Diversity of ecosystems and coastal ocean CO_2 fluxes

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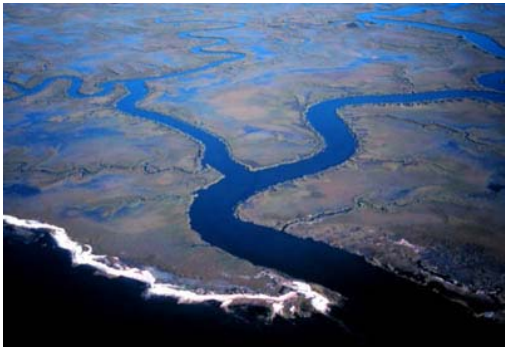


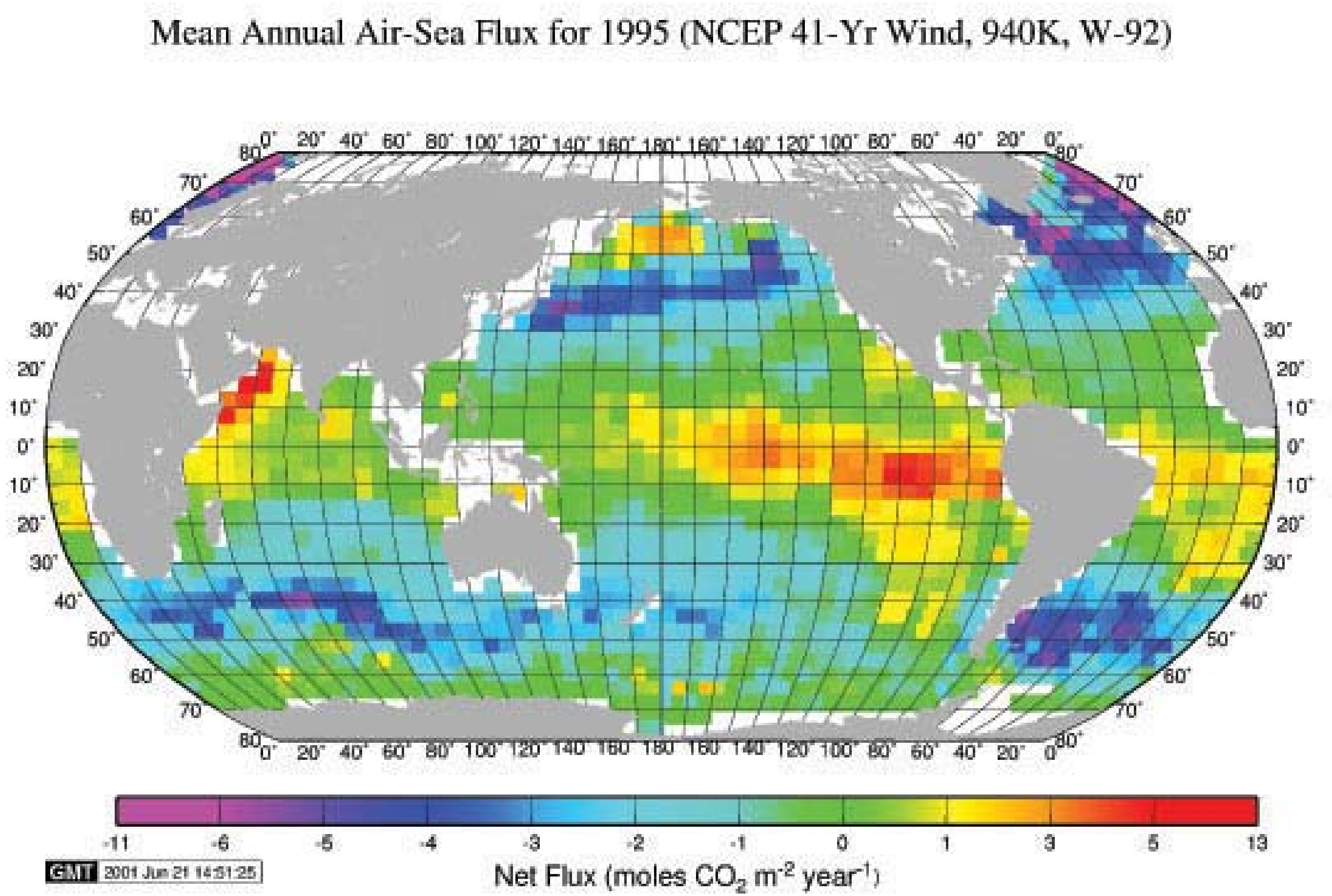
Carboocean (FP6 511176-2)

Eurotroph (FP5 EVK3-CT-2000-00040)

Belcanto (BSP EV/12/7E)

Canopy (BSP EV/12/20C)

