Cross-boundary transports of carbon across the land-continental shelf, continental shelf-open ocean and ocean-atmosphere boundaries

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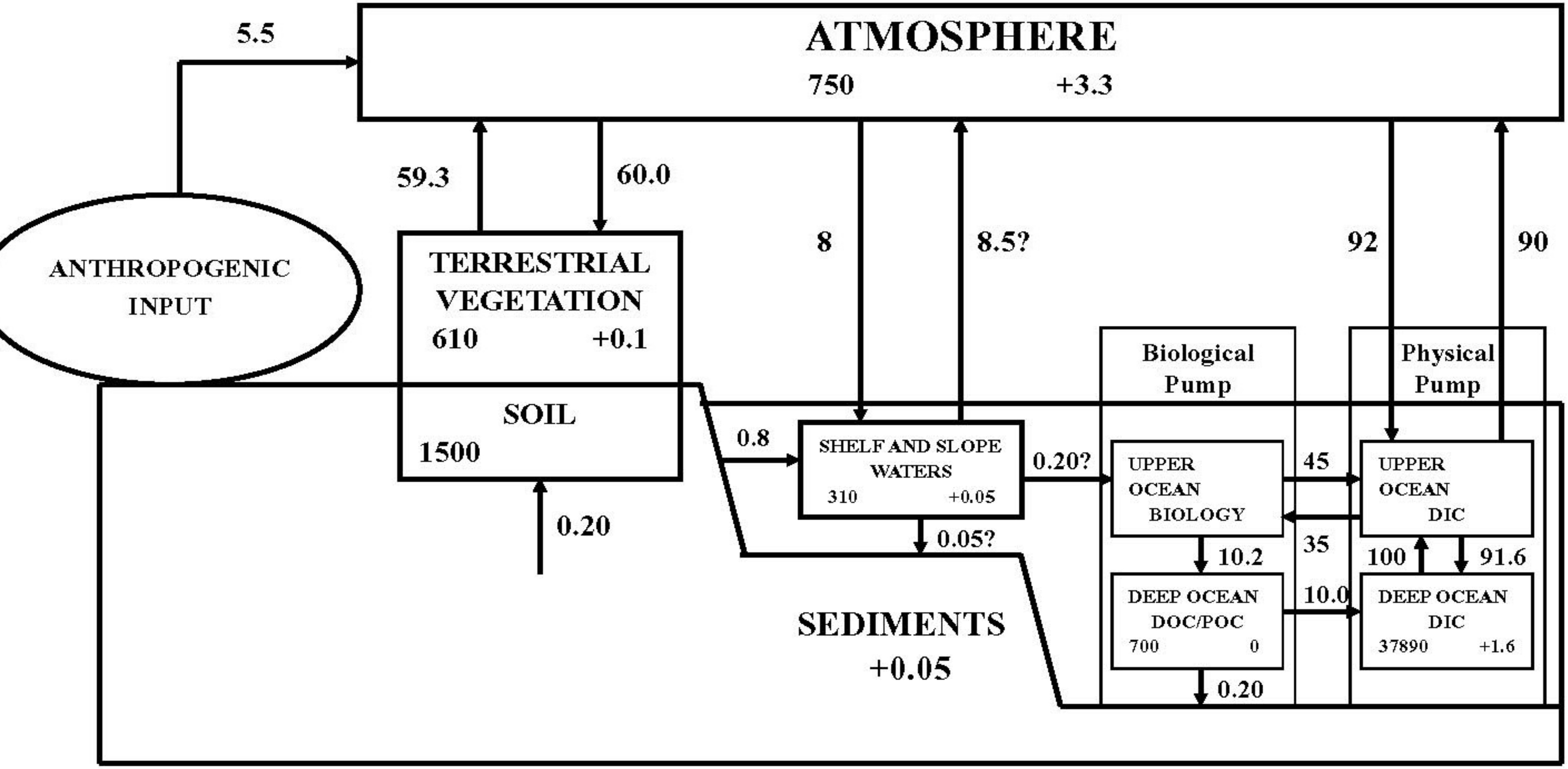
