheat (winter crop)	-58	no soil cover in winter
maize & rice	+60	more water demand in summer
cattles	-47	organic matter decrease in soil
pigs	+367	more wastewater to manage

RITMARE flagship project– deliverable SP3_ LI5_WP1_UO8_D01

Venice and the «artificial» lagoon

THE VENICE LAGOON CAN NOT PERSIST AND EXIST WITHOUT CONTINUOS MANAGEMENT OF THE HYDRO-MORPHOLOGY (modified from Solidoro et al., 2010; see details in the next slide)

THE VENICE LAGOON CAN NOT PERSIST AND EXIST WITHOUT CONTINUOS MANAGEMENT OF THE HYDRO-MORPHOLOGY (explanation of the previous slide)

1400-1600. Deforestation and wetland reclamation led to increased runoff. This resulted in increased lagoon siltation.

1600-1604. Cut-off of the Po river near the village of Porto Viro. The main arm of the Po river was deviated to South-East to avoid the lagoon siltation. This affected the Po delta progression southwards.

Since 1600 to date: diversion of the major river flowing into the lagoon (continuos blue line=original flow, dashed blue line=flow after diversion)

Since 1800s: fortification of coastal strips (dotted red line)

Since 1900s: modification and fortification of inlets; more recently, construction of the mobile dams (MOSE) to avoid the flooding of urban areas (double red arrow)

1900s: navigation channels in the central basin (light green lines)

1910-1960: development of industrial areas, mainly oil refinery and chemistry (yellow dashed circle),

1900s: reclamation of pond and marshes for aquaculture (dashed yellow rectangles)

Modified from Solidoro et al., 2010, CRC Press Boca Raton.

Main pressures in the Venice lagoon since 1950. Light to dark colors indicate the pressure intensity from low to high (partially reworked from Solidoro et al., 2010)

decade	1950	1960	1970	1980	1990	2000	2010
Subsistence fishery							
Benthic vegetation	healthy phanerogams		macroalgal blooms			phanerogam recovery	
Shellfish harvesting							
industry							
agriculture							
tourism							

Main features of the Venice lagoon from 1950 to 2010.

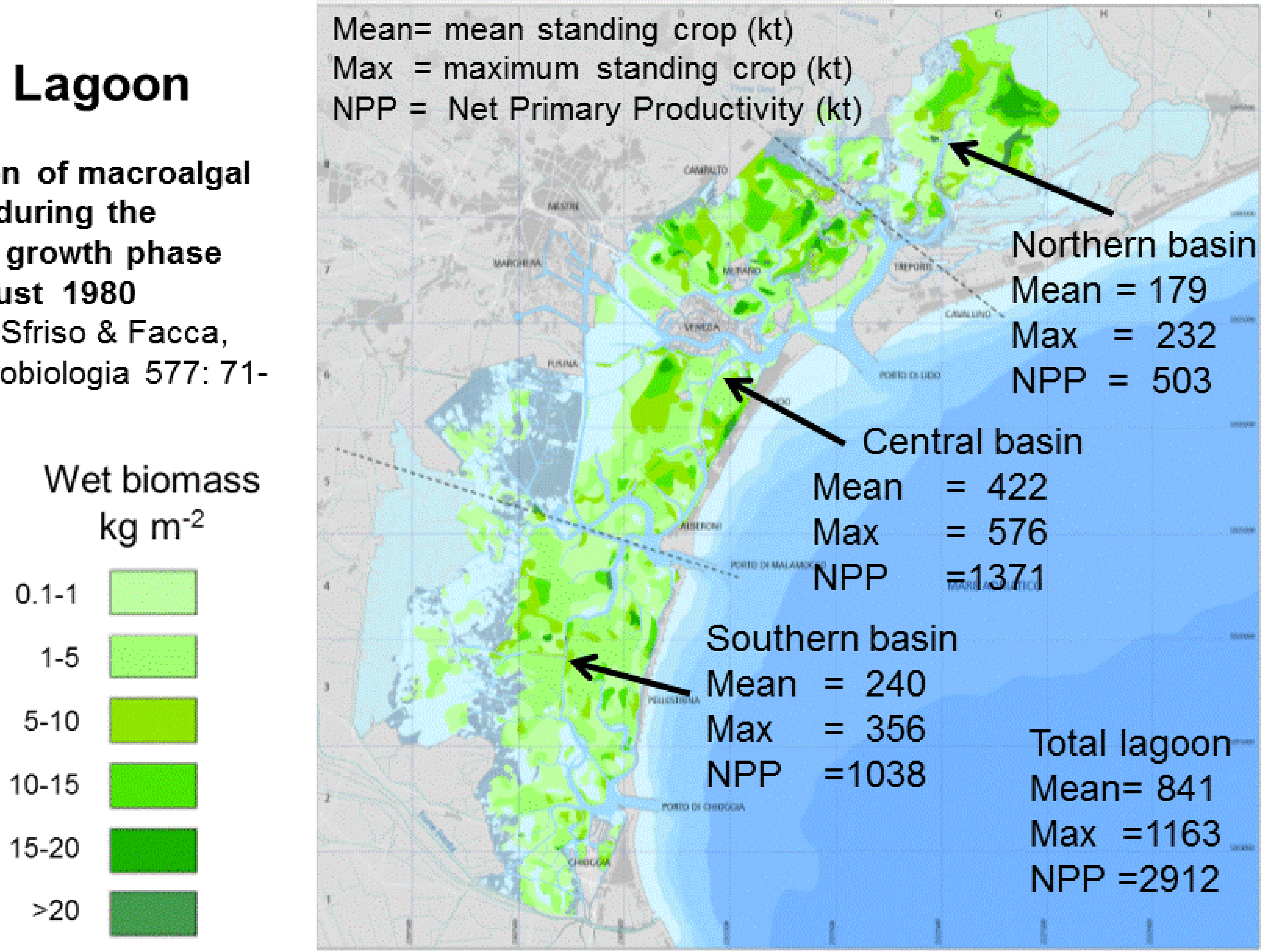
*concentration peaks in the central basin. The highest values are from the lagoon zone close to the industrial area (reworked from Solidoro et al., 2010)

na:=data not available

decade	1950	1960	1970	1980	1990	2000	2010
Manila clam yield (kt yr^{-1})	< 5				30-60		5-20
P loading (kt yr^{-1})	< 1	1-2	2-3		1-2	<0.5	
N loading (kt yr^{-1})	~5	5-7	7-12	10-12	8-10	3-7	
*** NH_4-N (mg N L^{-1})**	na	> 5	1-5	<0.5	<0.2		
*** NO_3-N (mg N L^{-1})**	na	<1	<2	< 3	<2	<1	
*** TP (mg P L^{-1})**	na	na	< 0.5		<0.5		

Venice Lagoon

Distribution of macroalgal biomass during the maximum growth phase June-August 1980
(details in Sfriso & Facca, 2007, Hydrobiologia 577: 71-85)