Issue



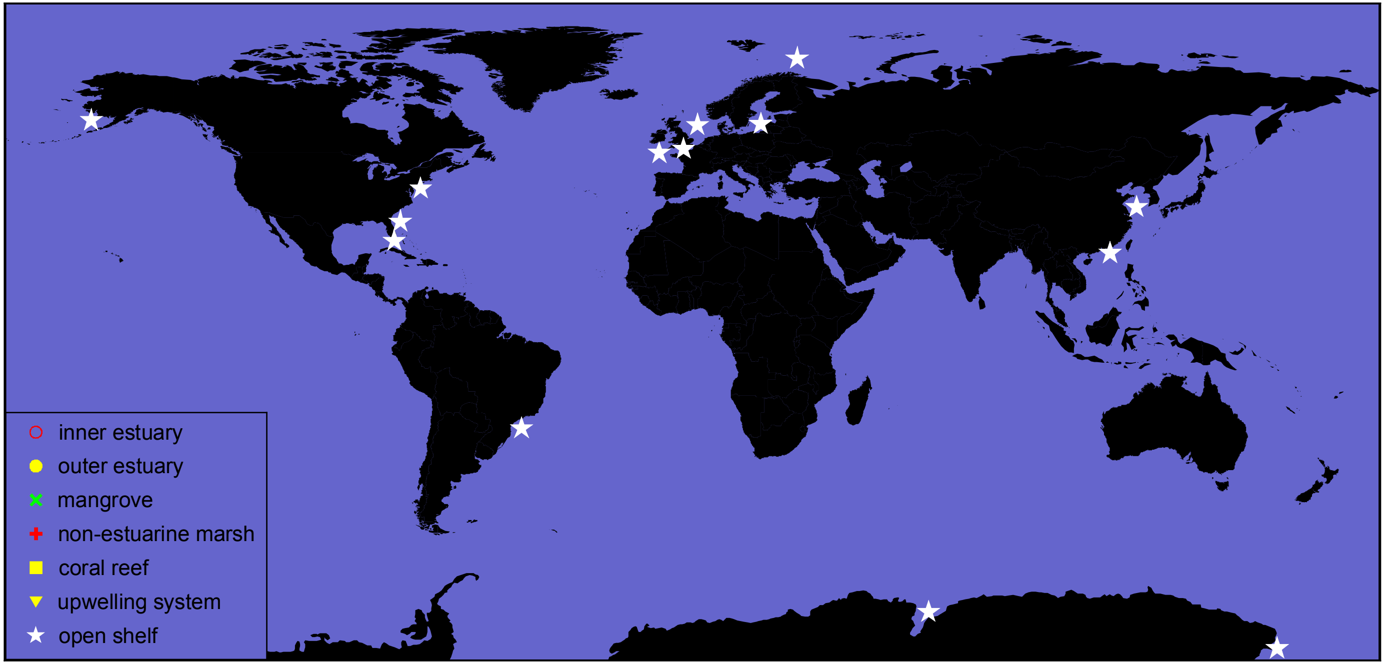
Takahashi, T. et al. (2002). Deep-Sea Res. II, 1601-1622.

What would happen if we tried to fill the white pixels ?

Approach

- Climatology approach not possible (too much heterogeneity, not enough data).
- Just about enough data to attempt an up-scaling approach (reasonable flux value for each ecosystem * respective surface area)
- Compilation of CO_2 fluxes in 44 coastal environments, gathered in 6 major coastal ecosystems.
- In some cases, enough pCO_2 data in literature but fluxes not estimated.
Computed from NOAA-CIRES NCEP daily wind speeds and Wanninkhof (1992) gas transfer parameterization (W92).
- For marginal seas, published fluxes were homogenised to W92 using conversion factors derived from the Rayleigh frequency distribution.

Marginal seas (Fluxes in mol C m^{-2} yr^{-1})



High latitude:

Barents Sea	-3.6
Bristol Bay	-0.2
Pryzd Bay	-2.2
Ross Sea	-1.8

"Seasonal Rectification Hypothesis"
Ice-free periods = biological CO_2 drawdown

Temperate latitudes:

Baltic Sea	-0.8
North Sea	-1.4
English Channel	0.0
Gulf of Biscay	-2.9
US Middle Atlantic Bight	-1.2
East China Sea	-2.1

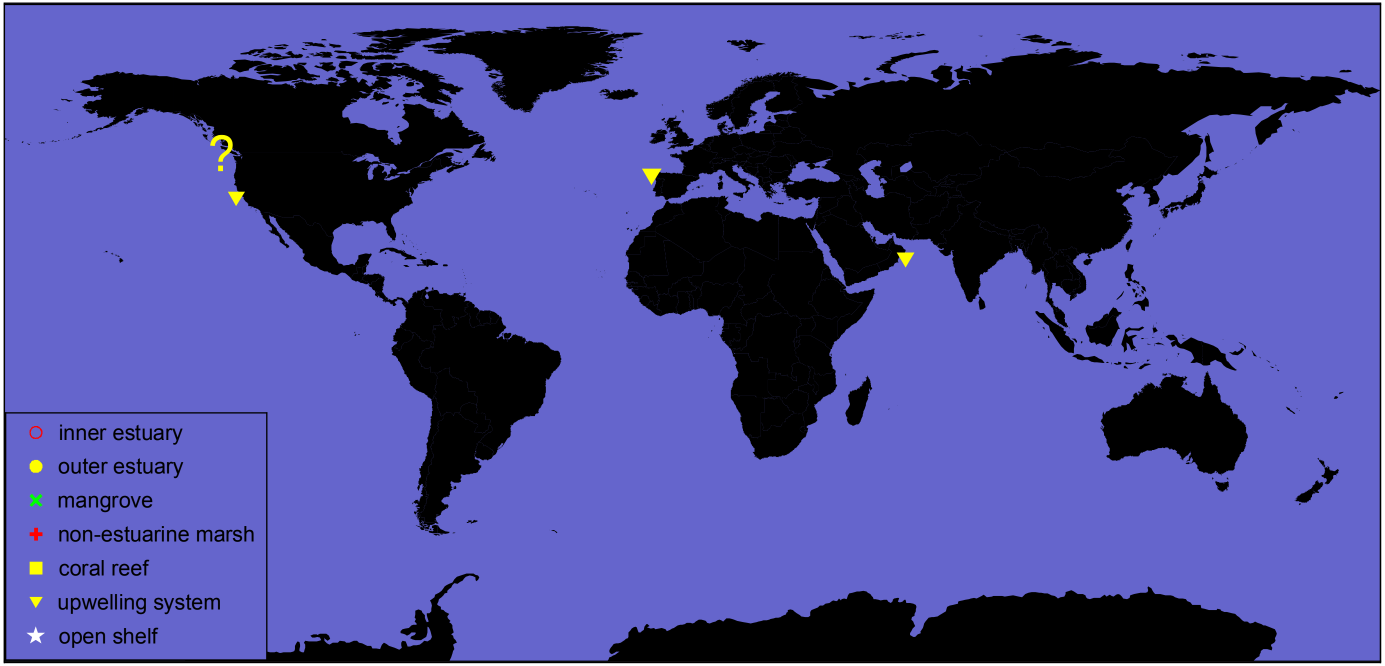
Incoming oceanic seawater under-saturated (annually)
+ biological CO_2 drawdown
("continental shelf pump hypothesis")