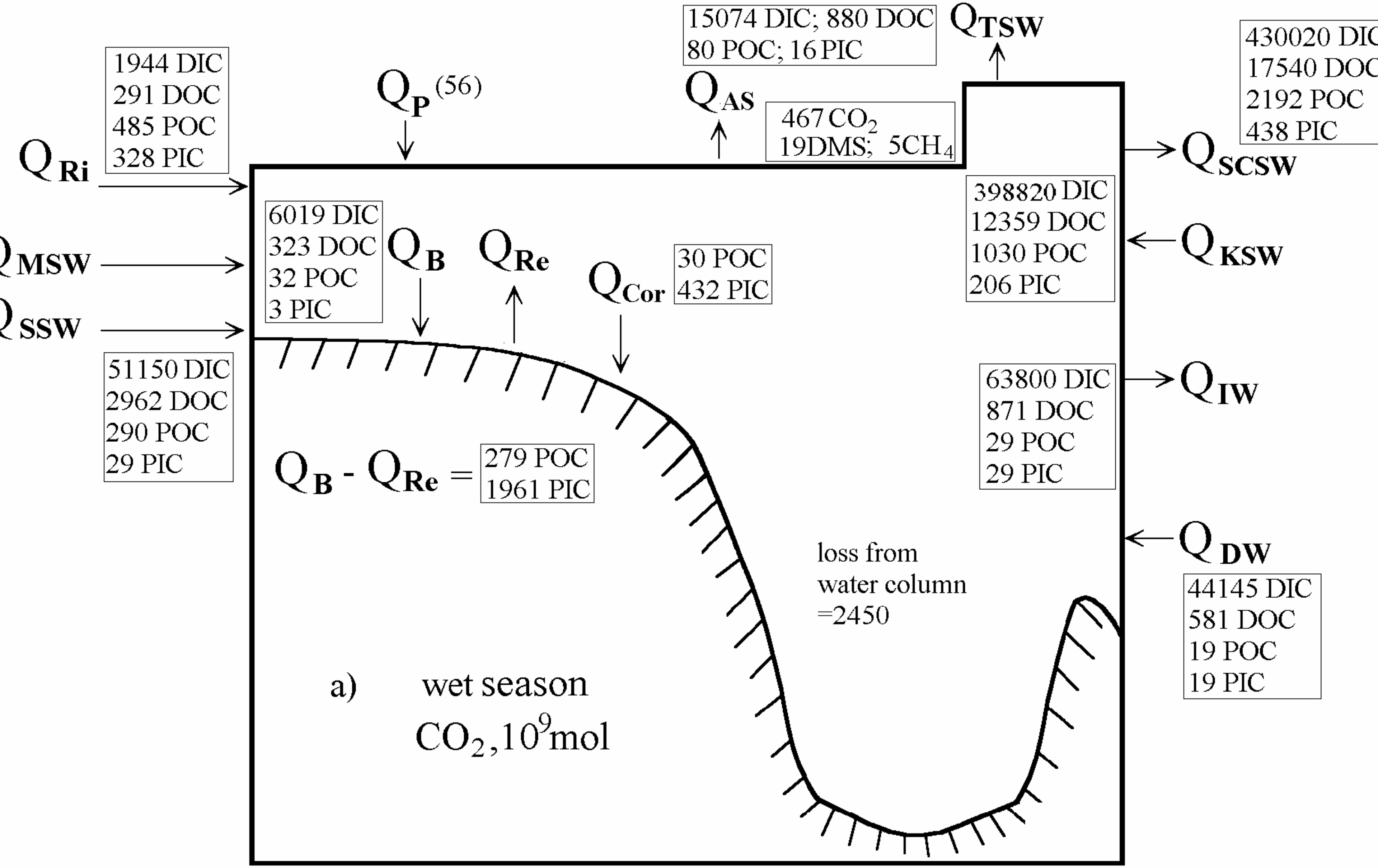
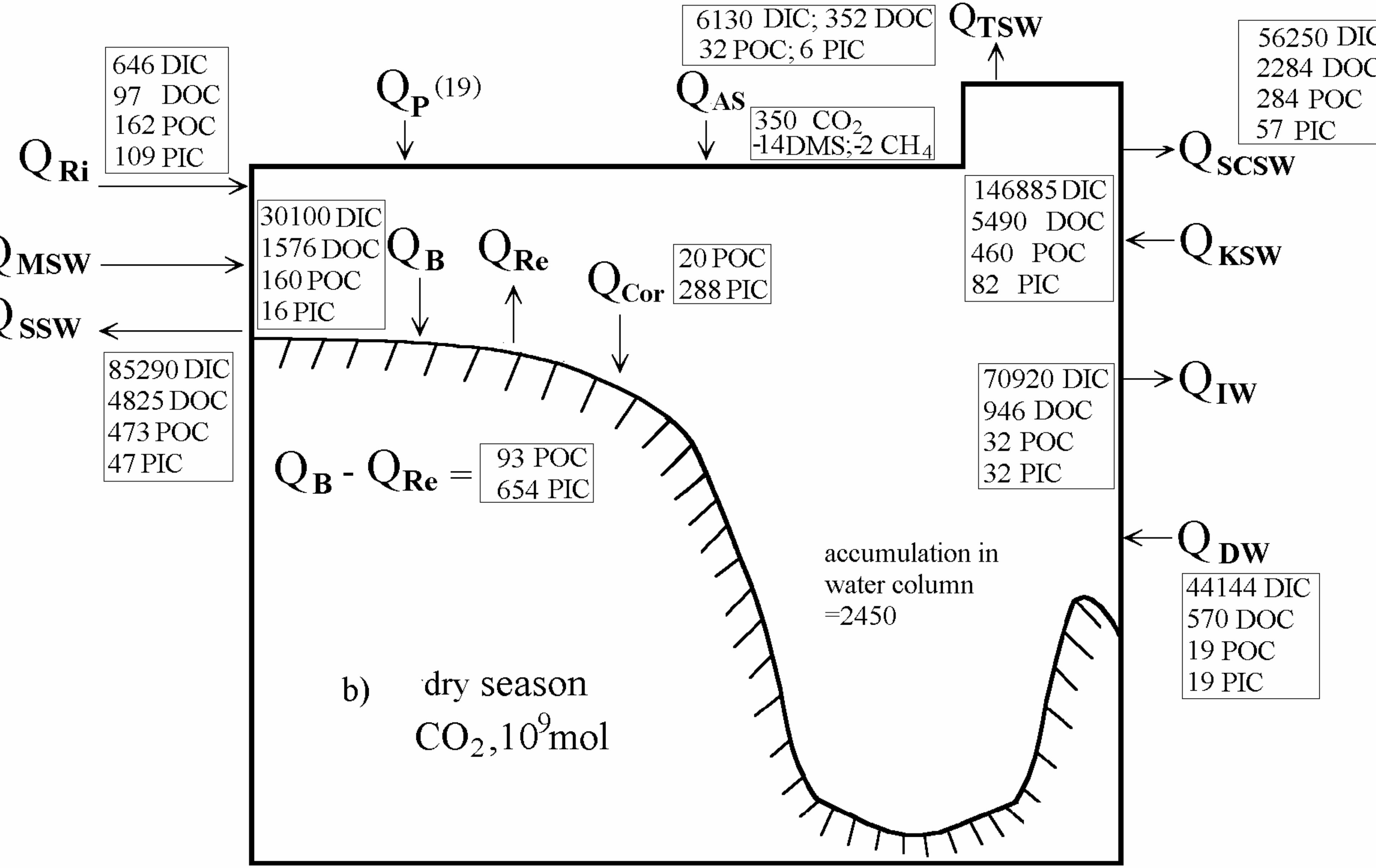
There is not even a consensus when it comes to the simple question, “Are continental shelves carbon sources or sinks?” (Kempe, 1995).



