Eutrophication Assessment using ASSETS
Approach, Application and Results

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Venice Water Authority Meeting
Exploring possibilities for collaborative work
December 3rd 2007

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	34+2

Coastal eutrophication
Drivers-Pressure-State-Response

Drivers

- Agriculture – loss of fertilizer, etc
- Urban and industrial discharges
- Aquaculture
- Atmospheric deposition
- Internal (secondary) sources (e.g. P from sediments)
- Advection from offshore (e.g. N and P, certain types of HAB)

Pressure

- N and P loading to the coastal system
- HAB phytoplankton "loading" from offshore

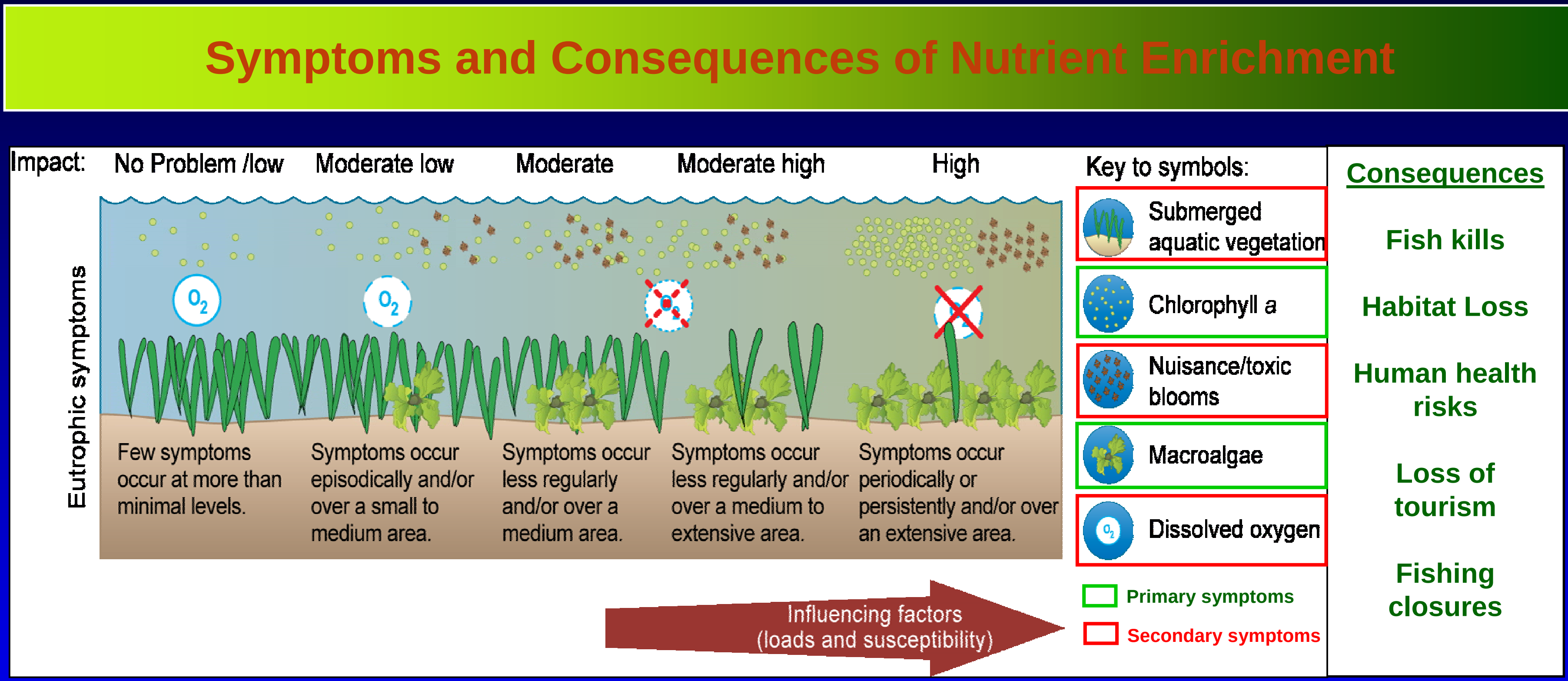
State

- Primary symptoms
  - Decreased light availability
  - Increased organic decomposition
  - Algal dominance changes
- Secondary symptoms
  - Loss of SAV
  - Low dissolved oxygen
  - Harmful algae

Response

- Fertilizer reduction
- WWTP (sewage, industry)
- Emmission controls
- Sediment dredging etc
- Time...
- Interdiction (e.g. HAB events)
- ...And aquaculture?

The Problem – The Assessment Approach



ASSETS: Pressure - State - Response

P: Influencing Factors – Natural processing + Human Nutrient Load
S: Overall Eutrophic Condition – Condition of waterbody
R: Future Outlook – What will happen in the future?

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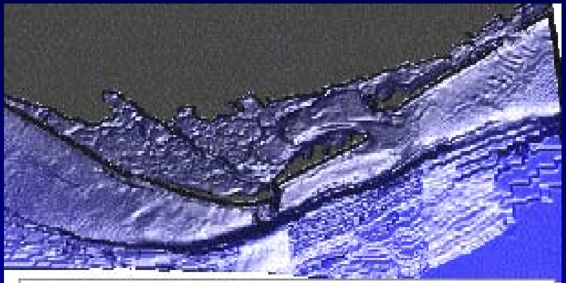
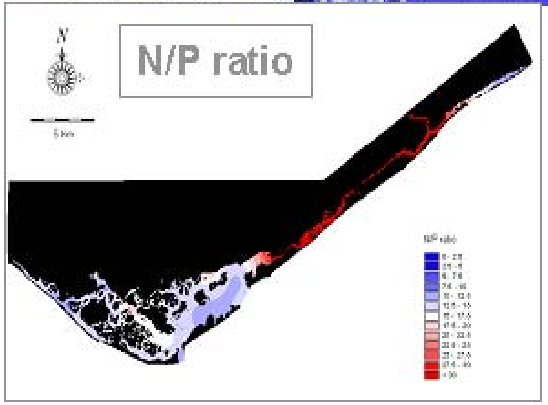
The Context and Guiding Legislation

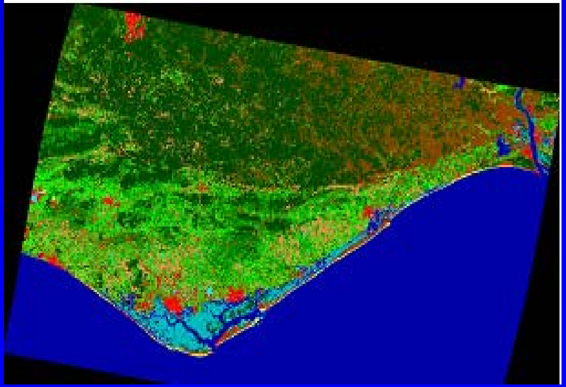
- US Clean Water Act of 1972, US Harmful Algal Bloom and Hypoxia Research and Control Act of 1998

- EU Water Framework Directive (2000/60/EC), EU older generation directives, such as UWWTD and Nitrates – Definition of Sensitive Areas and Vulnerable Zones

- Eutrophication is a significant problem worldwide (US, EU, Mediterranean, Baltic, Japan, Australia and elsewhere)







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Key Aspects of the ASSETS approach

The ASSETS approach may be divided into three parts:

- ✓ **Division of coastal systems into homogeneous areas**
  - Tidal freshwater (<0.5 psu)
  - Mixing zone (0.5-25 psu)
  - Seawater zone (>25 psu)
- ✓ **Evaluation of data completeness and reliability**
  - Spatial and temporal quality of datasets (completeness)
  - Confidence in results (sampling and analytical reliability)
- ✓ **Application of indices**

Pressure: Influencing Factors index (susceptibility + nutrient load)

State: Overall Eutrophic Condition index (Chl, macroalgae, **HABs, DO, SAV loss**)

Response: Future Outlook index (susceptibility + future nutrient load)

FINAL ASSETS GRADE

★ **Guide for management, research, monitoring**

ASSETS – Conceptual Approach

Model

EXTERNAL FORCING	PRIMARY SYMPTOMS	SECONDARY SYMPTOMS
	→ Decreased light availability Chlorophyll a Macroalgal growth	→ Loss of SAV SAV Spatial coverage SAV Coverage trends
Nitrogen and phosphorus	→ Increased organic decomposition Chlorophyll a Macroalgal growth	→ Low dissolved oxygen Dissolved oxygen
	→ Algal dominance changes Diatoms to flagellates Benthic to pelagic algae	→ Harmful algae Nuisance algal blooms Toxic algal blooms

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Pressure –Influencing Factors

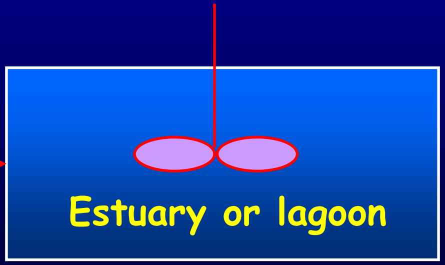
- Calculate m_h, the expected nutrient concentration due to land based sources (i.e. no ocean sources);
- Calculate m_b, the expected background nutrient concentration due to the ocean (i.e. no land-based sources);
- Calculate IF as the ratio of $m_h/(m_h+m_b)$;

Class	Thresholds
Low	0 to <0.2
Moderate low	0.2 to <0.4
Moderate	0.4 to < 0.6
Moderate high	0.6 to < 0.8
High	>0.8

Equations are based on a simple Vollenweider approach, modified to account for dispersive exchange:

Anthropogenic inputs

$$m_h = \frac{m_{in}\left(s_o - s_e\right)}{s_o}$$

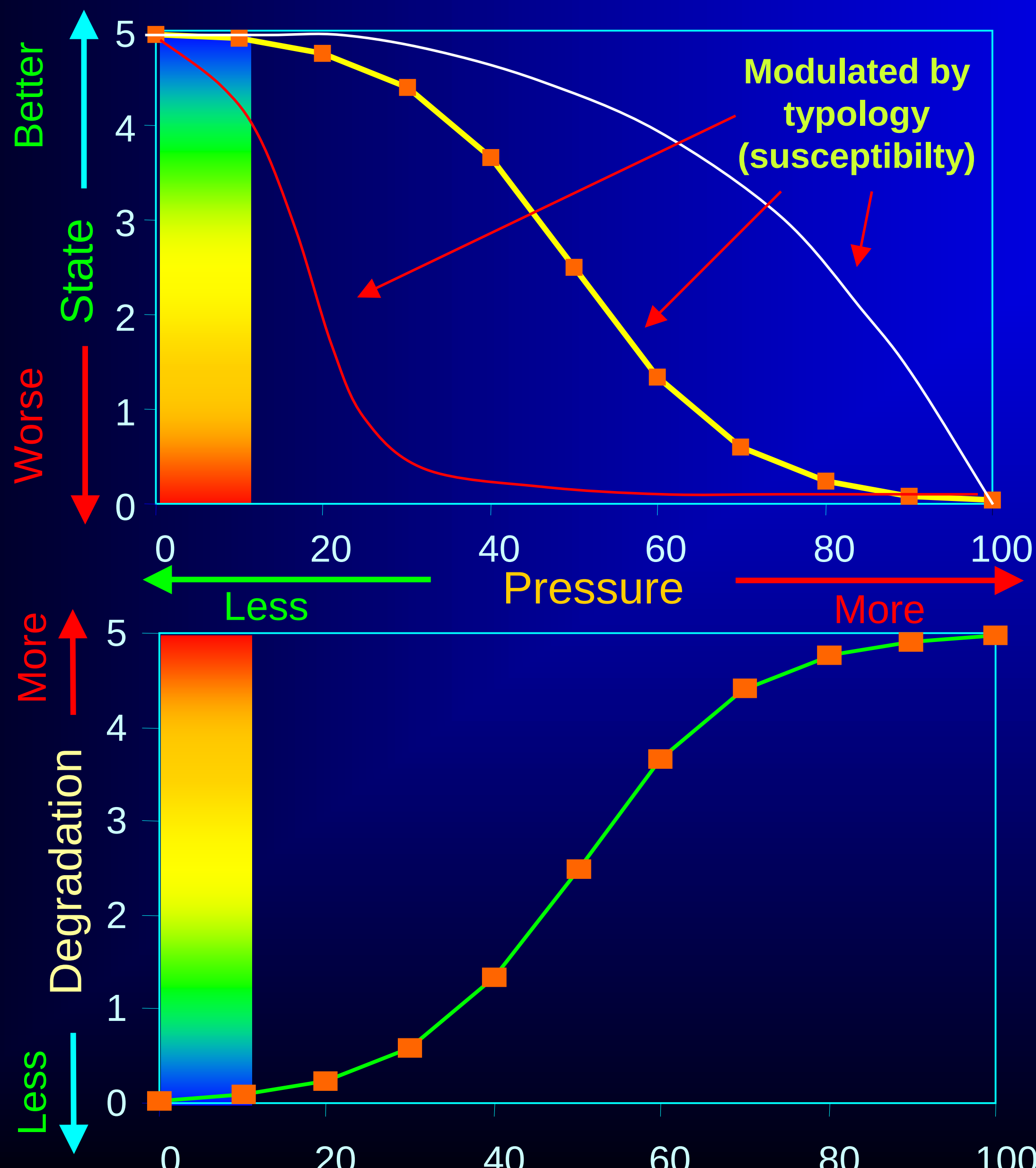


Ocean inputs

$$m_b = \frac{m_{sea} s_e}{s_o}$$

Bricker, S.B., Ferreira, J.G. & Simas, T. - An Integrated Methodology for Assessment of Estuarine Trophic Status. Ecol. Modelling 169: 39-60.

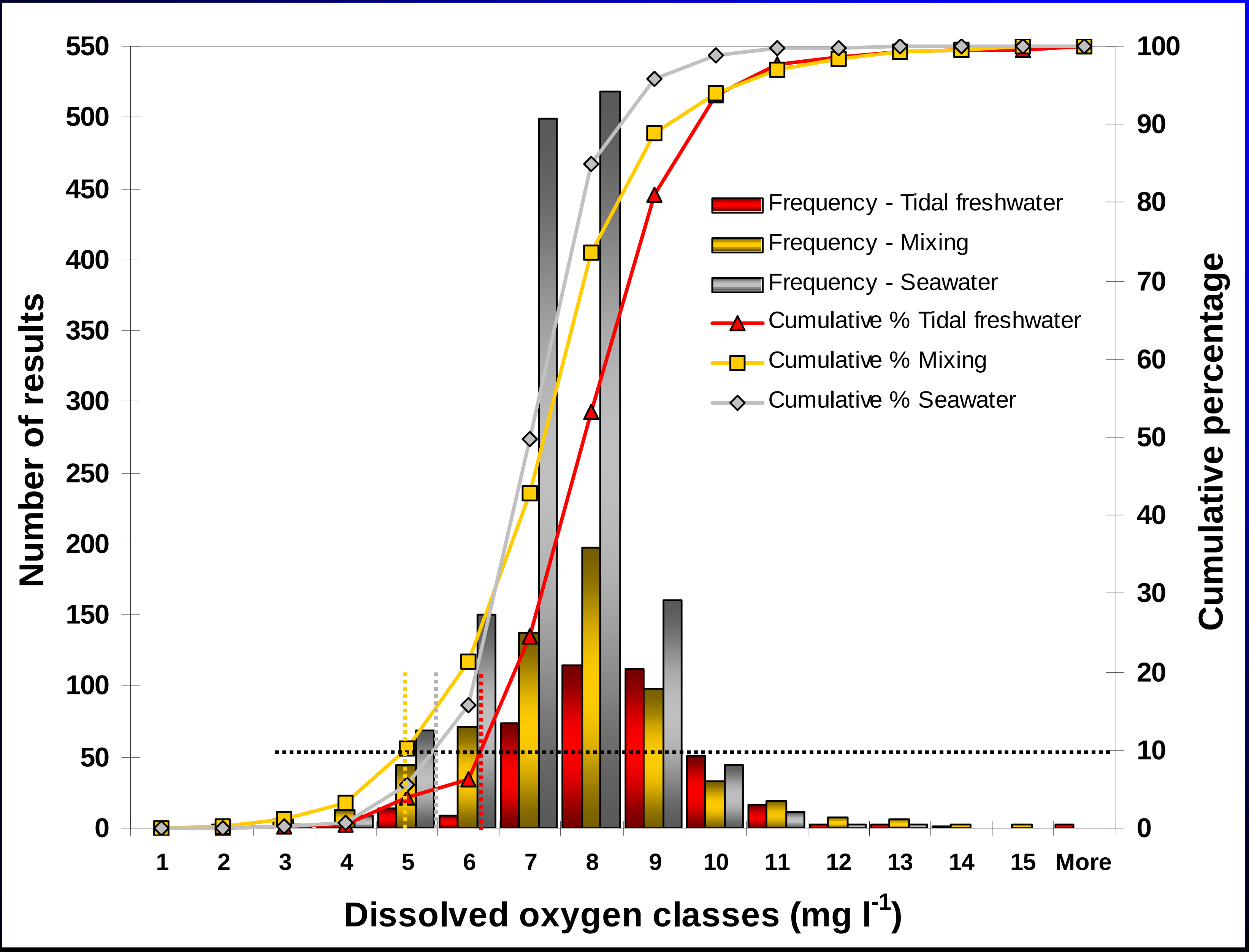
Pressure-State relationships



State as a function of pressure

Degradation as a function of pressure

ASSETS calculation of secondary symptom dissolved oxygen scores



ASSETS – Assessment of State

Overall level of expression of eutrophic conditions

	Low secondary symptoms (0–0.3)	Moderate secondary symptoms (0.3–0.6)	High secondary symptoms (0.6–1)
High primary symptoms (0.6–1)	MODERATE Primary symptoms high but problems with more serious secondary symptoms still not being expressed	MODERATE HIGH Primary symptoms high and substantial secondary symptoms becoming more expressed, indicating potentially serious problems	**HIGH** **High primary and secondary symptom levels indicate serious eutrophication problems**
Moderate primary symptoms (0.3–0.6)	MODERATE LOW Primary symptoms beginning to indicate possible problems but still very few secondary symptoms expressed	MODERATE Level of expression of eutrophic conditions is substantial	**HIGH** **Substantial levels of eutrophic conditions occuring with secondary symptoms indicating serious problems**
Low primary symptoms (0–0.3)	LOW Level of expression of eutrophic conditions is minimal	MODERATE LOW Moderate secondary symptoms indicate substantial eutrophic conditions, but low primary indicates other factors may be involved	MODERATE HIGH High secondary symptoms indicate serious problems, but low primary indicates other factors may also be involved in causing conditions

ASSETS scoring system for PSR

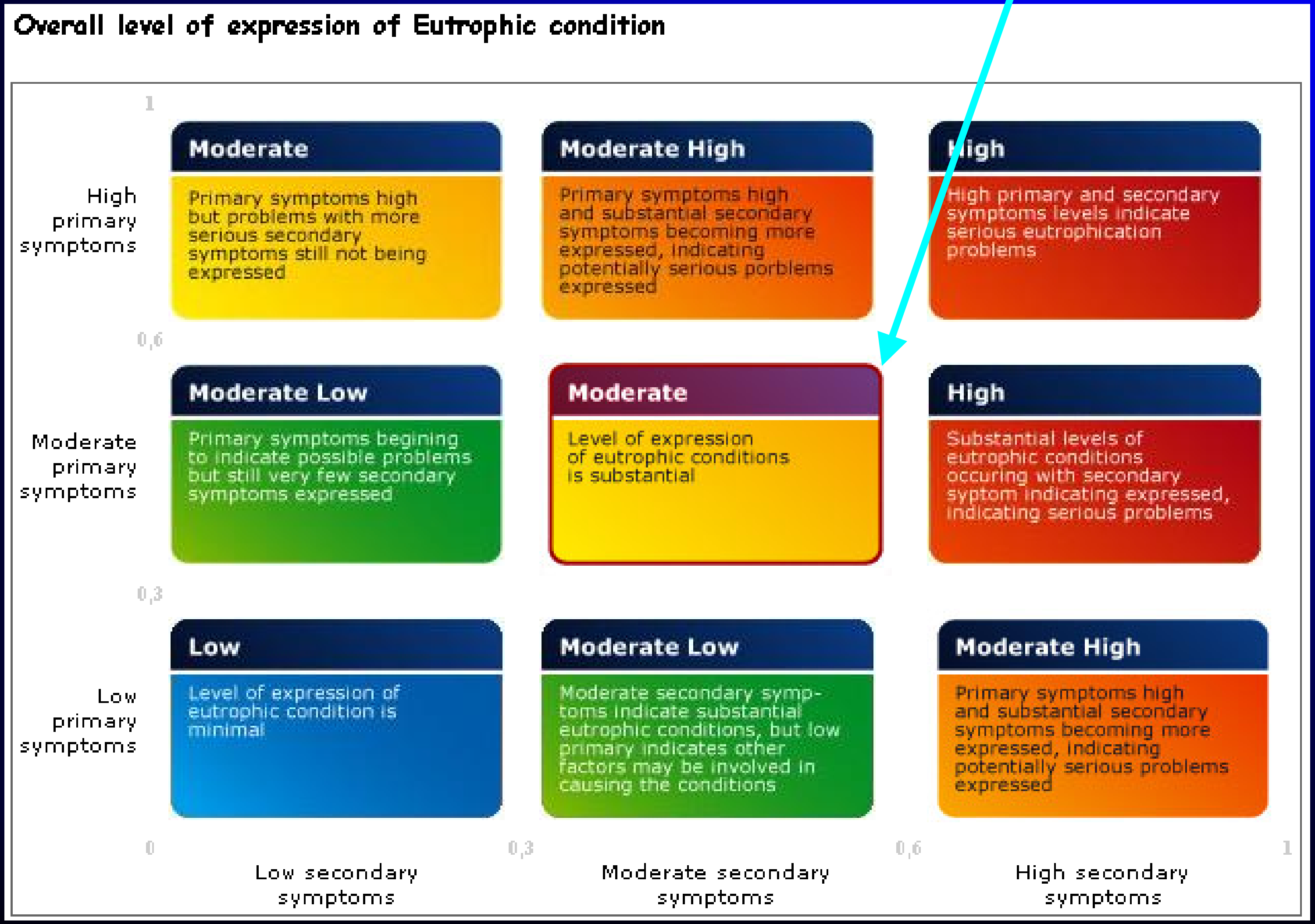
Grade	5	4	3	2	1
Pressure (IF)	Low	Moderate low	Moderate	Moderate high	High
State (OEC)	Low	Moderate low	Moderate	Moderate high	High
Response (FO)	Improve high	Improve low	No change	Worsen low	Worsen high