Sub-tropical & tropical latitudes:

US South Atlantic Bight	+2.5
South China Sea	+1.8
Southwest Brazilian coast	+1.3

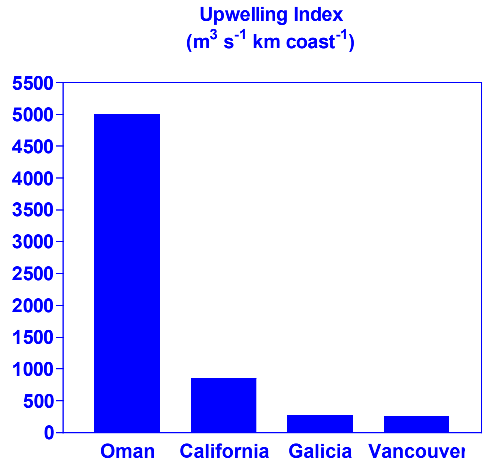
Incoming oceanic seawater over-saturated (annually)
+ biological CO_2 production (higher organic carbon terrestrial loadings, narrower shelves)

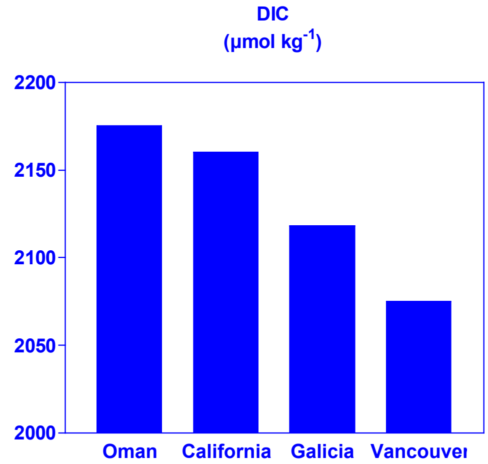
Coastal upwelling (Fluxes in mol C m^{-2} yr^{-1})

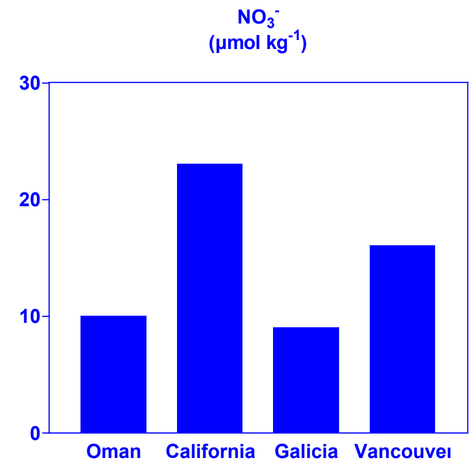


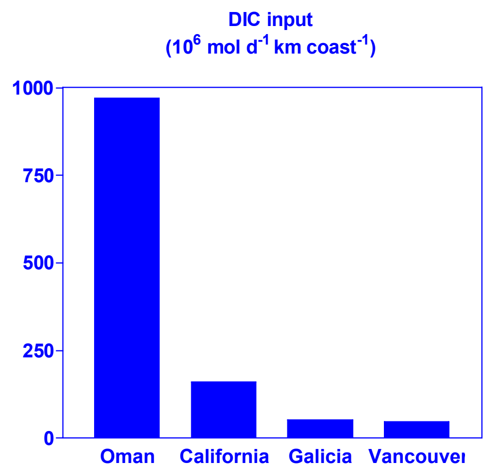
Galician coast	-2.2
Vancouver Island	-1.2
Californian coast	+0.5
Oman coast	+0.9