Global carbon cycle: Average annual fluxes between global carbon pools are given in petagrams of carbon per year (Pg C y^{-1}). Figures on the left side in each box denote the global inventory in Pg C, while figures on the right show the average annual increases in the inventory associated with the anthropogenic input. The fluxes associated with the shelf and slope waters are still uncertain. The figure is based on the 1995 Intergovernmental Panel on Climate Change (IPCC) analysis with additions from JGOFS results (redrawn from Fasham *et al*., 2001).


1944 DIC
291 DOC
485 POC
328 PIC
Q_P (56)
15074 DIC; 880 DOC
80 POC; 16 PIC
Q_{AS}
Q_{TSW}
467 CO_2
19DMS; 5CH_4
430020 DI
17540 DO
2192 POC
438 PIC
Q_{Ri}
Q_{SCSW}
398820 DIC
12359 DOC
1030 POC
206 PIC
Q_{MSW}
Q_{SSW}
6019 DIC
323 DOC
32 POC
3 PIC
Q_B
Q_{Re}
Q_{Cor}
30 POC
432 PIC
Q_{KSW}
51150 DIC
2962 DOC
290 POC
29 PIC
Q_B - Q_{Re} =
279 POC
1961 PIC
63800 DIC
871 DOC
29 POC
29 PIC
Q_{IW}
Q_{DW}
loss from
water column
=2450
44145 DIC
581 DOC
19 POC
19 PIC
a) wet season
CO_2,10^9mol