Metric	Combination matrix	Class
P	5 5 5 4 4 4	High
S	5 5 5 5 5 5	(5%)
R	5 4 3 5 4 3	
P	5 5 5 5 5 5 5 4 4 4 4 4 3 3 3 3 3 3	Good
S	5 5 4 4 4 4 4 5 5 4 4 4 5 5 5 4 4 4	(19%)
R	2 1 5 4 3 2 1 2 1 5 4 3 5 4 3 5 4 3	
P	5 5 5 5 5 4 4 4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 1 1	Moderate
S	3 3 3 3 3 4 4 3 3 3 3 3 5 5 4 4 3 3 3 4 4 4 4 4 3 3 3 2 3 3	(32%)
R	2 1 5 4 3 2 1 5 4 3 2 1 2 1 2 1 5 4 3 5 4 3 2 1 5 4 3 5 5 4	
P	4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 1 1 1 1 1	Poor
S	2 2 2 2 2 3 3 2 2 2 2 2 3 3 2 2 2 2 3 3 3 2 2	(24%)
R	5 4 3 2 1 2 1 5 4 3 2 1 2 1 4 3 2 1 3 2 1 5 4	
P	3 3 3 3 3 2 2 2 2 2 1 1 1 1 1 1 1 1	Bad
S	1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 1	(19%)
R	5 4 3 2 1 5 4 3 2 1 3 2 1 5 4 3 2 1	

ASSETS – Classification of State

http://www.eutro.org

Boston Harbor



ASSETS – Classification of State

http://www.eutro.org/syslist.aspx

Go | Links | Norton Ant

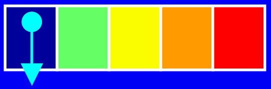
ASSETS Assessment of Estuarine Trophic Status

MODEL | SYSTEMS | RATINGS | RATING MAPS | TYPOLOGY | WATERBODIES

Systems

System	Country	Region	Surface area (Km^2)	OEC	ASSETS grade
Alamitos Bay	United States	U.S. Pacific	2	Moderate Low	
Albemarle Sound	United States	U.S. South Atlantic	2496.98	Low	
Alsea River	United States	U.S. Pacific	9	Moderate Low	
Altamaha River	United States	U.S. South Atlantic	39.1	Moderate Low	
Anaheim Bay	United States	U.S. Pacific	5	Moderate	
Apalachee Bay	United States	U.S. Gulf of Mexico	1773	Moderate Low	
Apalachicola Bay	United States	U.S. Gulf of Mexico	593.7	Low	

Strangford Lough, N. Ireland
ASSETS Application



ASSETS: HIGH

Indices	Methods	Parameters	Rating	Expression	Index
Influencing Factors (IF) ASSETS: 5	Susceptibility	Dilution potential	High	Low susceptibility	Low
		Flushing potential	Moderate		
	Nutrient inputs		Low		
Overall Eutrophic Condition (OEC) ASSETS: 5	Primary	Chlorophyll *a*	Moderate	Moderate	LOW
		Macroalgae	Problems observed		
	Secondary	Dissolved Oxygen	No problems	Low	
		Submerged Aquatic Vegetation	Losses observed		
		Nuisance and Toxic Blooms	No		
Future Outlook (FO) ASSETS: 4	Future nutrient pressures	Future nutrient pressures decrease			Improve Low

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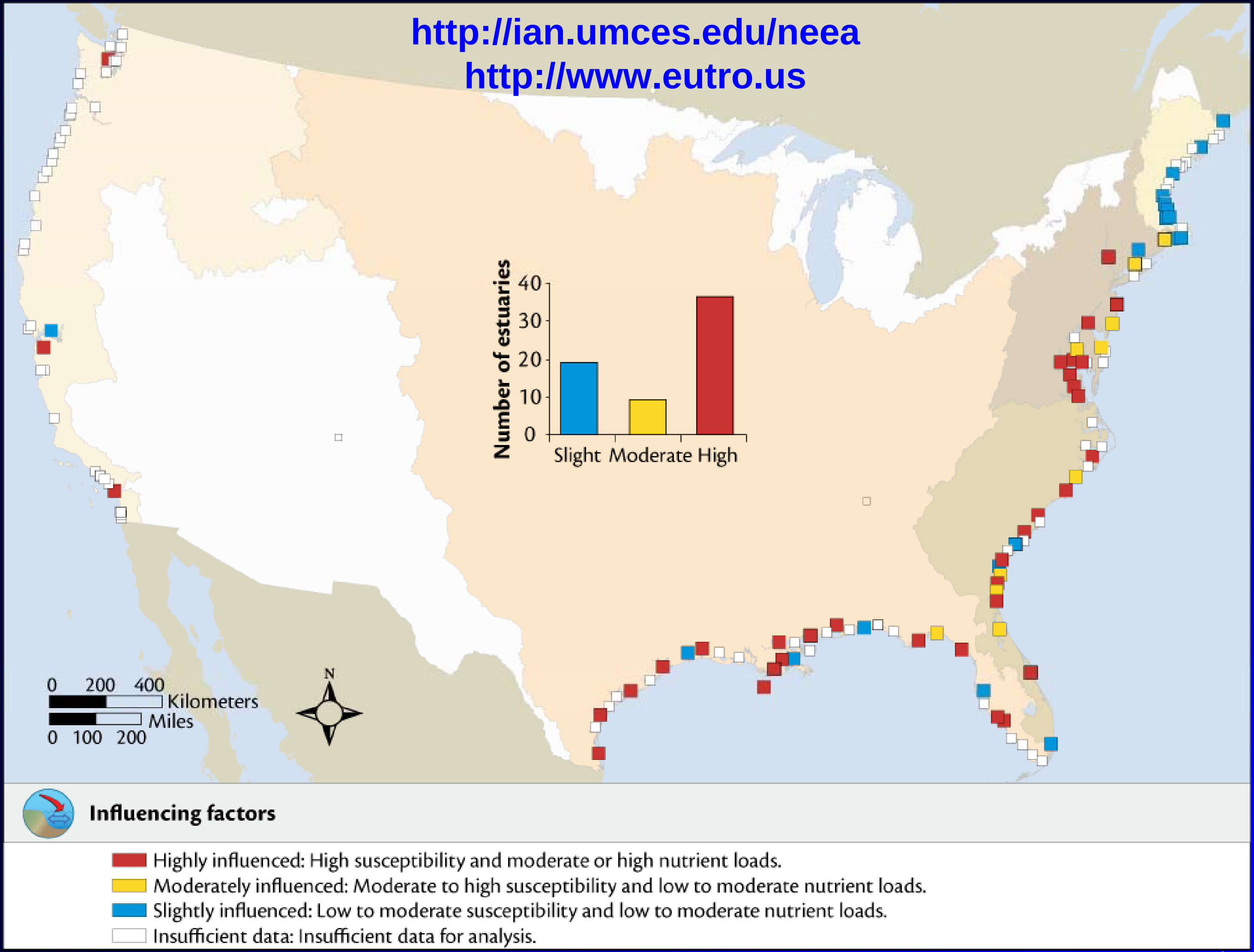
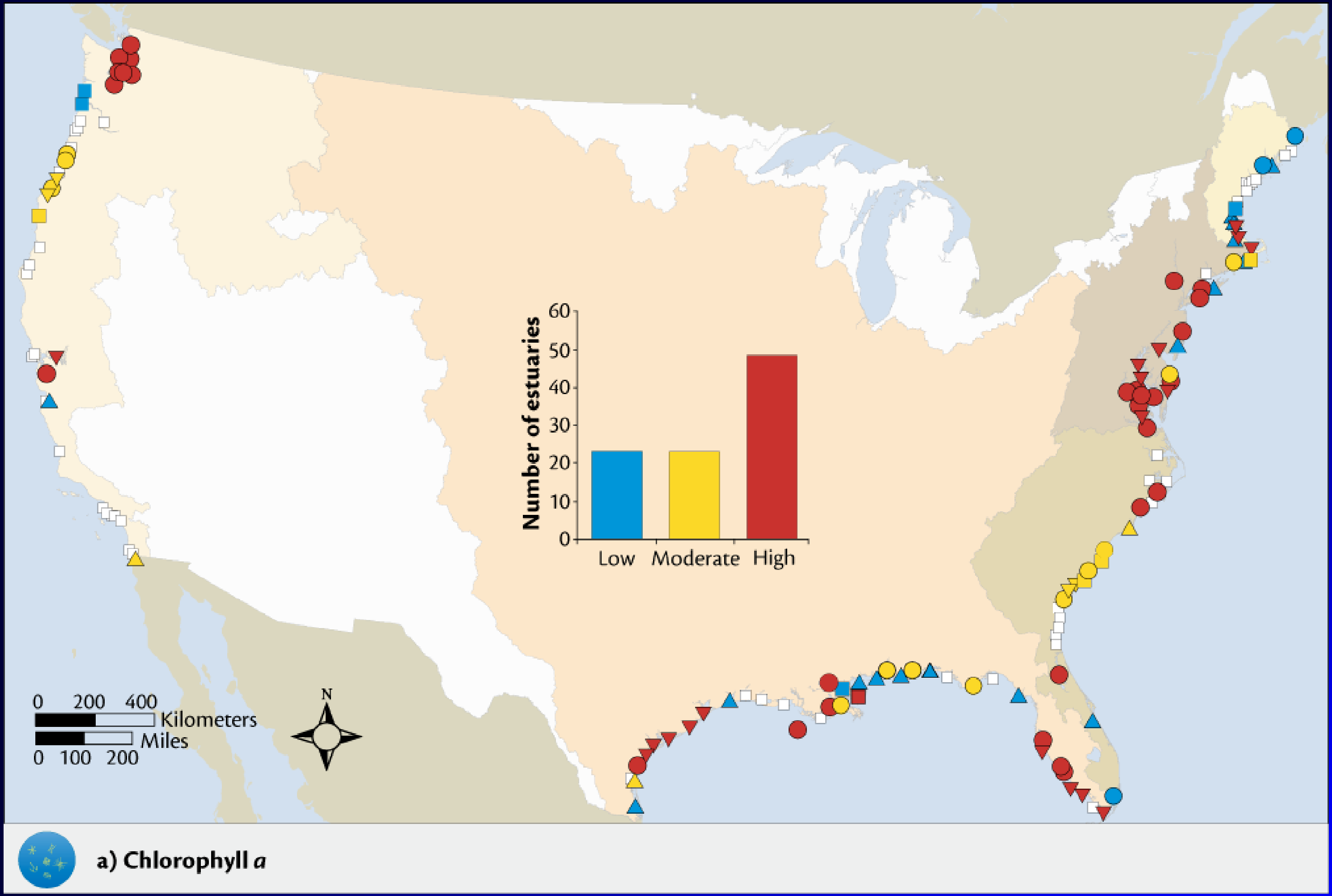
Influencing Factors