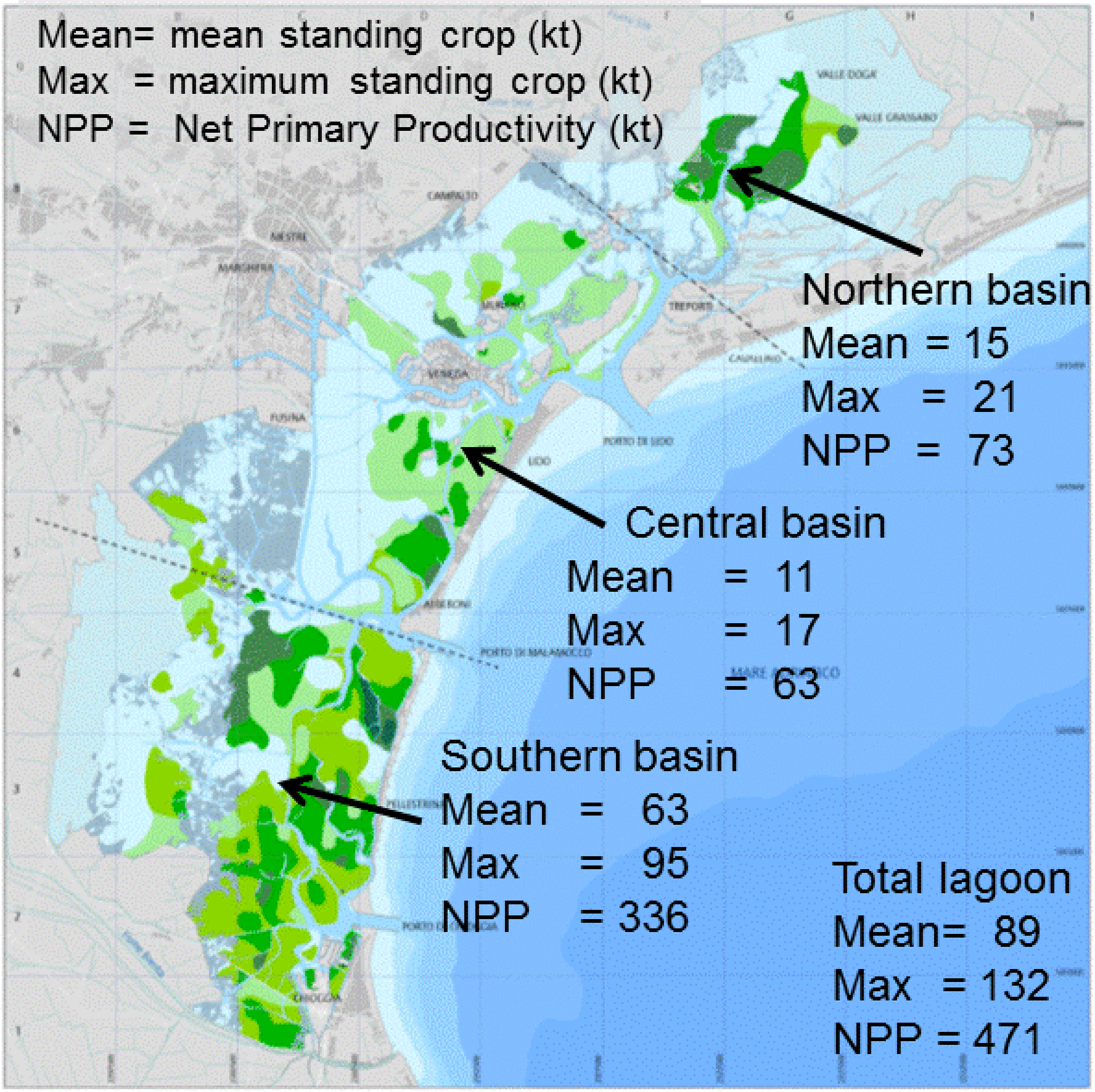
Guerzoni S & D Tagliapietra, 2006. *Atlante della laguna. Venezia tra terra e mare.* Marsilio ed, Padova

Venice Lagoon

Distribution of macroalgal biomass during the maximum growth phase June-August 2003
(details in Sfriso & Facca, 2007, Hydrobiologia 577: 71-85)

Wet biomass kg m^{-2}

Wet biomass (kg m^{-2})
0.01-0.1
0.1-0.5
0.5-1
1-5
5-10



Guerzoni S & D Tagliapietra, 2006. *Atlante della laguna. Venezia tra terra e mare.* Marsilio ed, Padova


The Venice lagoon: what else? The role of the urban area in the lagoon eutrophication has long been neglected
St. Marc
Venice - main urban area
Venezia, Venezia (Veneto)

The urban area in the lagoon (main islands) has
~55,000 inhabitants
~14,000,000 tourist /year visiting the town in < 1 day
~ 6,000,000 tourist/year staying on average 1 week
Inhabitants+tourists accounts for the delivery of wastewaters equivalent to **~150,000 inhabitants**

High organic load → reducing metabolism in water and sediments of the canals
Very high sulphate reduction rates with effects on
- increased NH_4^+ and SRP recyling
- increased nitrate reduction to ammonium (DNRA)
- low denitrification to N_2 in summer

Increased recycling and retention of inorganic nutrients

Azzoni et al., 2015. Estuaries and Coasts 38:1016–1031

Management and policies

1970-1980 Emergency intervention : macroalgal biomass harvesting expensive – not effective

1970 to date
Special laws for Venice (e.g. No 171/1973, 798/1984, 360/1991, 139/1992, 206/1995)

- Nutrient control from WWTP: TP< 1 mg P L^{-1}; TN<10 mg N L^{-1}
- Implementation of the sewerage system in the main urban areas
- Control of diffuse N and P sources in the farmland

Restoration of river flowing into the lagoon with constructed wetlands, buffer zones along rivers, etc. (www.venetoagricoltura.org; www.acquerisorgive.it)