646 DIC
97 DOC
162 POC
109 PIC
Q Ri
Q P (19)
Q AS
6130 DIC; 352 DOC
32 POC; 6 PIC
350 CO2
-14DMS;-2 CH4
Q TSW
56250 DI
2284 DO
284 POC
57 PIC
Q SCSW
146885 DIC
5490 DOC
460 POC
82 PIC
Q KSW
Q MSW
30100 DIC
1576 DOC
160 POC
16 PIC
Q B
Q Re
Q Cor
20 POC
288 PIC
Q SSW
85290 DIC
4825 DOC
473 POC
47 PIC
Q B - Q Re =
93 POC
654 PIC
70920 DIC
946 DOC
32 POC
32 PIC
Q IW
Q DW
44144 DIC
570 DOC
19 POC
19 PIC
accumulation in
water column
=2450
b) dry season
CO2, 10^9 mol

South China Sea

DOC outflow = 27698×10^9 mol/yr

DOC inflow = 23850×10^9 mol/yr

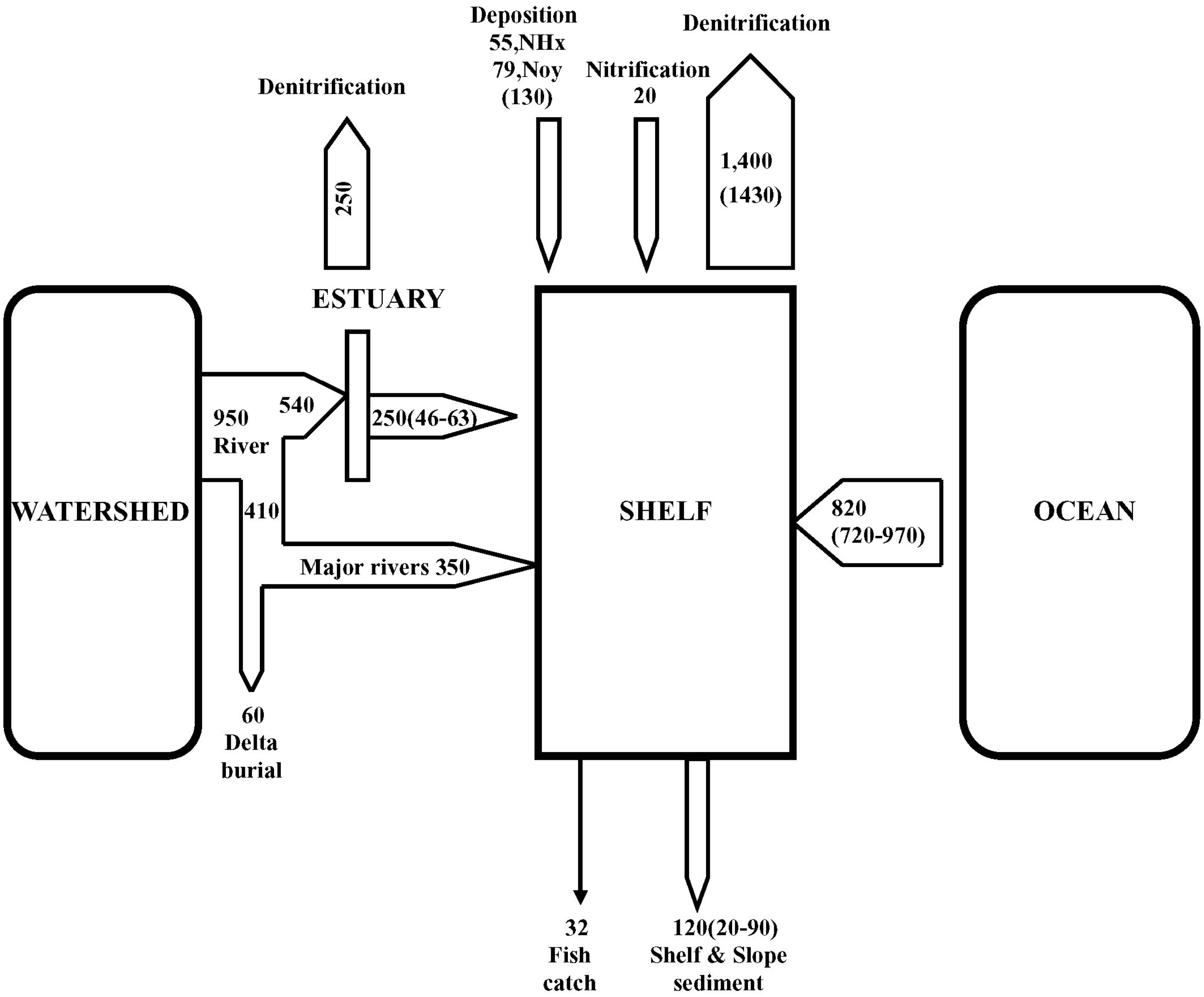
DOC rivers = 388×10^9 mol/yr

DOC export = 27698 - 23850 - 388

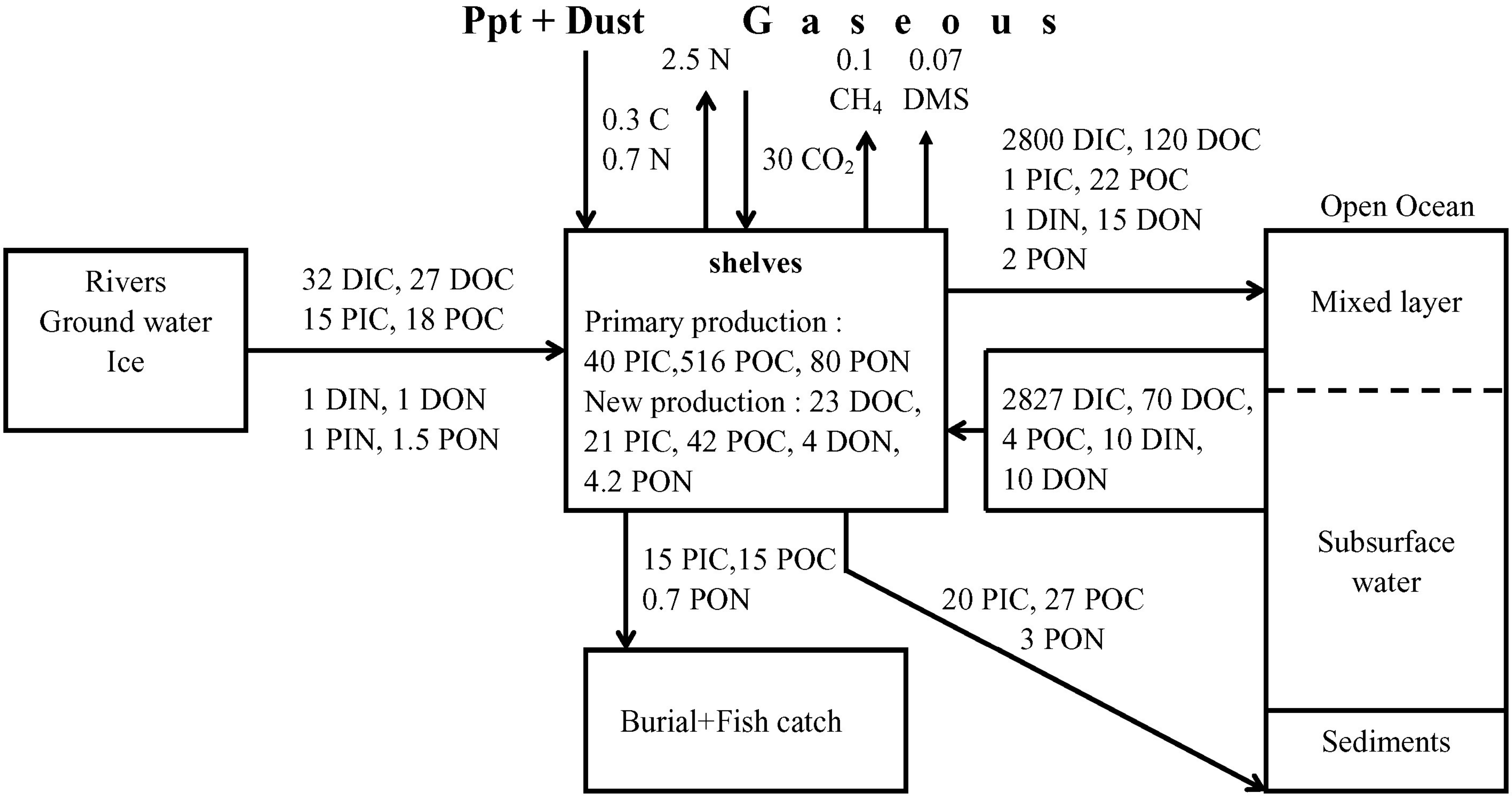
= 3460×10^9 mol/yr

POC export = 887×10^9 mol/yr

POC rivers = 647×10^9 mol/yr



N budget for the continental shelves of the North Atlantic Ocean (10^9 mol y^{-1}; modified from Galloway *et al*., 1996). Numbers in parentheses are from Seitzinger (2000).