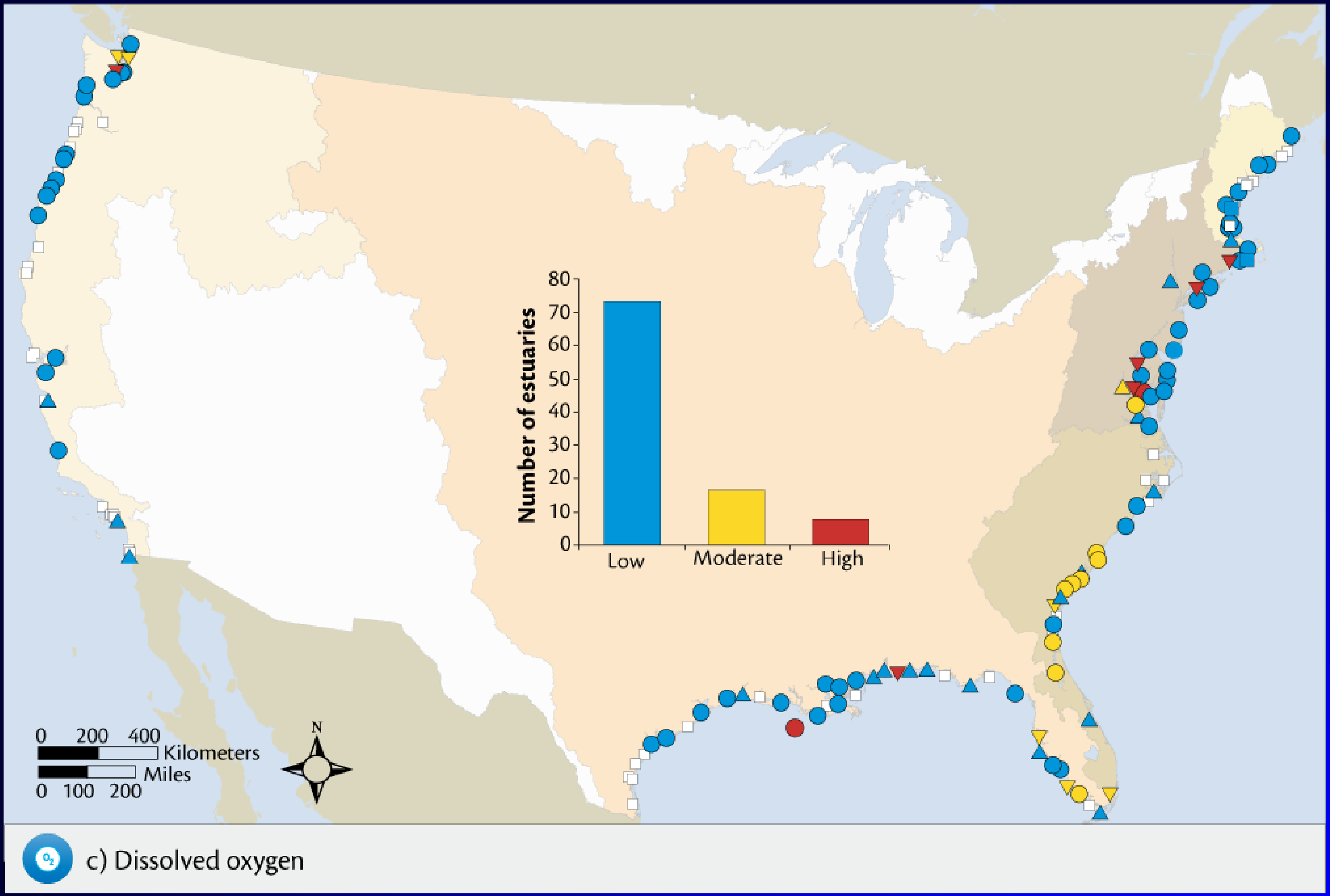
	1990s	2000s
Assessed systems with moderate to high rating	69%	72%
Unknown systems	2	76