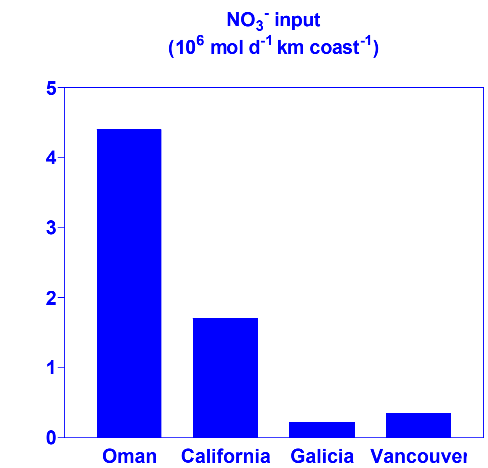
Coastal upwelling







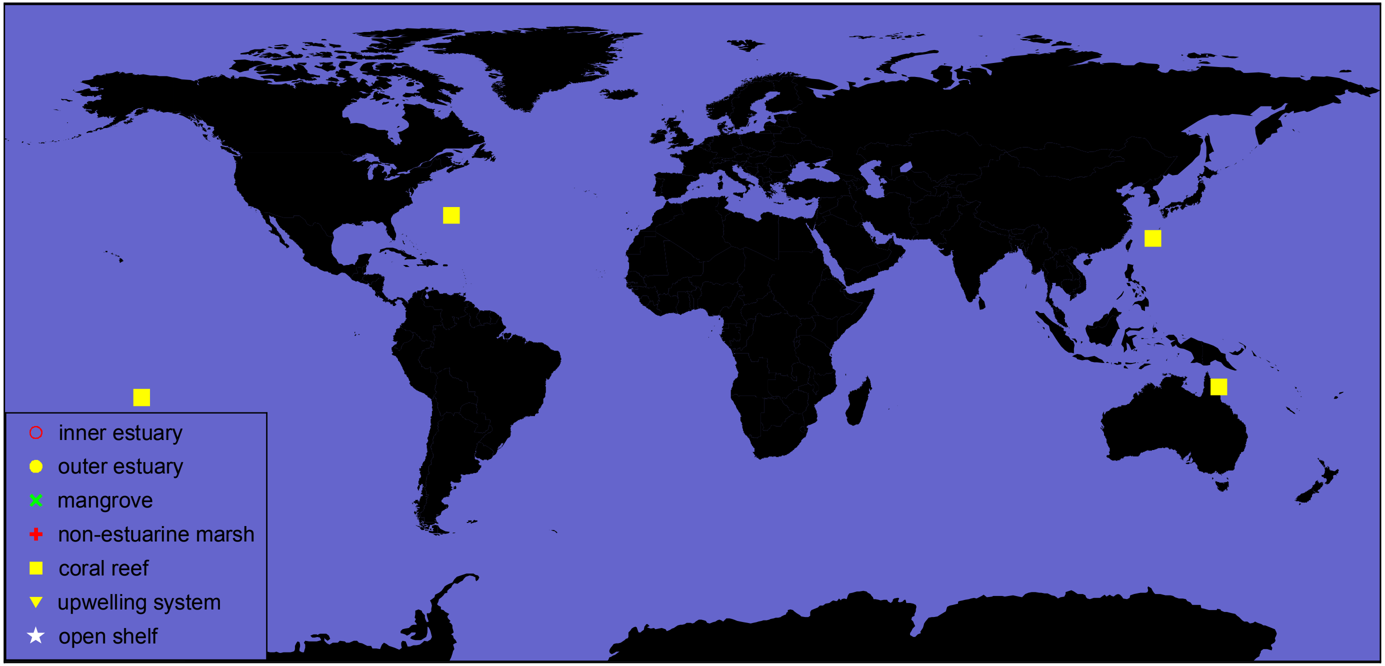




High Upwelling Index systems
= inputs of nutrients and DIC so intense that primary production "does not have enough time" to deplete surface waters and create under-saturation of CO_2 OVER THE SHELF.
= sources of CO_2

... Low Upwelling Index systems

Coral Reefs (Fluxes in mol C m^{-2} yr^{-1})



Hog Reef	+1.2
Okinawa Reef	+1.8
Yonge Reef	+1.5
Moorea	+0.1

By definition, intense calcification

$Ca^{2+} + 2\ HCO_3^- = CaCO_3 + CO_2 + H_2O$

At community level, GPP . R

Coral Reefs

Based on Suzuki & Kawahata (2003) and Bates (2002)

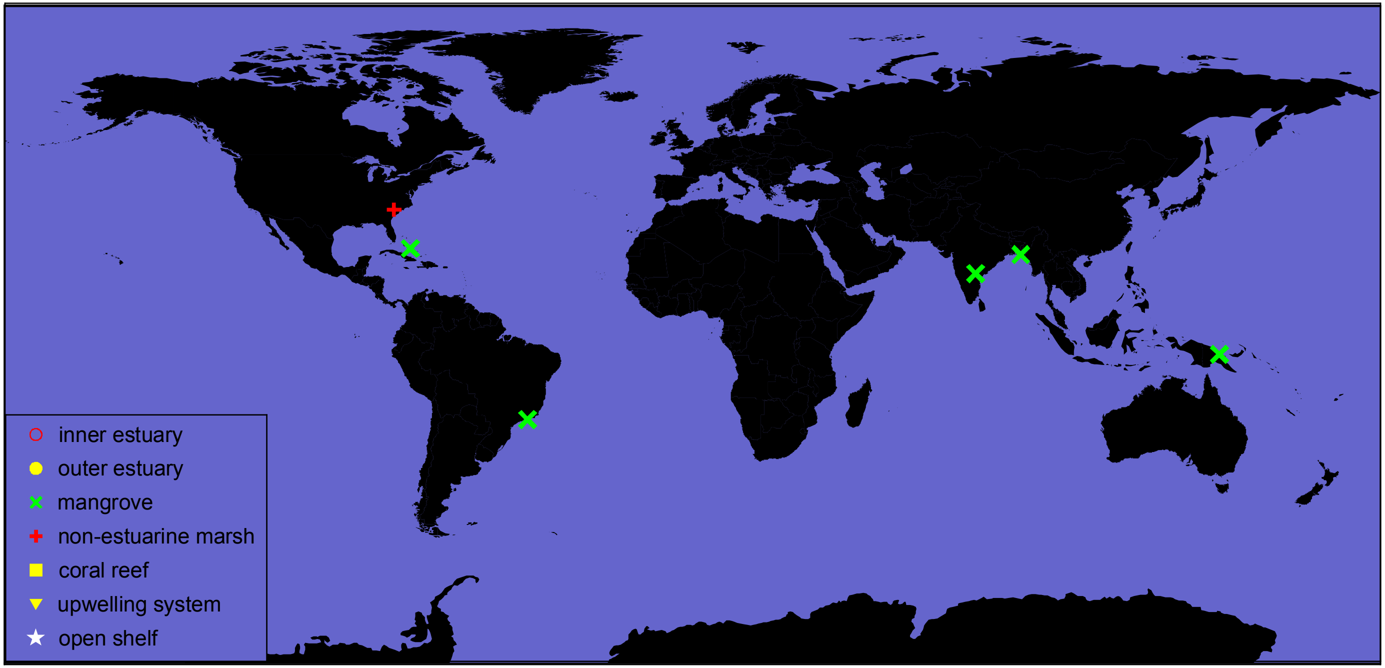
	pCO_2reef – pCO_2ocean (ppm)
Christmas Island	-80
Shiraho reef	7
Fanning atoll	30
Canton atoll	15
Palau reef	46
Majuro atoll	23
South Male atoll	6
Northern Great Barrier Reef	29
Southern Great Barrier Reef	12
Hog reef (1994)	26
Hog reef (1995)	16
Hog reef (1996)	16
Average	12