Ppt + Dust

Gaseous

0.3 C
0.7 N

2.5 N

30 CO_2

0.1 CH_4

0.07 DMS

Rivers
Ground water
Ice

32 DIC, 27 DOC
15 PIC, 18 POC

1 DIN, 1 DON
1 PIN, 1.5 PON

shelves

Primary production :
40 PIC,516 POC, 80 PON
New production : 23 DOC,
21 PIC, 42 POC, 4 DON,
4.2 PON

2800 DIC, 120 DOC
1 PIC, 22 POC
1 DIN, 15 DON
2 PON

Open Ocean

Mixed layer

Subsurface water

Sediments

2827 DIC, 70 DOC,
4 POC, 10 DIN,
10 DON

15 PIC,15 POC
0.7 PON

Burial+Fish catch

20 PIC, 27 POC
3 PON

Schematic diagram for the annual carbon and nitrogen budgets (in 10^{12} mol y^{-1}) for the continental margins of the world (modified from Chen *et al*., 2002).

- The continental shelves absorb 30×10^{12} mol C y^{-1}.
- New production supported by the external sources of nutrients represents only about 13% of primary production, while the rest is respired and recycled on the shelf.
- Some of the organic material that is not recycled accumulates in the sediments, but most of the detrital organic matter, mainly in its dissolved form, is exported to the slopes and open oceans.

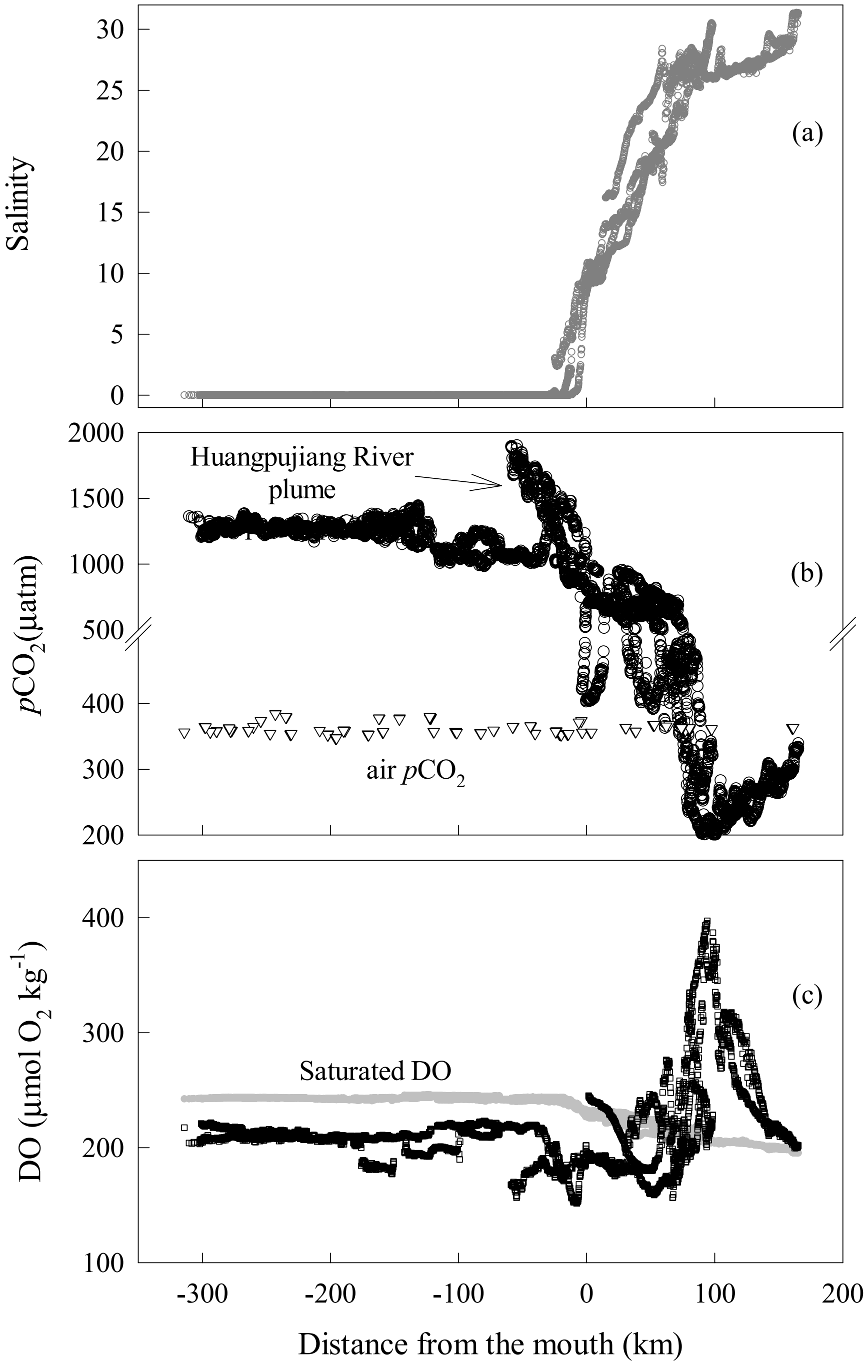
Table 2. Fluxes relevant to continental margins (All values except f-ratio are in 10^{12} mol yr^{-1} ; numbers in parentheses are reference numbers)