Symptom Expression - Chlorophyll *a*



Most commonly reported symptom

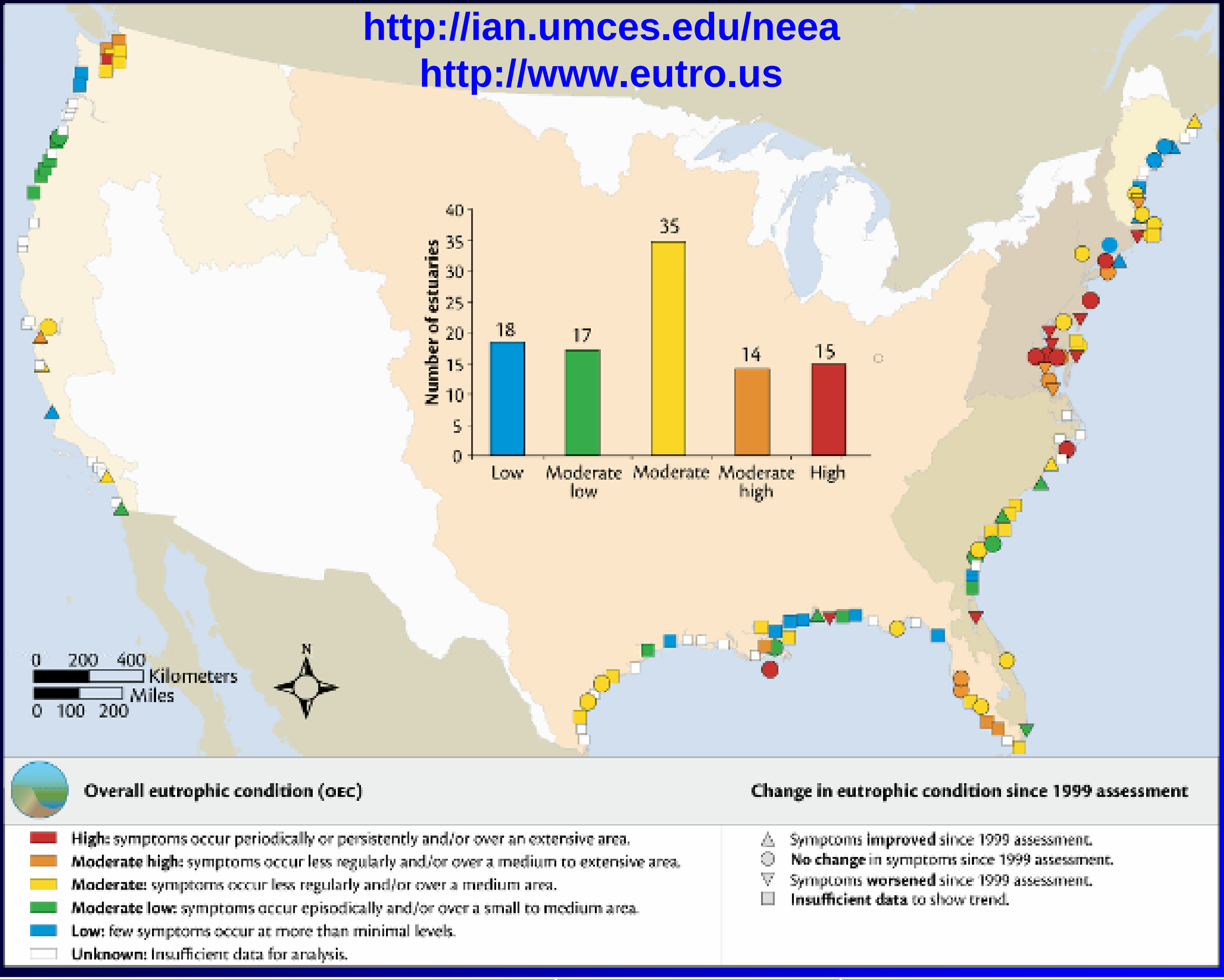
Symptom Expression -Dissolved Oxygen



Not a widespread problem

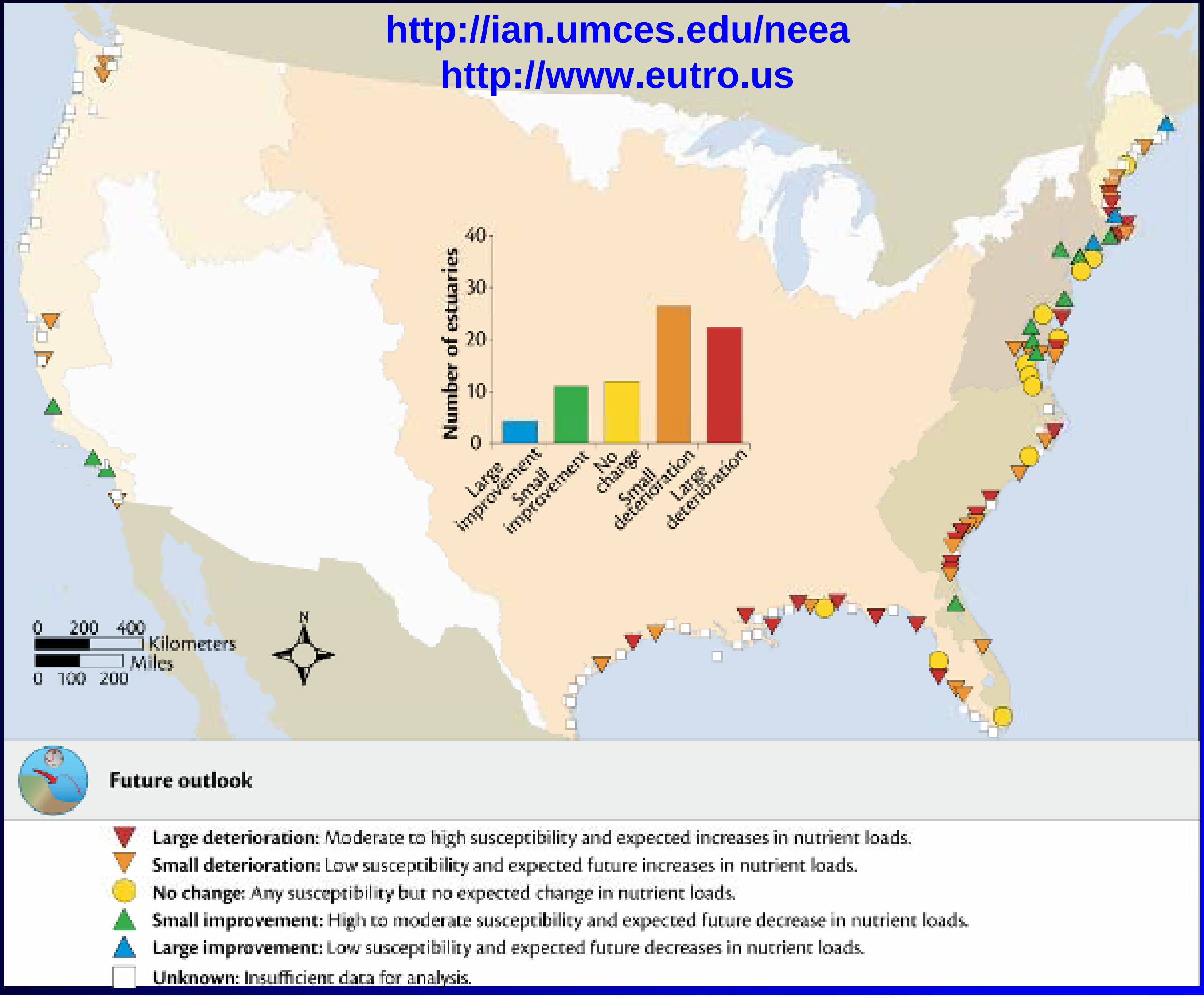
Overall Eutrophic Condition

http://ian.umces.edu/neea
http://www.eutro.us



	1990s	2000s
Assessed systems with moderate to high rating	69%	65%
Number of systems - Unknown	17	42

Future Outlook



	1990s	2000s
Assessed systems expected to worsen	71%	65%
Assessed systems expected to improve	7%	20%

Overalll Eutrophic Condition Changes USA: 1990s – 2000s

Improved:

- **13 systems (9%) assessed surface area**
- **Due to management efforts, primarily point source**

Worsened:

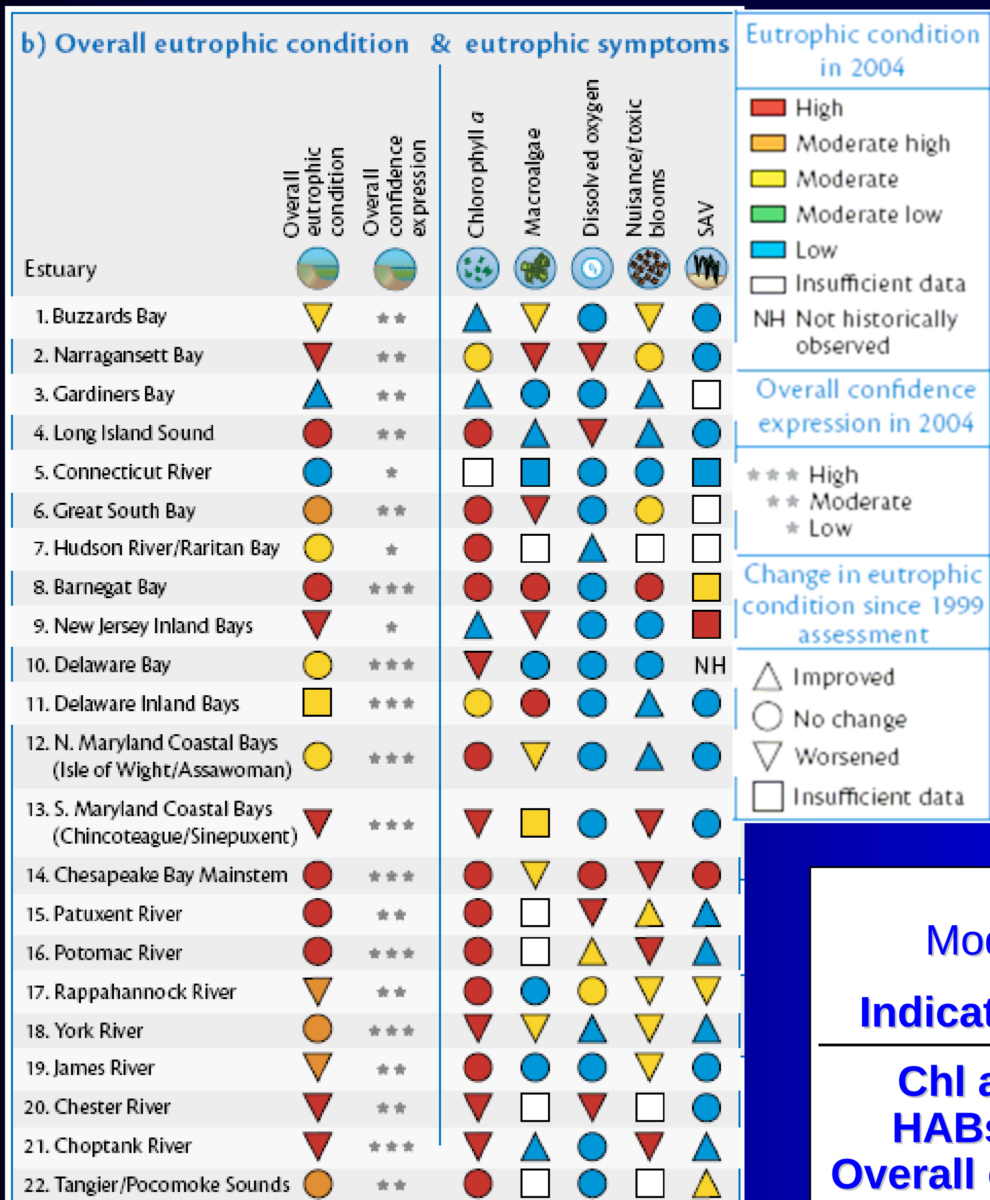
- **13 systems (14%) assessed area**
- **Due to population increase and associated activities**

Remained the same:

- **32 systems (77%) assessed area**

Analysis was possible for 58 of 141 systems

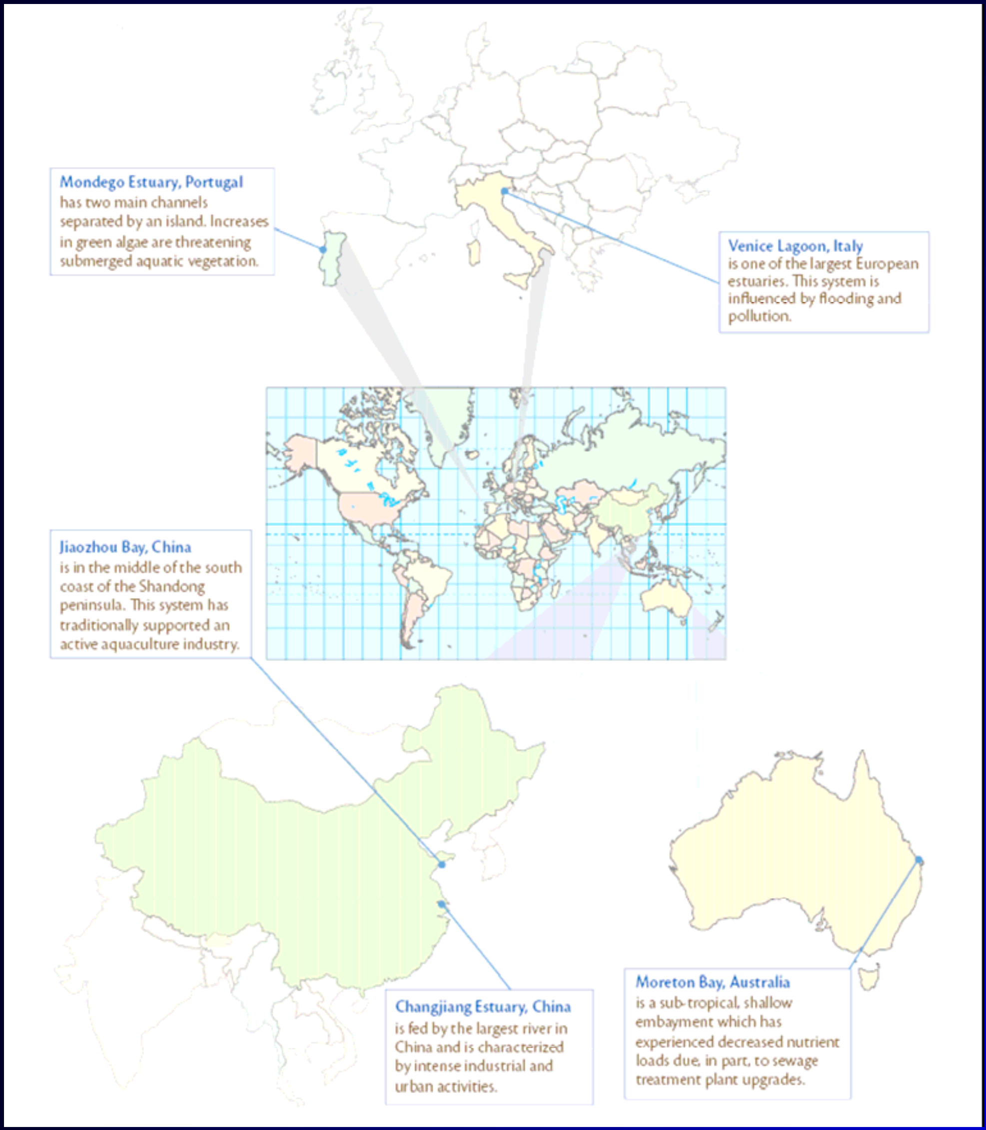
Trends - mid Atlantic Systems



% assessed systems with
Moderate & High symptom expression

Indicator	1999	2004	% change
Chl a	100	86	-14
HABs	50	63	13
Overall eutro	68	91	23