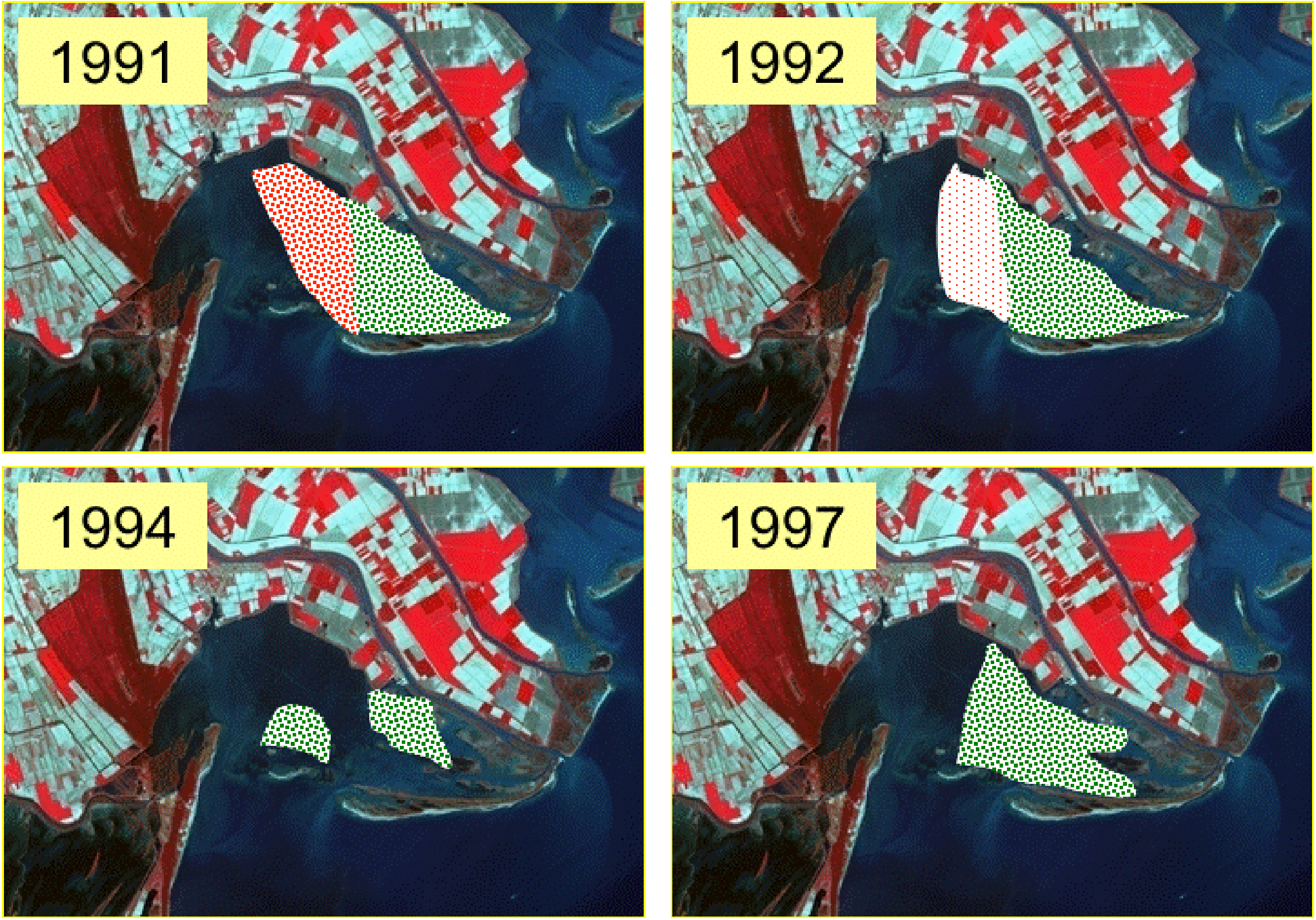
Contruction and restoration of sandbanks, e.g LIFE VIMINE project (www.lifevimine.eu)

Seagrass meadow restoration , e.g. LIFE12 NAT/IT/000331 *SERESTO: habitat 1150* (coastal lagoon) recovery by seagrass restoration. a new strategic approach to meet habitat directive and water framework directive objectives* (A. Sfriso; (www.lifeseresto.eu)

Mobile dams (MOSE): the closure of the three lagoon mouths will increase water retention time, with possible effects on water exchanges/flushing, especially in the chocked inner sub-basins

Po river delta

The Sacca di Goro lagoon is the main study site. Research programs from 1988 to date

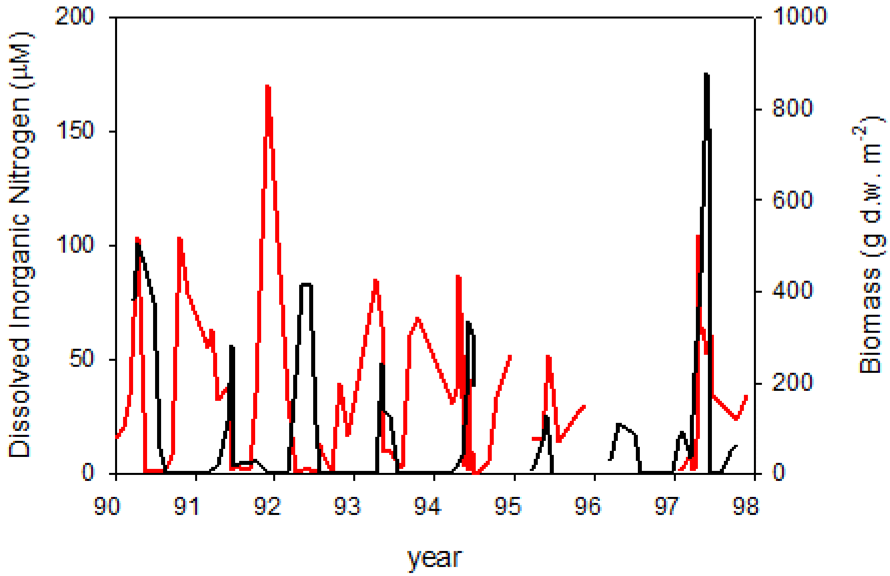


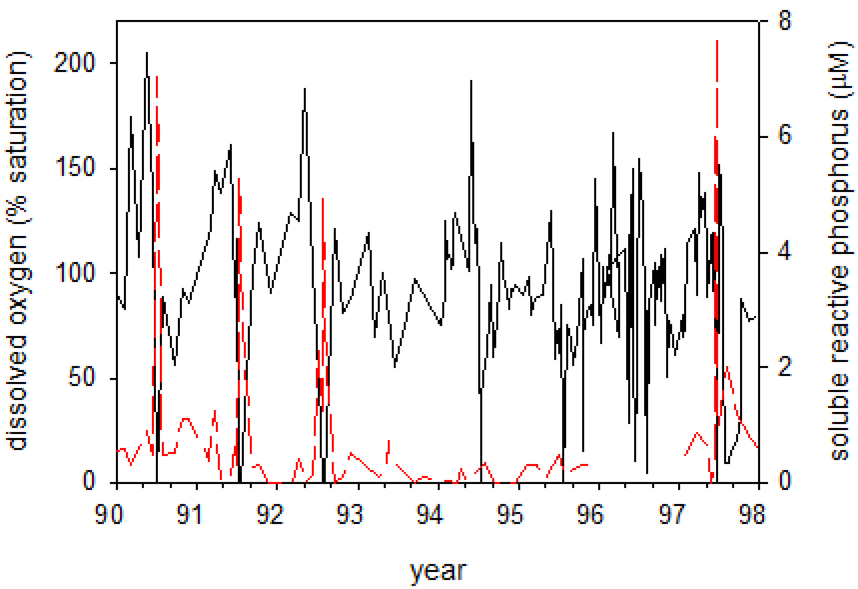
macroalgal blooms in late spring

lagoon surface: 26 km^2 macroalgal mats: 10-15 km^2

From Viaroli et al., 2006

Sacca di Goro lagoon (Italy): macroalgal bloom on 12 May 2008. Mixed stands of *Ulva* and *Gracilaria* (Viaroli et al., 2012)