Tropical and subtropical open ocean waters are net sources of CO_2 on average:

0.35 molC m^{-2} yr^{-1} $\Delta pCO2$ = 11 ppm (Takahashi et al. 2002)

Assuming an enrichment of 12 ppm during transit, reefs would act as a source of 0.73 molC m^{-2} yr^{-1}

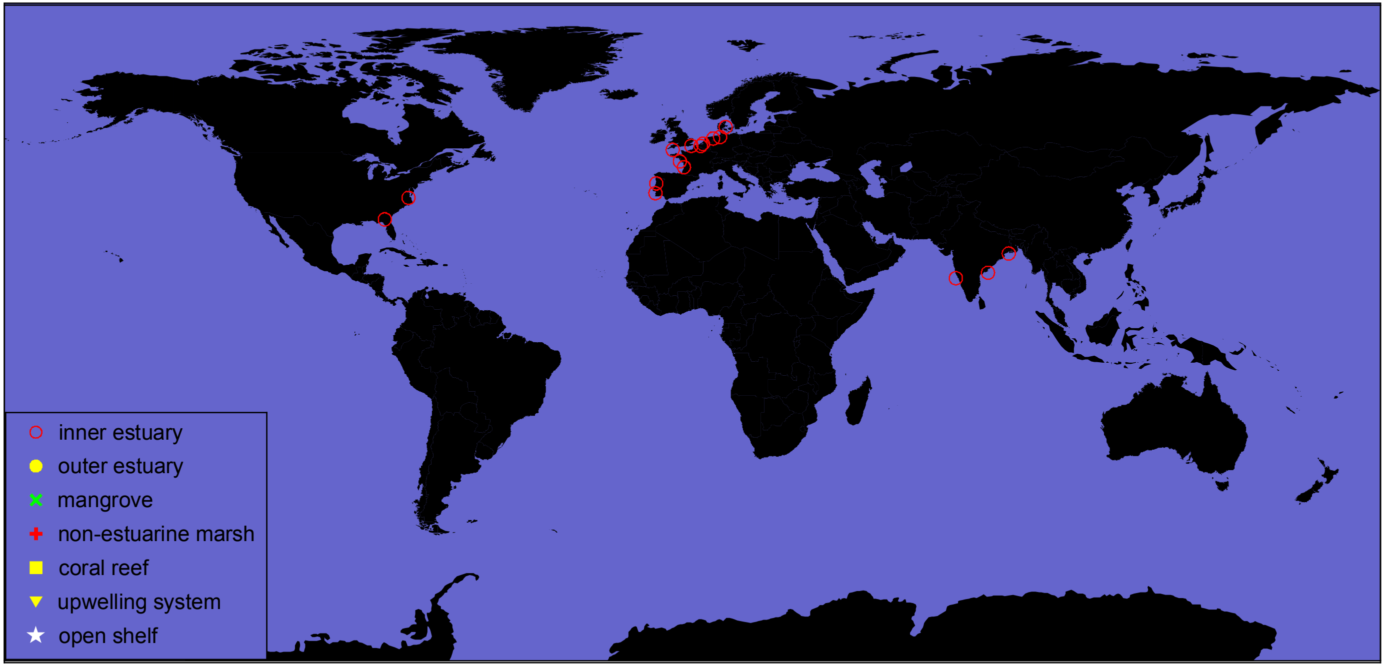
Mangrove & saltmarsh (Fluxes in mol C m^{-2} yr^{-1})



Mangrove waters	Norman's Pond	+5.0
	Mooringanga Creek	+8.5
	Saptamukhi Creek	+20.7
	Gaderu Creek	+20.4
	Nagada Creek	+15.9
	Itacuraça Creek	+41.4
Saltmarsh waters	Duplin River	+23.5