International Case Studies



Some examples:

Boston Harbor

Diversion of sewage effluent to offshore discharge reduced eutrophic symptoms

Long Island Sound

Reduction in point source nutrients ameliorated hypoxia in the 1990s

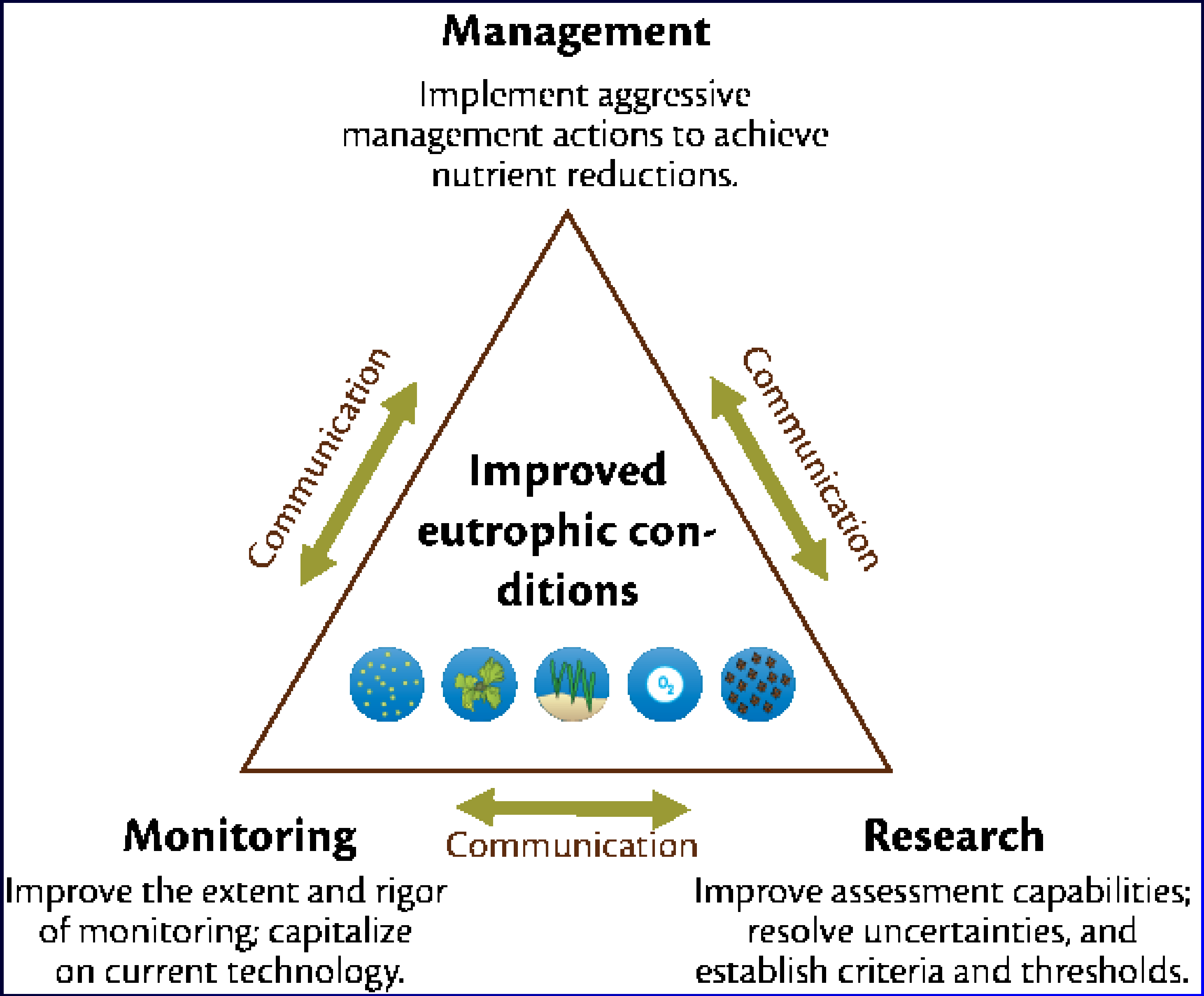
Venice Lagoon, Italy

Flood protection measures can accentuate eutrophic symptoms (e.g., dissolved oxygen, macroalgae, and loss of SAV)

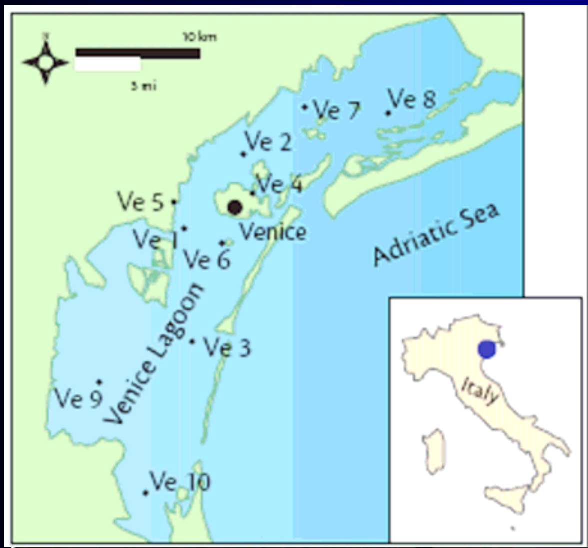
Jiaozhou Bay, China

Threats from eutrophication to large scale aquaculture stimulate nutrient management)

Recommendations



Venice Lagoon case study: The Problem



1960s and 1970s
Uncontrolled discharge of nutrients

_1980s_
Hypereutrophic conditions

Macroalgal density = 20 kg FW m^{-2}

Loss of SAV beds and change in species abundance

Severe anoxia in parts of the lagoon

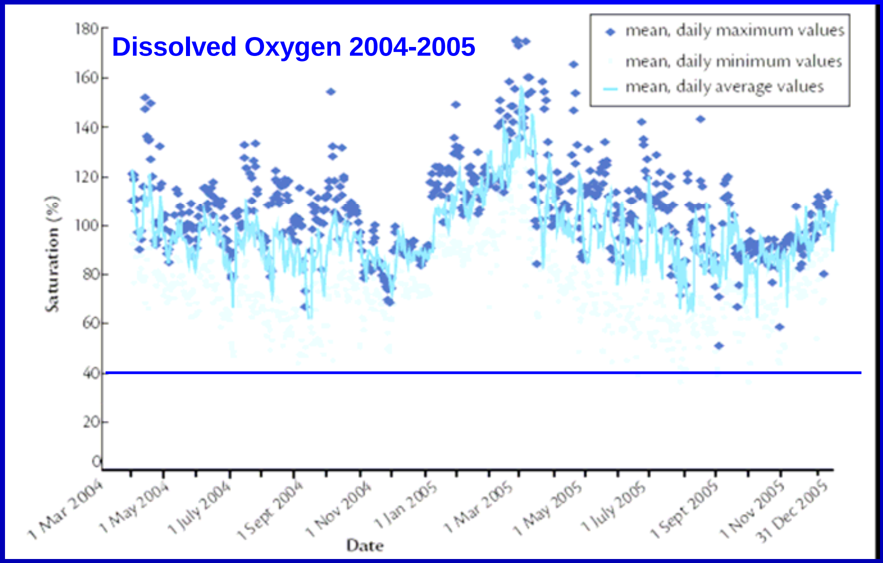
Venice Lagoon case study: The Solution

1980s

- ❑ Wastewater treatment plants (WWTP) built
- ❑ Phosphorus banned from detergents and replaced by zeolites

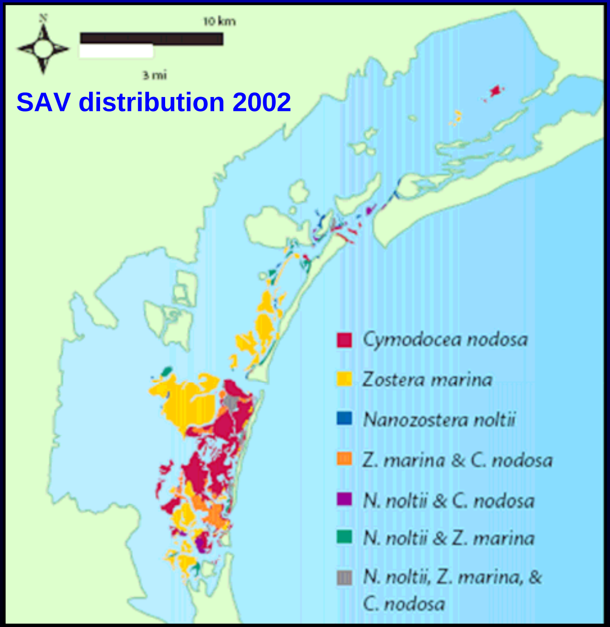
1990s to present

- ❑ Decrease in nutrient loads and P concentrations
- ❑ Macroalgal density now 0.5 FW m^{-2}
- ❑ SAV beds returning - since 1992:
- ❑ *Zostera marina* increased (2.6 – 22 km^2) together with *Cymodocea nodosa*
- ❑ *Nanozostera noltii* decreased (14 – 0.7 km^2). This may be linked to light limitation due to other factors
- ❑ No anoxia – DO at 40% saturation, adequate for aquatic life



Future

- ❑ New WWTP and phytodepuration plants planned
- ❑ Industrial zone effluents closely monitored
- ❑ Continued improvement expected



Venice Lagoon
ASSETS Application (early 2000s)

ASSETS: GOOD

Indices	Methods	Parameters	Rating	Expression	
Influencing Factors (IF) ASSETS: 3	Susceptibility	Dilution potential	Moderate	Moderate susceptibility	Moderate
		Flushing potential	Moderate		
	Nutrient inputs		Moderate		
Overall Eutrophic Condition (OEC) ASSETS: 5	Primary	Chlorophyll *a*	Low	Low	LOW
		Macroalgae	Low		
	Secondary	Dissolved Oxygen	Low	Low	
		Submerged Aquatic Vegetation	Low		
		Nuisance and Toxic Blooms	Low		
Future Outlook (FO) ASSETS: 4	Future nutrient pressures	Future nutrient pressures decrease			Improve Low