Sacca di Goro lagoon

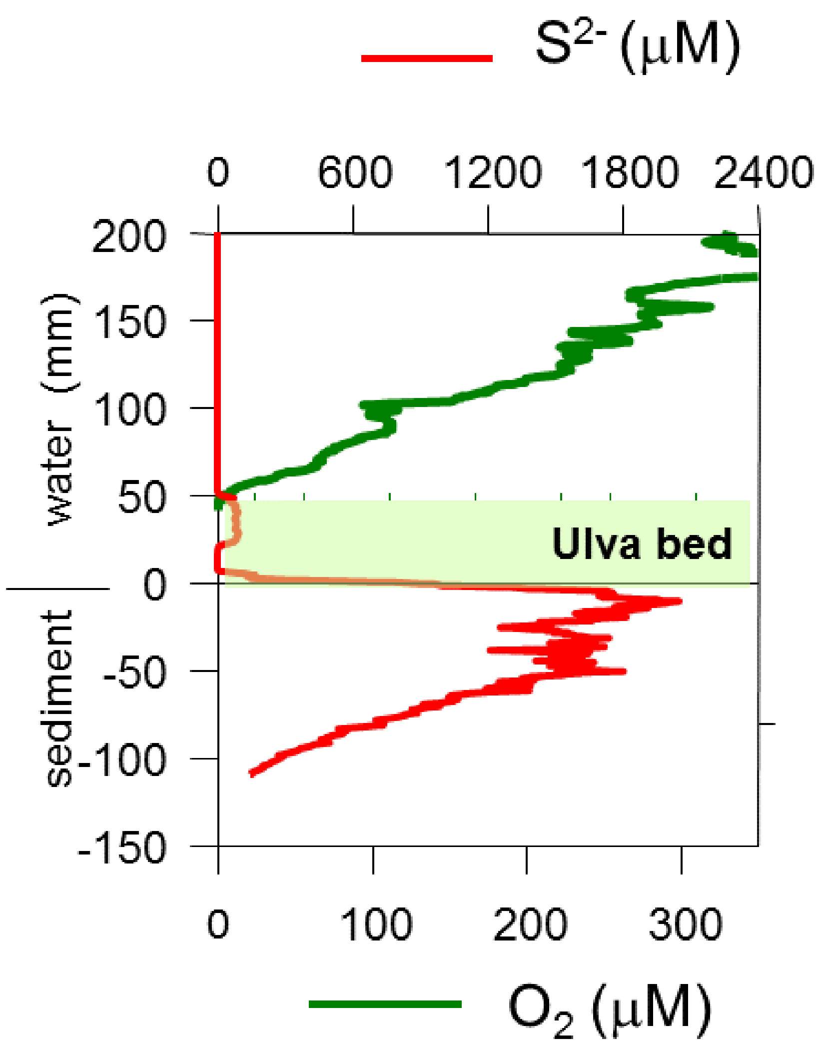
the seasonal biomass dynamic (black line) is linked to nitrogen availability (red line). Winter peaks of dissolved inorganic nitrogen (DIN) are usually followed by huge biomass peaks in late spring

Macroalgal blooms affect oxygen availability (black line) , which oscillates between supersaturation and anoxia

The bloom collapse is then followed by the sudden and abrupt release of phosphates (red line)

Viaroli et al. 2006. The Handbook of Environmental Chemistry, Estuaries, Volume 5/H: 197-232 .