	C	N
Rivers plus ground water nd ice	32(1, 6, DIC), 30(1, DOC), 15(1, 6, PIC), 20(1, POC), 34(2, OC), 27 (6, DOC), 18(6, POC), 30(7, OC), 37 (7, IC), 31(8, OC), 13(17, IC)	1.0(1, 6, DIN), 1.0(1, 6, DON), 1.0(1, 6, PIN 1.5(1,2, 6, PON), 0.3(2, DIN), 0.7(2, DON), 1.5(9, DIN), 1.8-3.1(13, total), 0.05(18, PIN 4.8(18, DIN+DON+ PON), 1.35(19, DIN)
Air-to-Sea (gaseous)	25(1), 20(2), 49(3), 46-75(4), 30(6), 8.3(7), 62(14), 83(15), -0.1(6, CH_4), -0.07(6, DMS)	-2.5(1, 6), -6.5(2)
Precipitation plus ust	0.3(1, 6, PIC), 0.2 (8, OC)	0.7(1, 6), 0.1(2) , 0.85(18)
Net burial plus fish catch	15(1, 6, 17, PIC), 15(1, 6, 17, POC), 14(2, POC), 12.5(7, total), 14.5(17, PIC)	0.7(1, 6, PON), 1.1(2, PON), 1(18)
Gross upwelling plus surface nflow	2800(1, DIC), 80(1, DOC), 4(1, 6, POC), 27(6, POC), 2827(6, DIC), 70 (6, DOC)	10(1, 6, DIN), 10(1, 6, DON), 10.15(2, DIN, upwelling only)
Down-slope export of articulates	20(1, 6, 17, PIC), 20(1, 17, POC), 27(6, POC), 167(7, total)	3(1, 6, PON)
Gross surface water outflow	2800(1,6, DIC), 120(1, 6, DOC), 1.0(1, 6, PIC), 12(1, POC), 22(6, POC), 58(7, net)	1.0(1, 6, DIN), 15(1, 6, DON), 2(6, PON)