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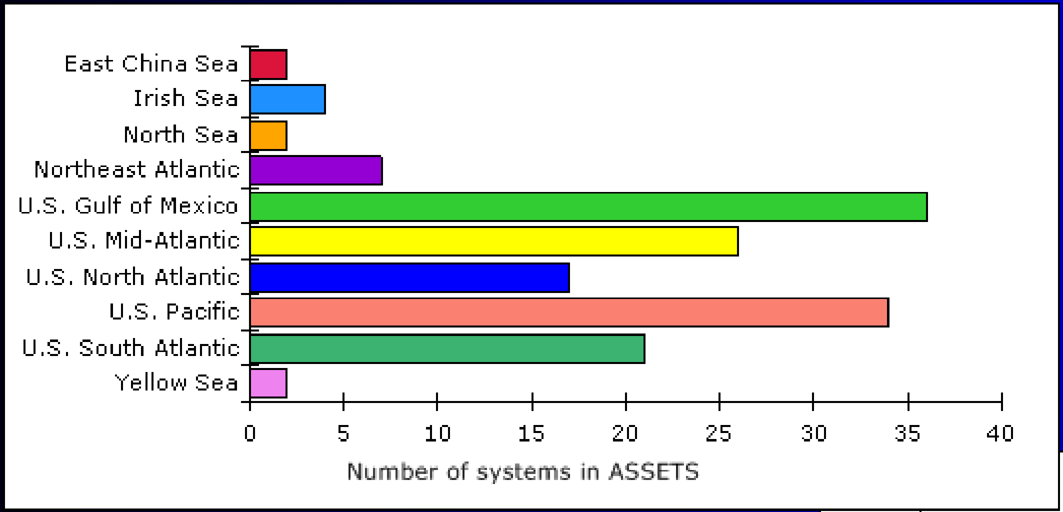
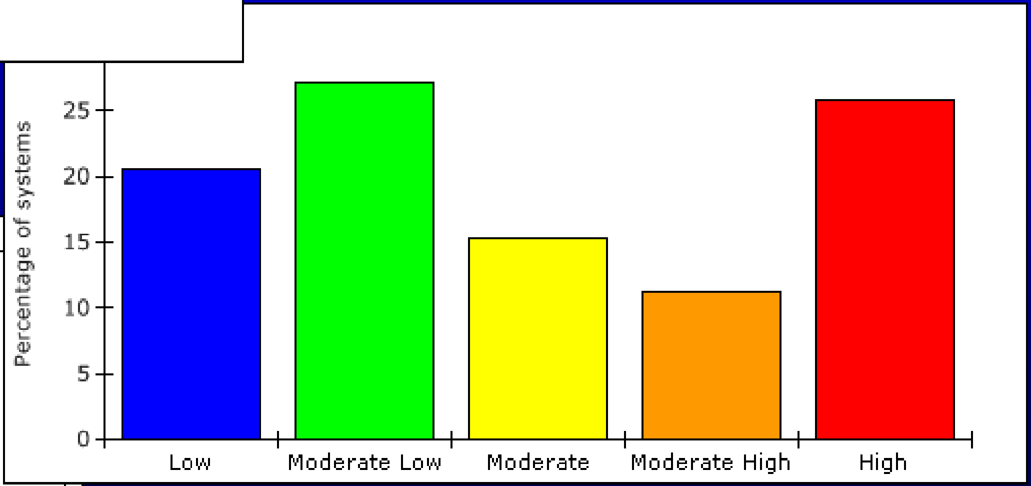
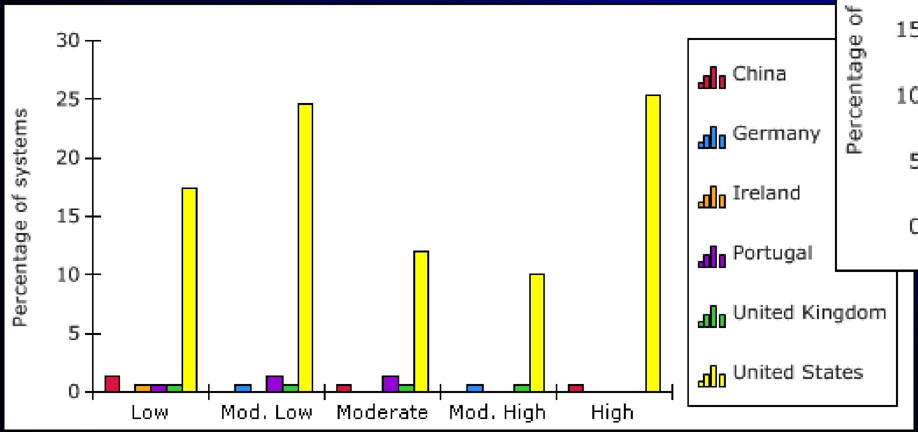
ASSETS systems and grades







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ASSETS Synthesis (as percent assessed)

	US 1990s	US 2000s	EU	CN
High	2	2	29	25
Good	16	10	43	25
Moderate	23	38	29	
Poor	44	23		25
Bad	15	27		25

Management challenge

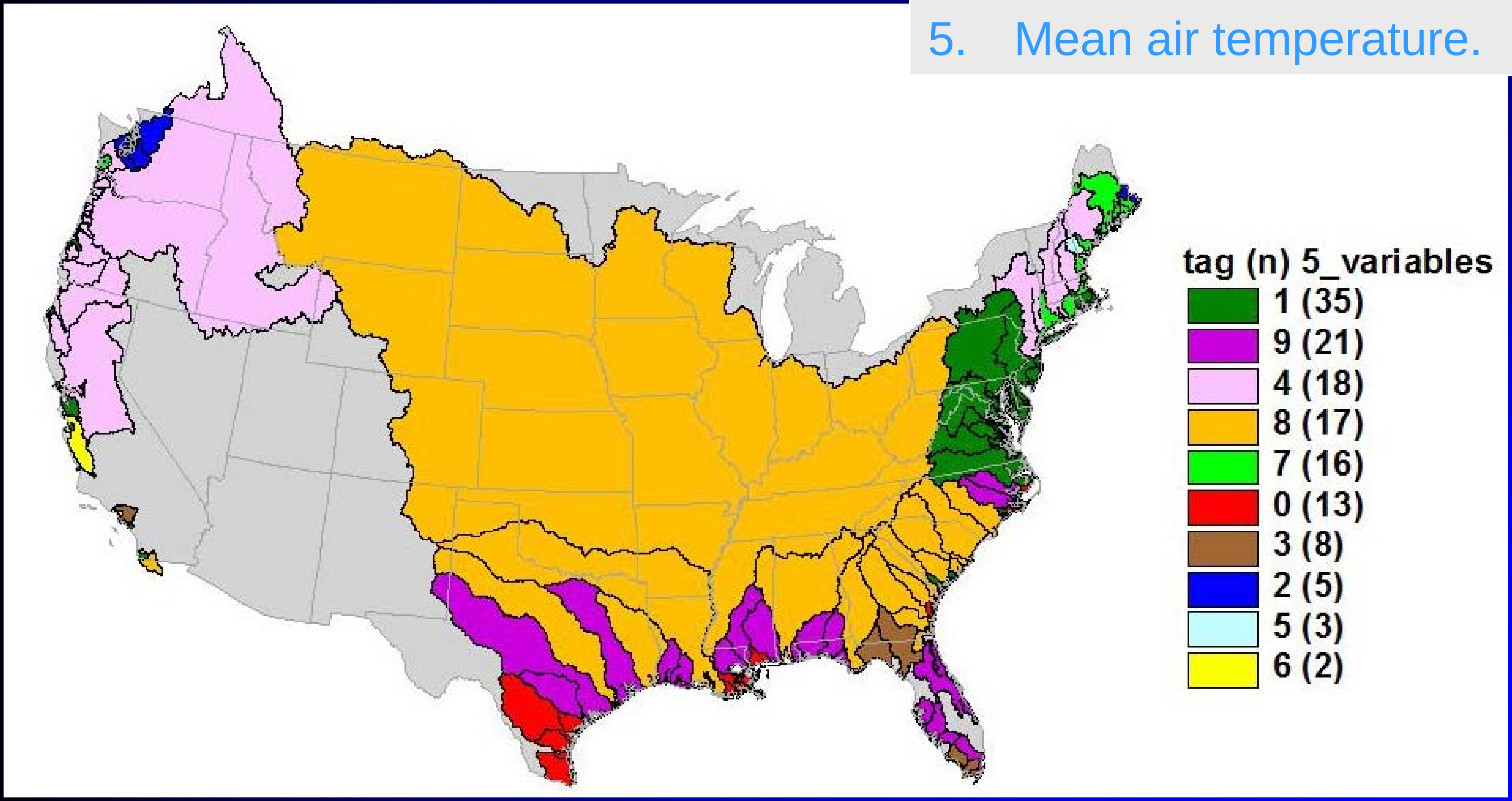
Total assessed in 1990s = 120, in 2000s = 48, EU = 7, CN = 4

US typology

DISCO – Deluxe Integrated System for Clustering Operations (successor of LOICZView)

Example: Division into ten types

1. Mean depth;
2. Percentage open mouth;
3. Tide height;
4. log (freshwater flow/area);
5. Mean air temperature.



S. V. Smith, R. W. Buddemeier, S. B. Bricker, P. Pacheco, A. Mason, B.A. Maxwell. Estuarine Typology: Perturbations and Eutrophication Responses. ASLO/TOS ORC, February 2004.