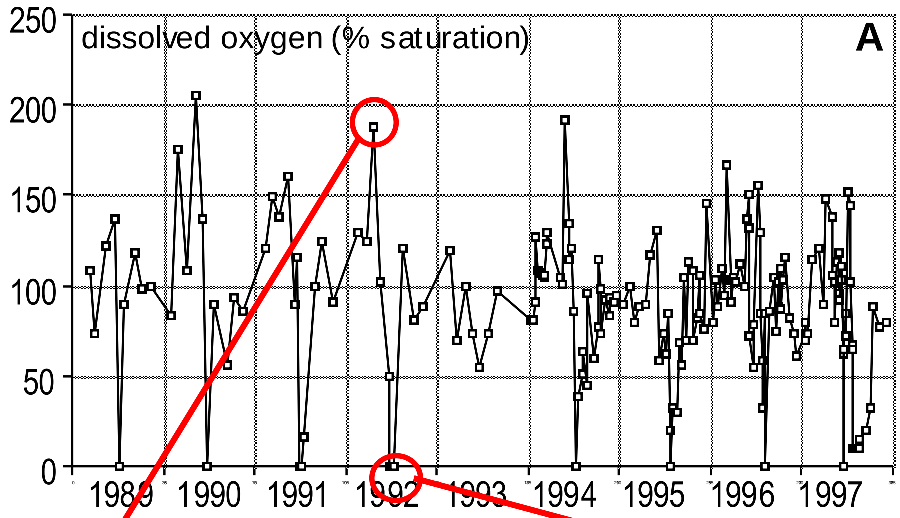
Effects of macroalgal blooms

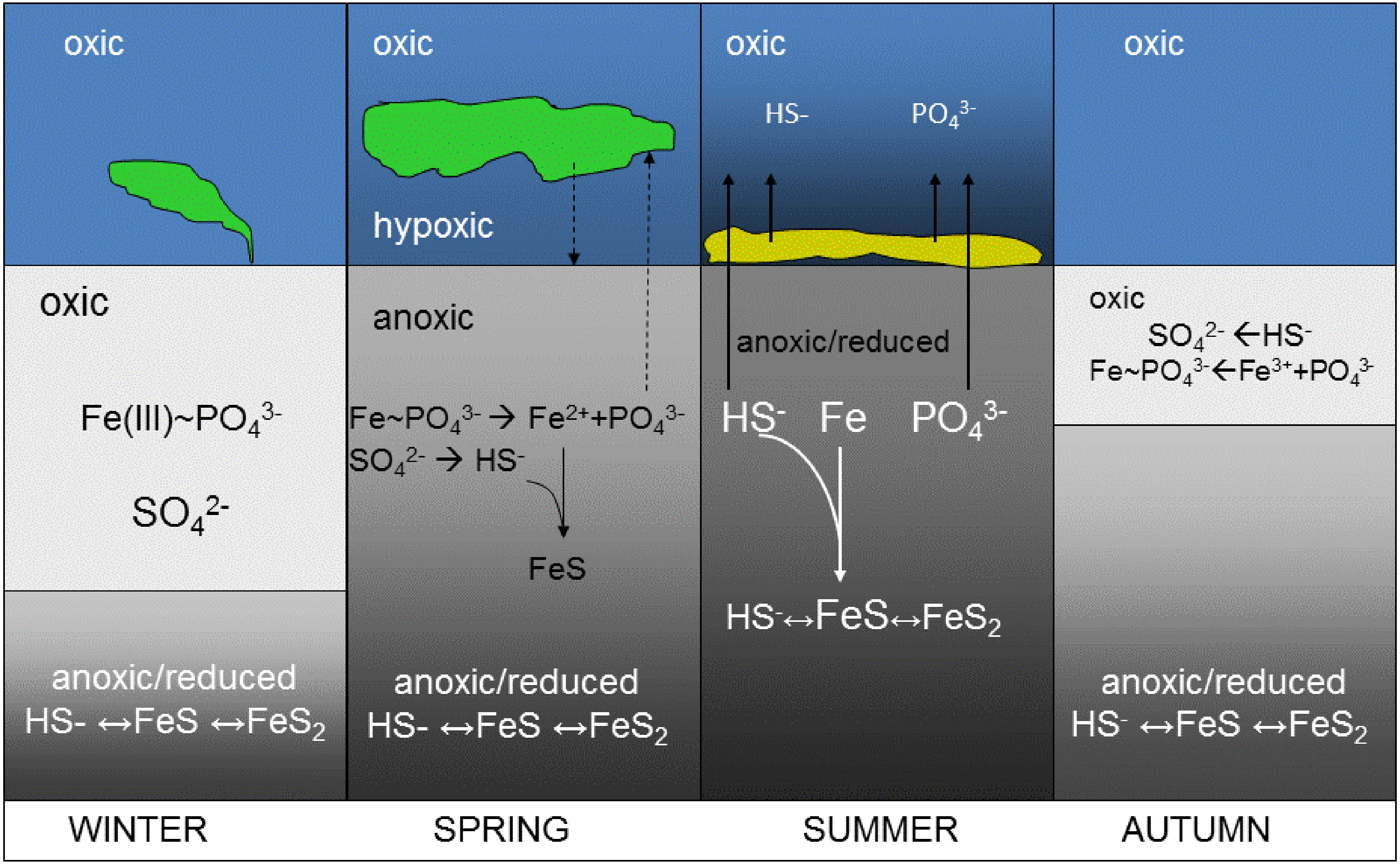


Oxygen and sulphide profiles through a layer of *Ulva* thalli at the water-sediment interface – in Sacca di Goro lagoon, st. 17

In situ microprofiling with the SWIMP: Sediment-Water Interface MicroProfiler, ISMES©, Italy (modified from Bartoli et al., 1996)

oxygen depletion (hypoxia-anoxia) and dystrophic crises
Impacts on shellfish farming = loss of 30-50% annual crop