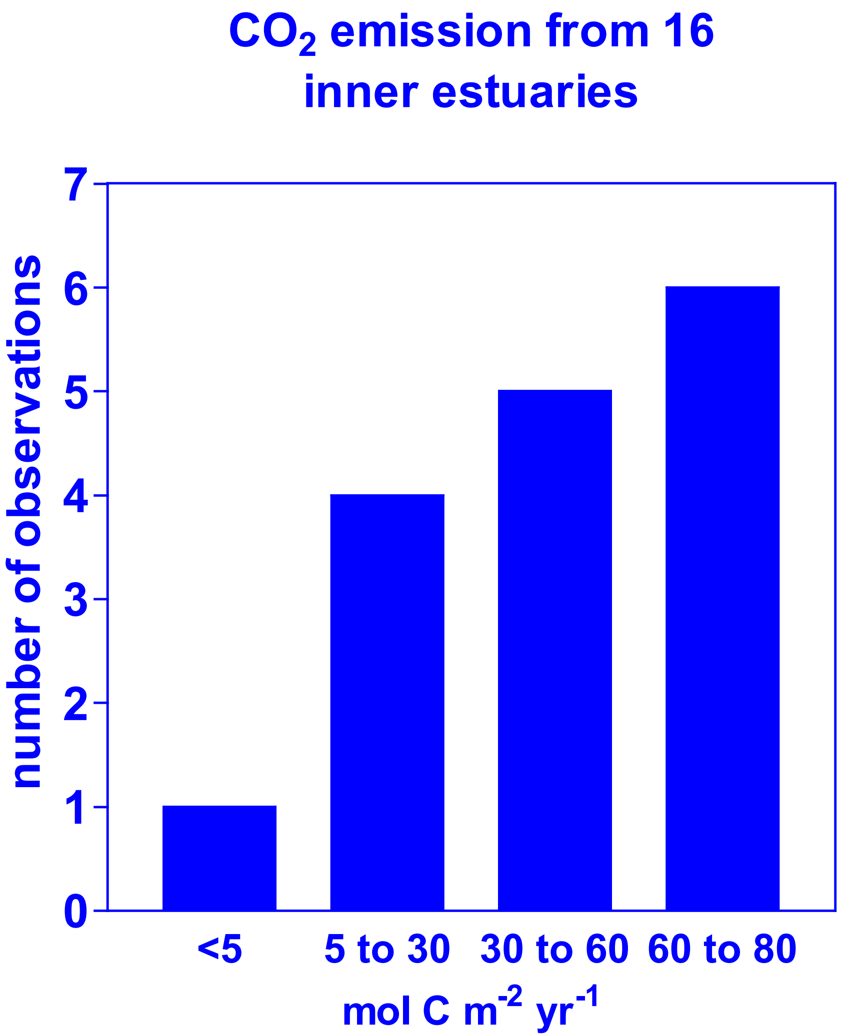
Massive terrestrial organic matter iputs
= strong heterotrophy of water column and sediments
= CO_2 production

Estuaries



Europe	11
U.S.A.	2
India	3

Estuaries



Temperate estuaries (12)
46 mol C m^{-2} yr^{-1}

Tropical estuaries (4)
19 mol C m^{-2} yr^{-1}

High latitude estuaries
= temperate estuaries ?

Up-scaling

Surface areas:
- marginal seas + upwelling systems from Walsh (1988)
- mangroves from FAO (2003)
- coral reefs from Spalding et al. (2001)
- estuaries : global estimate from Woodwell et al. (1973)

partitioned into latitudinal bands (linear dependence on freshwater discharge)

Open ocean CO_2 fluxes from Takahashi et al. (2002) revised climatology

Latitudinal bands of 30°:
- high latitudes (90°-60°)
- temperate latitudes (60°-30°)
- subtropical and tropical latitudes (30°-0°)