Use of ASSETS with research models

ASSETS Model	Methods	Parameters	Value	Level of expression	Index
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25	0.57 Moderate	MODERATE LOW
		Epiphytes	0.50		
		Macroalgae	0.96		
ASSETS OEC: 4	SSM	Dissolved Oxygen	0	0.25 Low	
		Submerged Aquatic Vegetation	0.25		
		Nuisance and Toxic Blooms	0		
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25	0.58 Moderate	MODERATE LOW
		Epiphytes	*0.50*		
		Macroalgae	1.00		
ASSETS OEC: 4	SSM	Dissolved Oxygen	0	0.25 Low	
		Submerged Aquatic Vegetation	0.25		
		Nuisance and Toxic Blooms	0		
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25	0.42 Moderate	MODERATE LOW
		Epiphytes	*0.50*		
		Macroalgae	0.50		
ASSETS OEC: 4(5)	SSM	Dissolved Oxygen	0	0.25 Low	
		Submerged Aquatic Vegetation	0.25		
		Nuisance and Toxic Blooms	0		

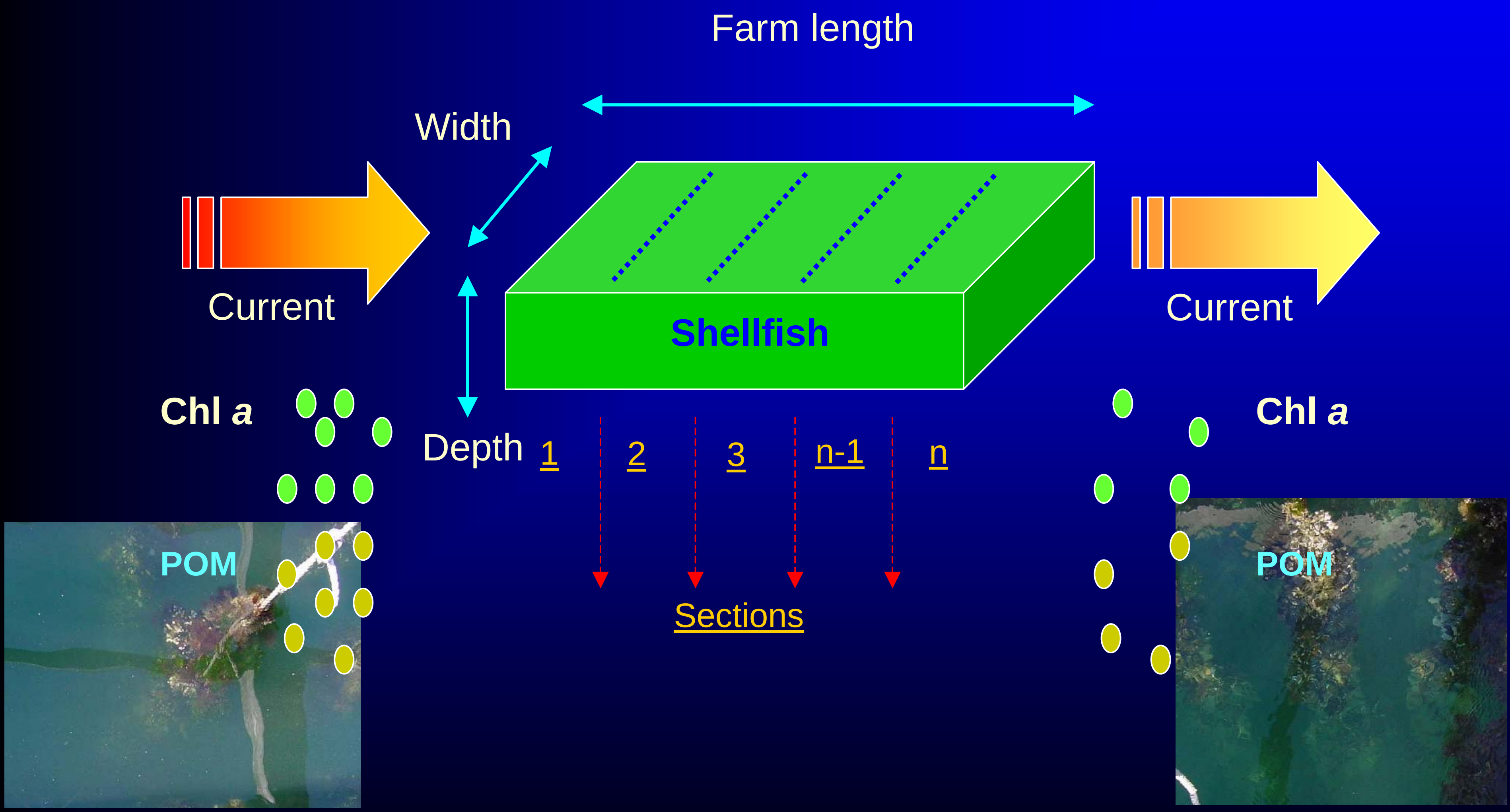
Field data

Research model

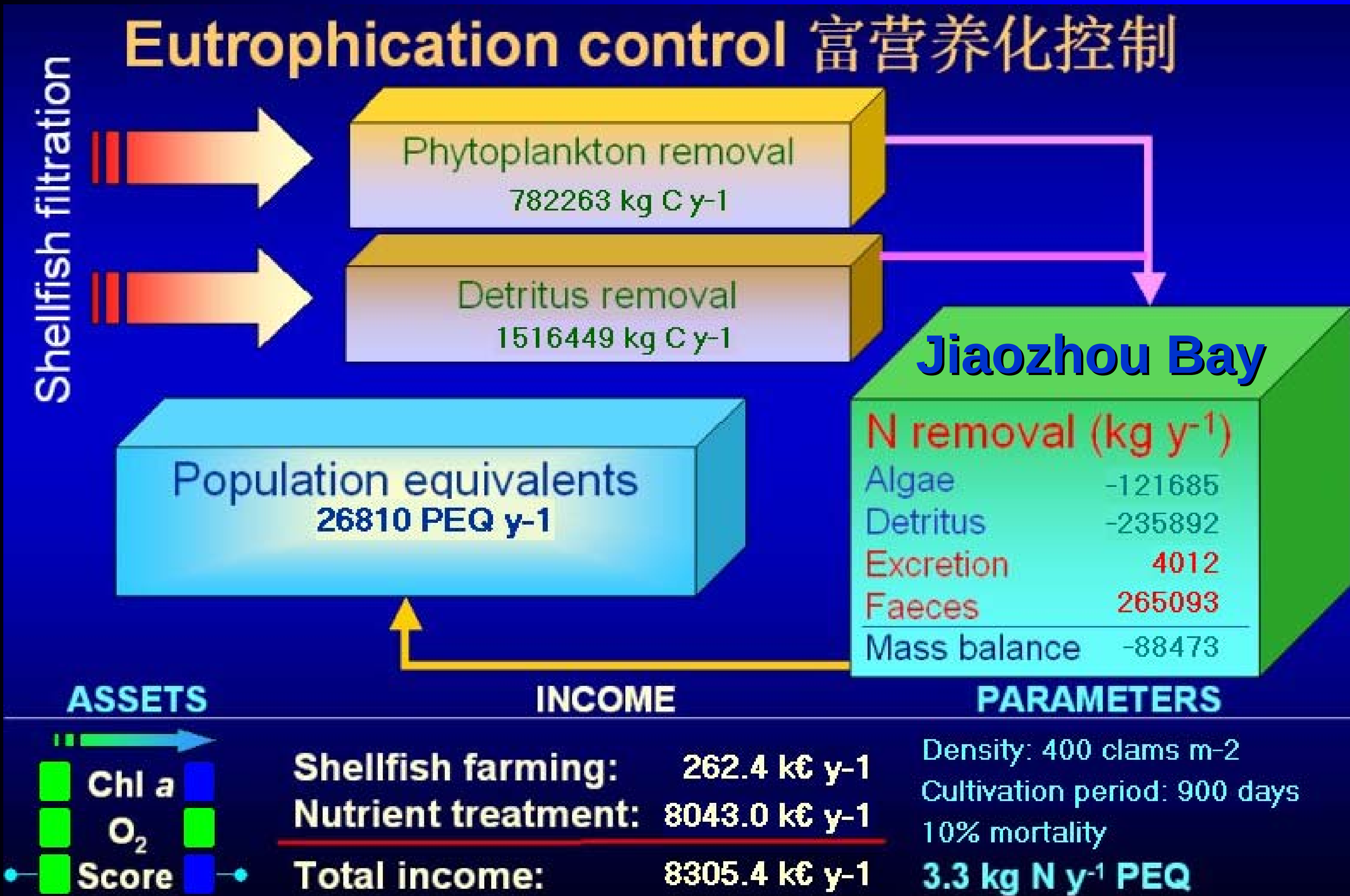
Model green scenario

28% lower

Farm-scale conceptual diagram



ASSETS application within FARM



ASSETS SCI journal papers

2007

- Xiao, Y., Ferreira, J.G., Bricker, S.B., Nunes, J.P., Zhu, M., Zhang X., 2007. Trophic Assessment in Chinese Coastal Systems - Review of methodologies and application to the Changjiang (Yangtze) Estuary and Jiaozhou Bay. Estuaries and Coasts, In Press.
- D. Whitall, S.B .Bricker, J.G. Ferreira, A.M. Nobre, T. Simas, M.C. Silva, 2007. Assessment of Eutrophication in Estuaries: Pressure-State-Response and Nitrogen Source Apportionment. Environmental Management, 40, 678-690.
- J. G. Ferreira, A.J.S. Hawkins, S.B. Bricker, 2007. Management of productivity, environmental effects and profitability of shellfish aquaculture – the Farm Aquaculture Resource Management (FARM) model. Aquaculture, 264, 160-174.
- J.G. Ferreira, S.B. Bricker, T.C. Simas, 2006. Application and sensitivity testing of an eutrophication assessment method on coastal systems in the United States and European Union. J. Environmental Management, 82, 433-445.
- J. G. Ferreira, A. M. Nobre, T. C. Simas, M. C. Silva, A. Newton, S. B. Bricker, W. J. Wolff, P.E. Stacey, A. Sequeira, 2006. A methodology for defining homogeneous water bodies in estuaries – Application to the transitional systems of the EU Water Framework Directive. Estuarine, Coastal and Shelf Science, 66 (3/4), 468-482.
- J.G.Ferreira, W.J.Wolff, T.C.Simas, S.B.Bricker, 2005. Does biodiversity of estuarine phytoplankton depend on hydrology? Ecological Modelling, 187(4) 513-523.
- A.M.Nobre, J.G.Ferreira, A.Newton, T.Simas, J.D.Icely, R.Neves, 2005. Management of coastal eutrophication: Integration of field data, ecosystem-scale simulations and screening models. Journal of Marine Systems, 56 (3/4), 375-390.
- Newton, A., Icely, J.D., Falcão, M., Nobre, A., Nunes, J.P., Ferreira, J.G., Vale, C., 2003. Evaluation of Eutrophication in the Ria Formosa coastal lagoon, Portugal. Continental Shelf Research, 23, 1945-1961.
- Bricker, S.B., J.G. Ferreira, T. Simas, 2003. An Integrated Methodology for Assessment of Estuarine Trophic Status. Ecological Modelling, 169(1), 39-60.

2003

Potential collaboration topics

- Use historical data from the Venice Lagoon to test the sensitivity and responsiveness of ASSETS, given that the system has changed significantly over the years;

- Apply system-scale ecological models to look at loading scenarios, and use the outputs to drive ASSETS, as a management-oriented tool;

- Link these models to socio-economic work to try to improve the valuation aspect of management alternatives. Venice could be a template site for bringing this capability to ASSETS.

National and International Partners