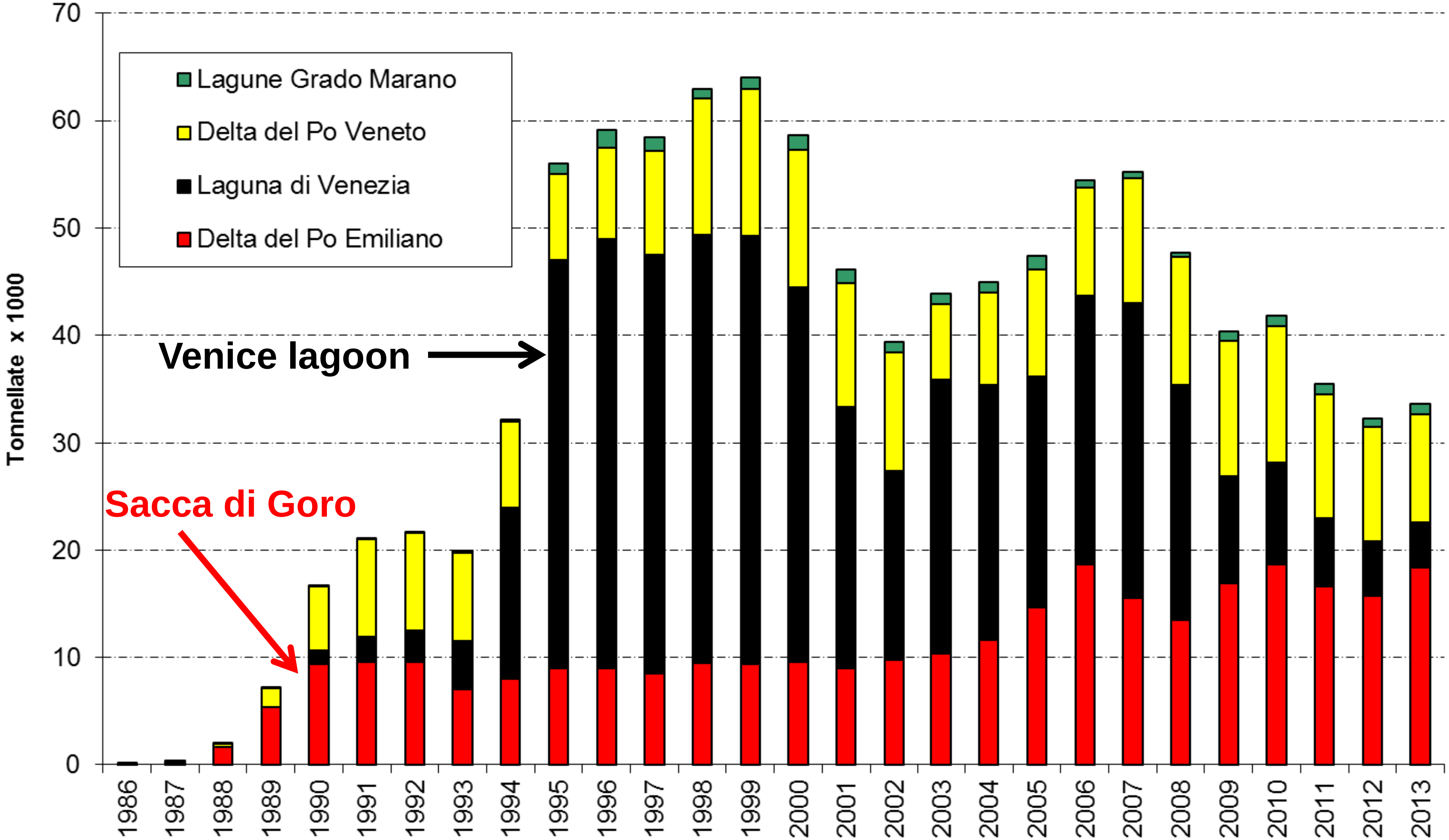




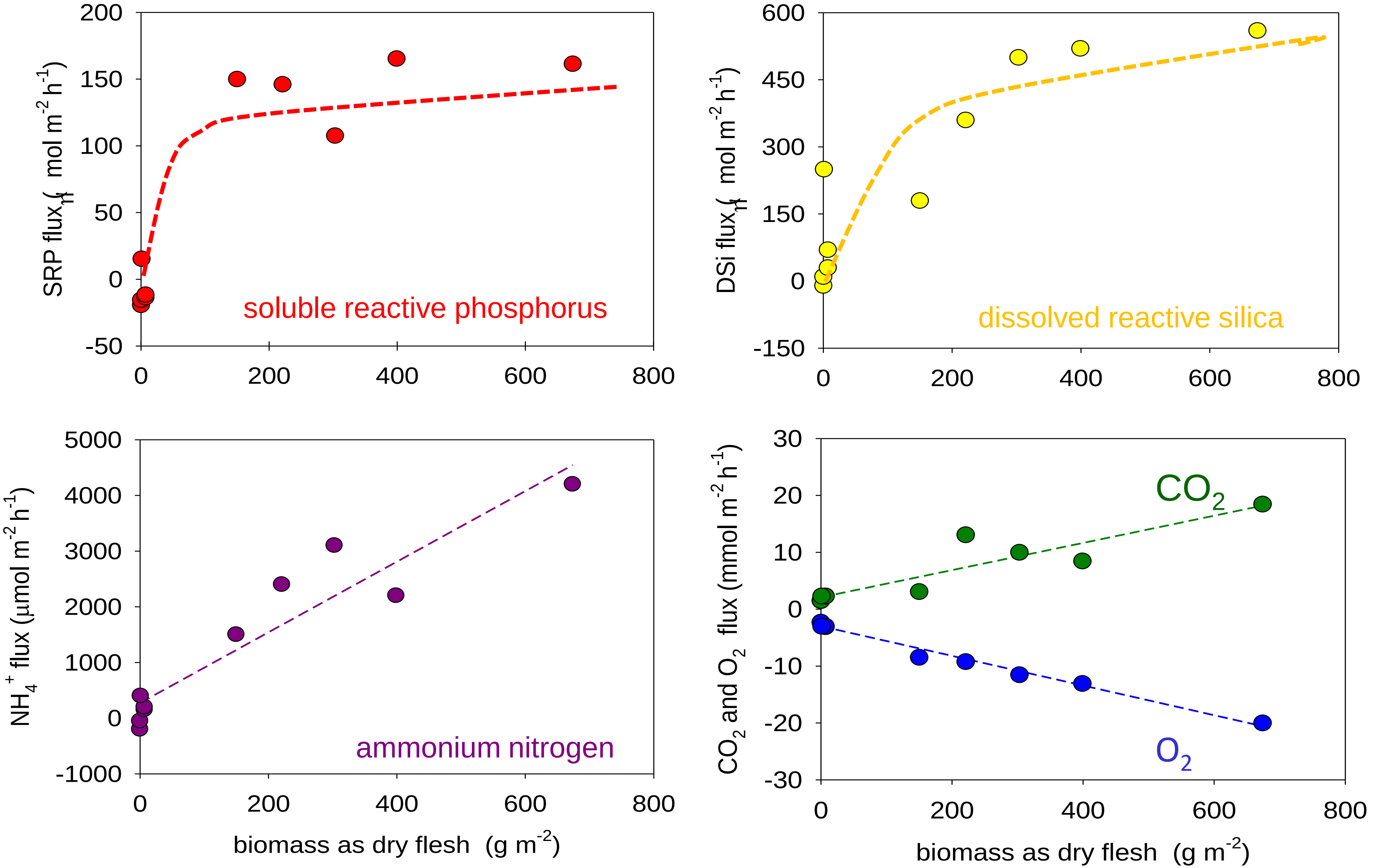
Schematic representation of the main reactions of sulphide/iron-monosulphide/pyrite and iron hydroxide/phosphate/sulphide buffers during a macroalgal bloom (modified by Viaroli et al. 2008, from de Wit et al., 2001, Continental Shelf Research 21: 2021-2041; Rozan et al., 2002, Limnology and Oceanography 47: 1346-1354)

Coastal lagoons are exploited for shellfish farming, e.g. oysters in France; clams in Italy

Italian production of Manila clams (*Ruditapes philippinarum).*
Total Income = 150-300 M$ (Bartoli et al., 2016)

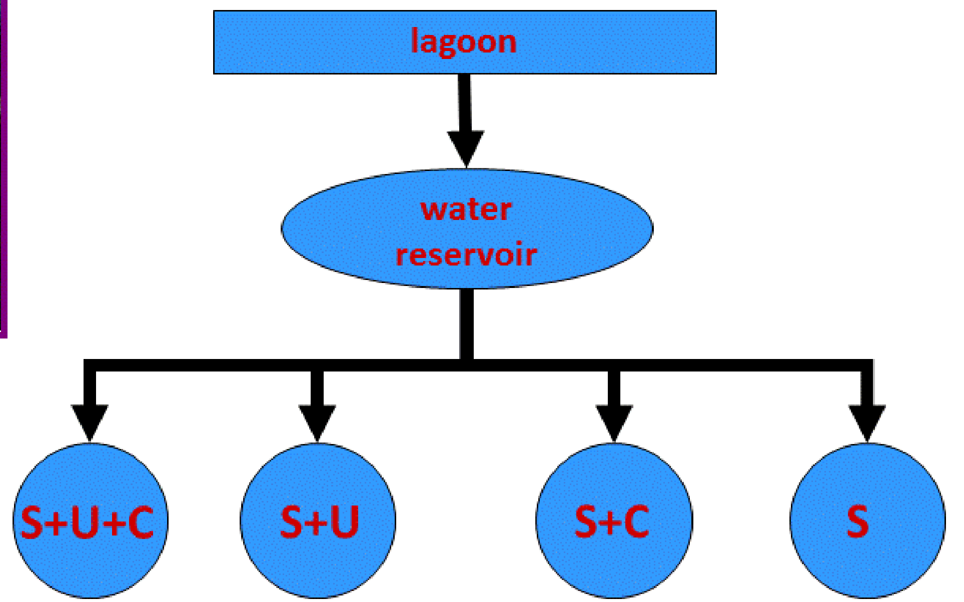


Nutrient, oxygen and carbon dioxide fluxes and nutrient stoichiometry depend on clam biomass. Measurements of benthic fluxes of dissolved inorganic nutrients, oxygen and carbon dioxide in cores with increasing clam biomass (redrawn from Bartoli et al., 2001)



Do clams and *Ulva* interact causing a feedback loop?
(Bartoli et al., 2011, 2003; Nizzoli et al., 2006, 2007, 2011)