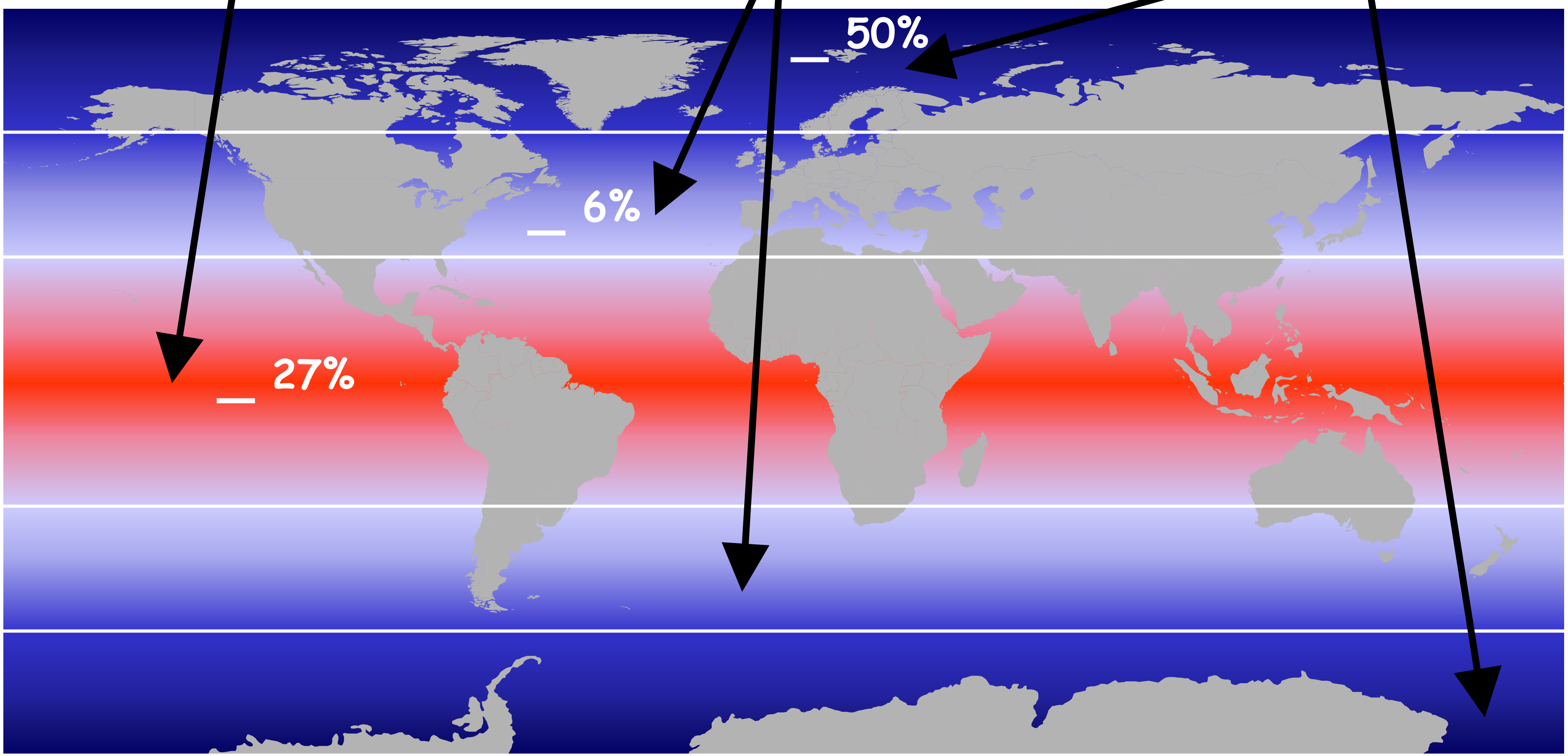
Up-scaling

Coastal -0.05 Pg C y^{-1} Open -1.57 Pg C y^{-1} Global -1.61 Pg C y^{-1} _3%

Coastal +0.18 Pg C y^{-1}
Open +0.71 Pg C y^{-1}
Global +0.90 Pg C y^{-1}

Coastal -0.13 Pg C y^{-1}
Open -2.06 Pg C y^{-1}
Global -2.19 Pg C y^{-1}

Coastal -0.10 Pg C y^{-1}
Open -0.22 Pg C y^{-1}
Global -0.33 Pg C y^{-1}



Up-scaling : ecosystem diversity counts !

Overall coastal ocean small CO_2 sink (–0.05 PgC yr^{-1})

Marginal seas strong sink (–0.45 PgC yr^{-1})

Near-shore systems (estuaries, mangroves, marshes, coral reefs, upwelling systems) strong source (0.40 PgC yr^{-1})

Up-scaling : reliability ?

	$PgC\ yr^{-1}$	% total
Estuaries	0.324	81.1
Marsh waters	0.036	9.0
Mangroves waters	0.033	8.2
Coral reefs	0.005	1.3
Upwelling	0.002	0.5
Nearshore systems	0.400	100

Up-scaling : reliability ?

The estimate of surface area of inner estuaries given by Woodwell et al. (1973) has been widely used in literature.

They estimated a ratio of inner estuary surface area / coast length for the US that they extrapolated to the worldwide coastline.

These authors caution their own estimate: "It would be surprising if estimates derived in this way were accurate within ±50%".

Up-scaling : reliability ?

CO_2 emission from estuaries of 0.32 Pg C yr^{-1}

- emission of 0.08 Pg C yr^{-1} ☹

  (river POC input from Ludwig et al. 1996; 50% of river POC is degraded and ventilated in estuaries - Abril et al. 2002)

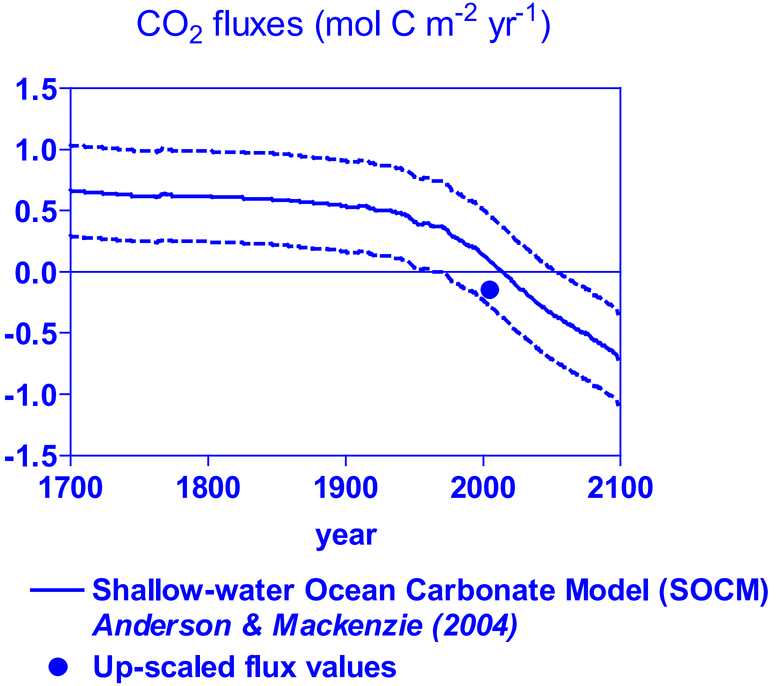
- emission of 0.25 Pg C yr^{-1} ☺

  (river POC input from Richey 2004 ; 50% of river POC is degraded and ventilated in estuaries - Abril et al. 2002)

- emission of 0.35 Pg C yr^{-1} ☺ ☺

  (river POC input from Richey 2004; 70% of river POC is degraded and ventilated in estuaries – Keil et al. 1997)

Up-scaling : reliability ?