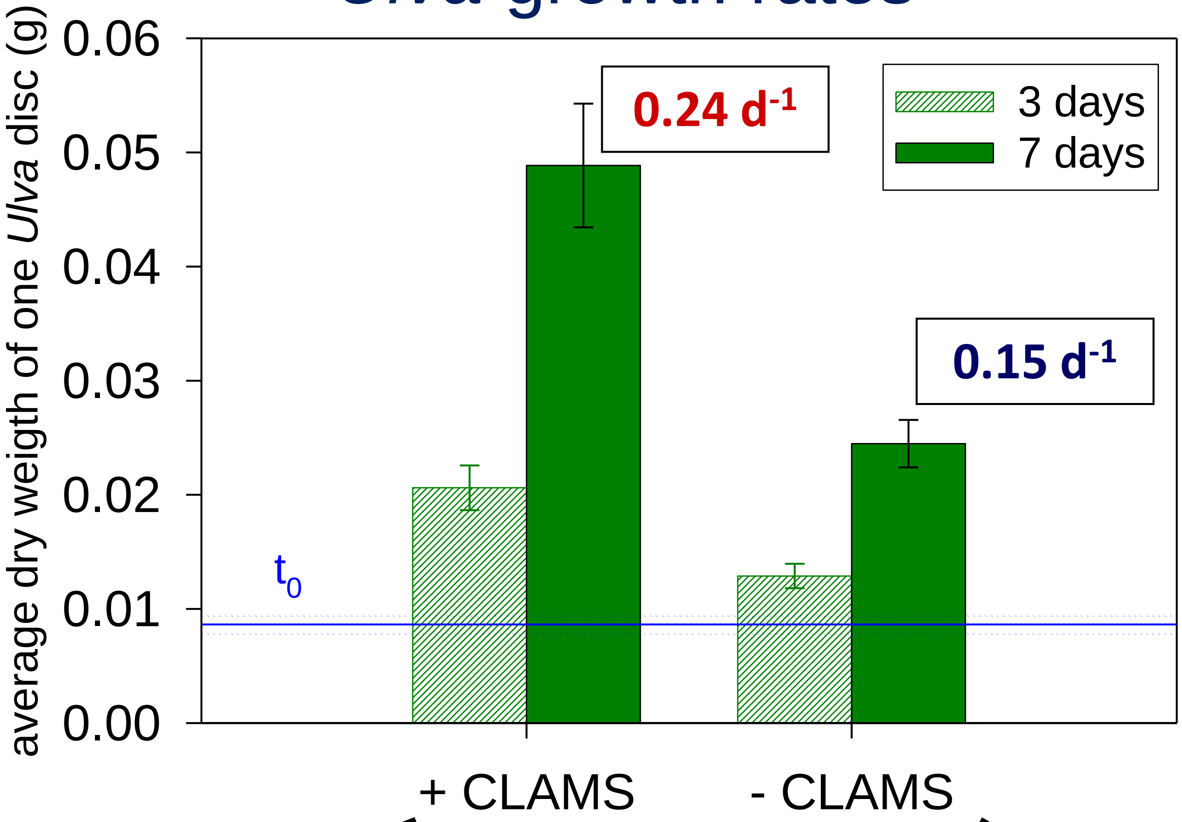
a mesocosm experiment



S = sediment
U = *Ulva*
C = clams

Water depth (cm)	30	30	30	30
Water volume (L)	151	151	151	151
Q (L h^{-1})	23	23	23	23
Clam density (ind m^{-2})	500		500	
Ulva biomass (g_{DW} m^{-2})	2	2		

Ulva growth rates



Summary and possible trends

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Contents lists available at SciVerse ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Recent changes in the marine ecosystems of the northern Adriatic Sea

Michele Giani [a,*], Tamara Djakovac [b], Danilo Degobbis [b], Stefano Cozzi [c], Cosimo Solidoro [a], Serena Fonda Umani [d]

The North Adriatic Sea is apparently undergoing recovery (oligotrophication?)

- less nutrients, especially P, generated from watersheds
- less runoff due to climate changes

Open questions

- What is the effect of changing nutrient stoichiometry: N»P and N»Si?
- Is Venice lagoon (and other lagoons) recovering pristine conditions?
- Can ecological restoration help in stabilizing less eutrophic conditions?
- What about alien species (e.g. *Sargassum muticum, Gracilaria vermiculophylla*, *Crassostrea gigas*) ?
- Are lagoons undergoing heterotrophic conditions, i.e. saprobity? Saprobity being the state of an aquatic ecosystem resulting from the input and decomposition of organic matter and the removal of its catabolites (Tagliapietra et al., 2012). The higher the saprobity is, the more impaired the system is, with progressively poorer benthic communities characterized by species that are increasingly tolerant of reducing conditions and toxicity.

Exploitation of lagoons with shellfish farming

Clam banks are frequently covered by dense *Ulva* mats

- Clam shells are an hard substratum to which rhizoids attach allowing the development of *Ulva* stands – *Ulva* is favoured
- Clams remove particulate matter (including phytoplankton) increasing water trasparency – *Ulva* is favoured
- Clams regenerate inorganic N and P in a ratio that stimulates *Ulva* to grow (N:P $\cong$ 30) – *Ulva* is stimulated

At high densities (> 1000 ind m^{-2})

- clams seem to favor a shift to a macroalgal dominated community
- a feedback loop can establish leading the system to collapse
- more cost for managing the farming? Unsustainable farming?
- shellfish farming as a measure for contrasting eutrophication?

Marine Pollution Bulletin 62 (2011) 1385–1388

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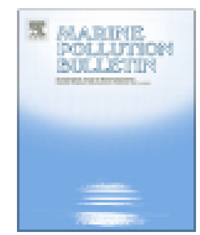

Viewpoint

Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles

J. Stadmark*, D.J. Conley

Vol. 348: 1–18, 2007
doi: 10.3354/meps07132

MARINE ECOLOGY PROGRESS SERIES
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FEATURE ARTICLE: REVIEW

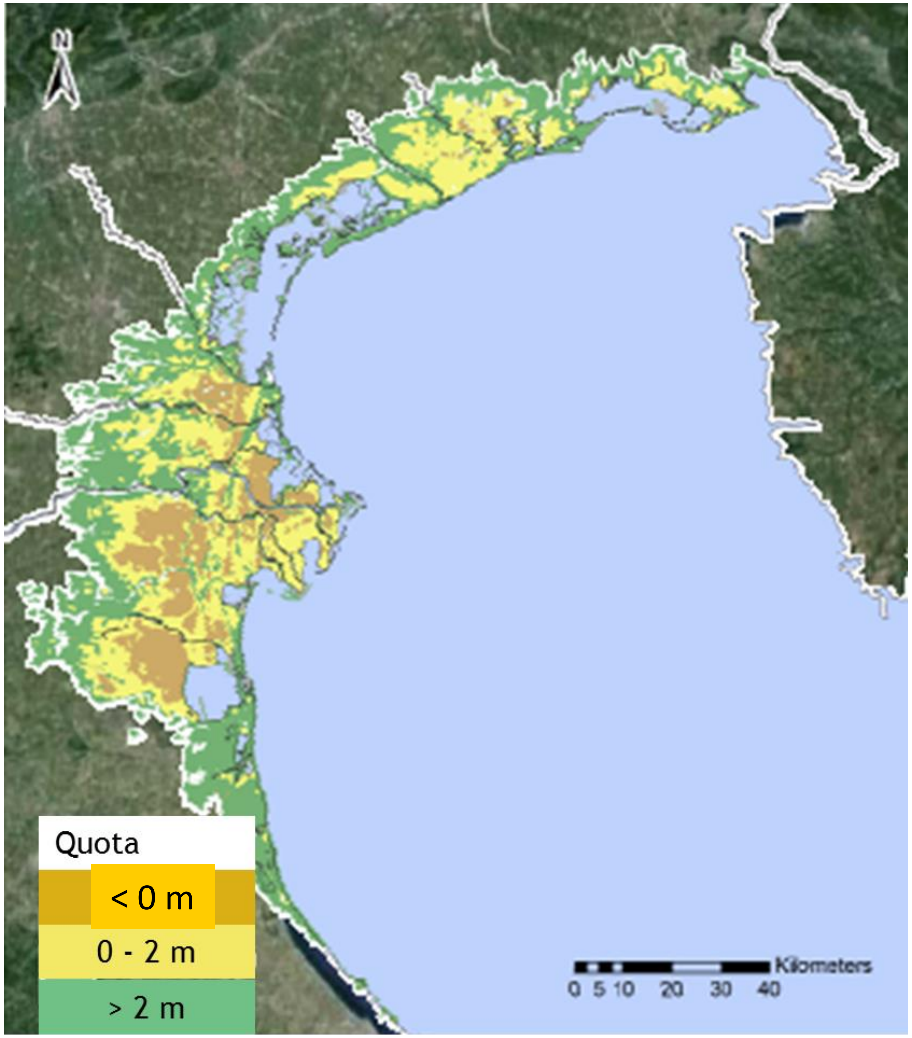
Eutrophication in shallow coastal bays and lagoons: the role of plants in the coastal filter

Karen J. McGlathery[1,*], Kristina Sundbäck[2], Iris C. Anderson[3]

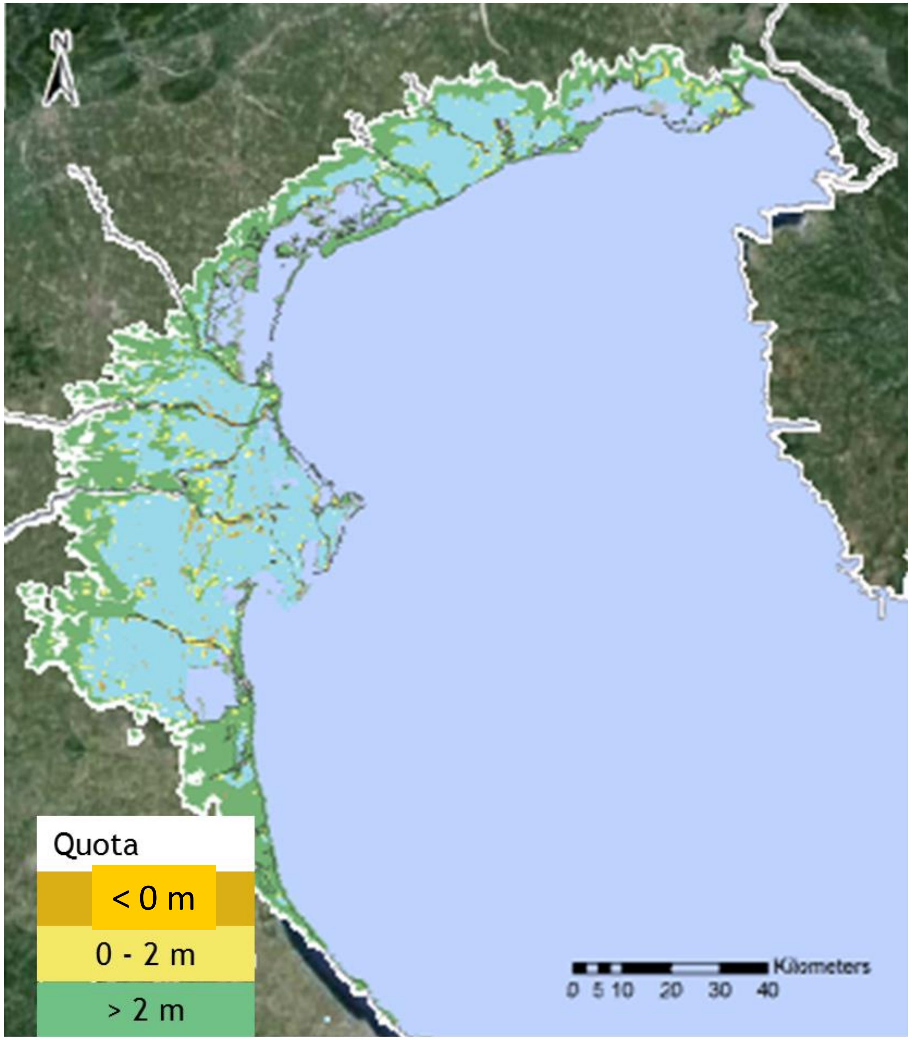
The "filter" depends on the vegetation typology. An example is given by denitrification, nitrogen uptake rates and nitrogen storage in different benthic communities. 1: Welsh *et al*. (2000); 2: Risgaard-Petersen (2004); 3: Eyre and Ferguson (2002), 4: Bartoli *et al*. (2001, 2012), Viaroli *et al*. (2005), 6) Sfriso and Marcomini (1996); 7) Sundback and McGlatery (2005). MPB: microphytobenthos; BS: bare sediments. Table and references from Viaroli et al., 2008.

	Maximum denitrification rates	**Maximum nitrogen bulk at biomass peak**	**Nitrogen uptake rates at biomass peak**	**ref.**
	(mmol m^{-2} d^{-1})	(mmol m^{-2})	(mmol m^{-2} d^{-1})	
seagrass	0.1-0.4	200 - 600	10-25	1, 2, 3, 4
macroalgae	0.2	500 - 1250	6-25	5, 6, 7
MPB/BS	0.4-1.6	---	2.5-5.0	4, 7

Coastal flooding: more lagoons in the next half-century?



Coastal areas at different elevation (m asl) along the Adriatic coast from Trieste to Ravenna. Areas that can undergo submersion have been inferred from Bondesan *et al*.,1995 and Castiglioni *et al*.,1995 (see also Tagliapietra et al., 2014 for references)



Areas that can be potentially flooded due to a 50 cm sea level rise account for ~3000 km². Simulation by D. Tagliapietra CNR-ISMAR-Venezia

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