		Anthropogenic CO_2 flux
pre-industrial (SOCM)	+0.69 mol C m^{-2} yr^{-1}	
present day (SOCM)	+0.15 mol C m^{-2} yr^{-1}	-0.2 PgC yr^{-1}
present day (up-scaling)	-0.15 mol C m^{-2} yr^{-1}	-0.3 PgC yr^{-1}

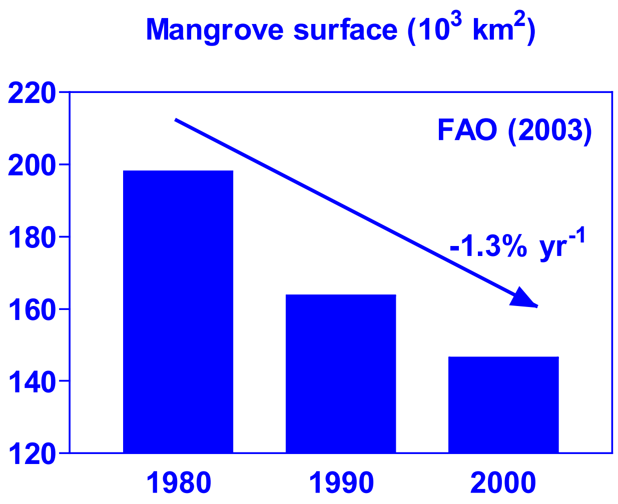
Anthropogenic CO_2 flux in coastal ocean = 9 to 13% of open ocean (Sabine et al. 2004)
Higher than ratio of surface areas (7%)

Up-scaling : future challenges

- delimitation of near-shore ecosystems
- surface area estimates :

Coral reefs (10^3 km^2):	
Smith (1978)	617
De Vooys (1979)	112
Cooper (1994)	1994
Spalding & Grenfell (1997)	255
Spalding et al. (2001)	284

- surface area estimates – real temporal change :



Thalassodendron ciliatum seagrass bed in a mangrove creek + brackish waters of Kidogoweni estuary (Gazi Bay – Kenya)

Help needed !!
GIS ? Satellite images ?

Up-scaling : future challenges

- no CO_2 flux data in high latitude estuaries
- river plumes were not included (no surface area estimate; not enough data)
- no (or little) data in certain ecosystems (segrass beds, lagoons, …)
- coastal ? open ? systems:
  - high freshwater discharge estuaries (plumes at sea)
  - upwelling filaments
- significant fluxes only very recently highlighted

Antarctic first year sea-ice (-3 mmol C m^{-2} d^{-1} during 45 d)

	if sea-ice impermeable (mol C m^{-2} yr^{-1})	if sea-ice CO_2 sink (mol C m^{-2} yr^{-1})
Prydz Bay	-2.2	-2.4 (_ 6%)
Ross Sea	-1.8	-1.9 (_ 8%)

Up-scaling : latitudinal variability counts !

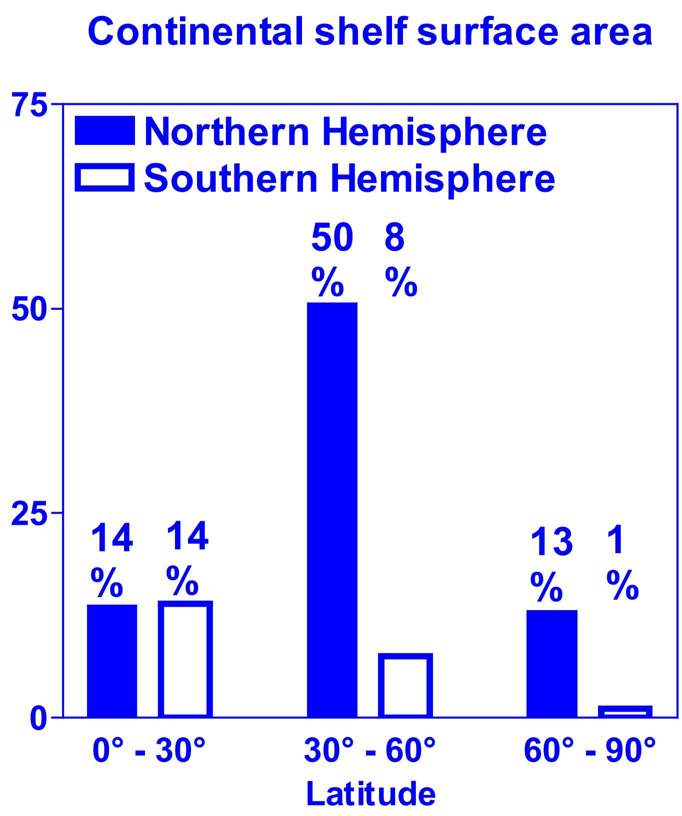
Marginal seas sink of –0.45 PgC yr^{-1} consistent with previous estimates :

-0.43 to –0.96 PgC yr^{-1}
(global extrapolation of data from East China Sea – Wang et al. 2000)

-0.40 PgC yr^{-1}
(global extrapolation of data from North Sea – Thomas et al. 2004)

Marginal seas	PgC yr^{-1}
High latitudes	-0.16
Temperate latitudes	-0.32
Subtropical & tropical latitudes	+0.03

Up-scaling : latitudinal variability counts !



Relevance of coastal ocean for CO_2 inversion models ?
Relevance of coastal ocean for CO_2 inter-hemispheric transport ?

Acknowledgments

Borges (2005) Do we have enough pieces of the jigsaw to integrate CO_2 fluxes in the Coastal Ocean ? Estuaries, 28(1): 3-27

Borges, Delille & Frankignoulle (in revision) Budgeting sinks and sources of CO_2 in the coastal ocean: Diversity of ecosystems counts, GRL

For ideas, discussions, comments, data & help in the field, thanks to :

Gwenaël Abril, Renzo Biondo, Steven Bouillon, Wei-Jun Cai, Bruno & Ioen Delille, Jean-Pierre Gattuso, Frédéric Gazeau, Jack J. Middelburg, Milos, Abdirahman Omar, Frédérique Seyler, Jean-Marie Théate.

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