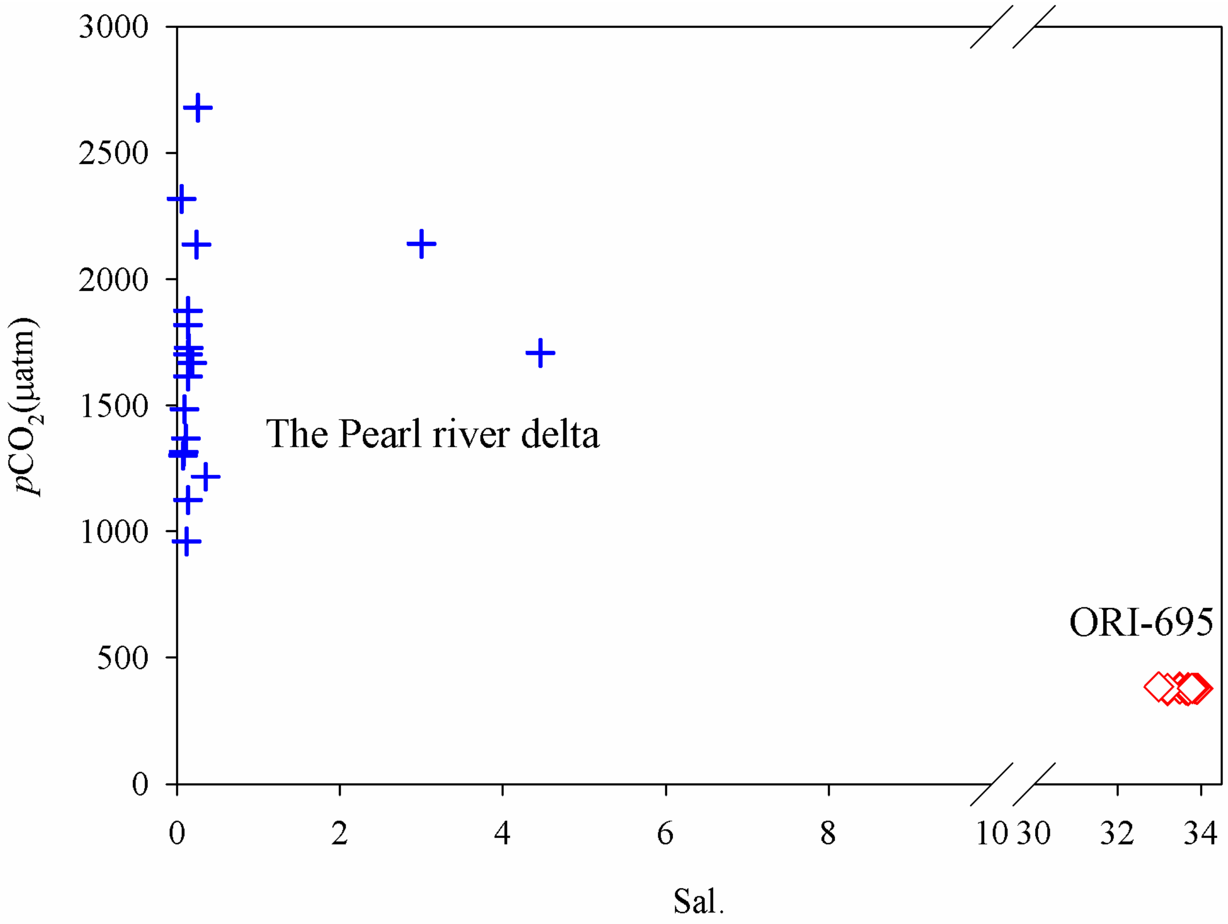
	C	N
Gross offshelf export (down-slope+surface outflow)	2800(1, 6, DIC), 120(1, 6, DOC), 21(1, 6, PIC), 32(1, POC), 49(6, POC), 225(7, net)	1.0(1, 6, DIN), 15(1, 6, DON), 5(1, 6, PON
let offshore export (down-slope+surface outflow-pwelling plus surface inflow)	0(1, DIC), 40(1, DOC), 21(1, 6, PIC), 28(1, POC), 40(2, OC), -27(6, DIC), 50(6, DOC), 45(6, POC), 58(7, total), 38(12, OC), 33(16, DOC), 4(17, IC)	-9(1, 6, DIN), 5(1, 6, DON), 5(1, 6, PON), 5.15(2, ON), 5.8(12, ON), 0.4(18)
rimary productivity	40(1, 6, 17, PIC), 516(1, 6, 17, POC), 368(2, OC), 789(5, OC), 830(7, total), 24.5(17, PIC),	80(1, 6, PON), 54 (2, ON)
lew productivity	6(1, PIC), 75(1, POC), 43(2, OC), 231(5, OC), 167(7, total), 158(16, OC) 23(6, DOC), 21(6, PIC), 42(6, POC)	8(1, PON), 5.6(2, ON), 4(6, DON), 4.2(6, PON)
-ratio	0.15(1), 0.12(2), 0.29(5), 0.2(7), 0.13(6)	0.1(1, 6), 0.1(2)
I-fixation	--	1(2, benthic)
Denitrification	--	7.5(2), 8.5(10), 7.2(13)
let Denitrification	--	2.5(1, 6), 6.5(2), 1.5(11), 2.1(18)

aken from: 1.Table 9 of Chen *et al.*, 2002 and the 27 references therein; 2.Rabouille *et al.*, 2001; 3.Yool and asham, 2001; 4.extrapolated from data on the European shelves by Frankignoulle and Borges, 2001; 5.Gattuso *et* . (1998); 6.this study; 7.Liu *et al.* (2000); 8.Smith *et al.* (2001); 9.Kroeze and Seitzinger (1998); 10.Seitzinger and orege (1998); 11.Seitzinger (2000); 12.Alvarez-Salgado *et al.* (2001a); 13.Middelburg *et al.* (1996); 14.Walsh and ieterle (1994); 15.Tsunogai *et al.* (1999); 16.Hansell and Carlson (1998); 17.Milliman (1993) and Wollast (1994); 3.Mackenzie *et al.* (2002) and 19.Smith *et al.* (2003).

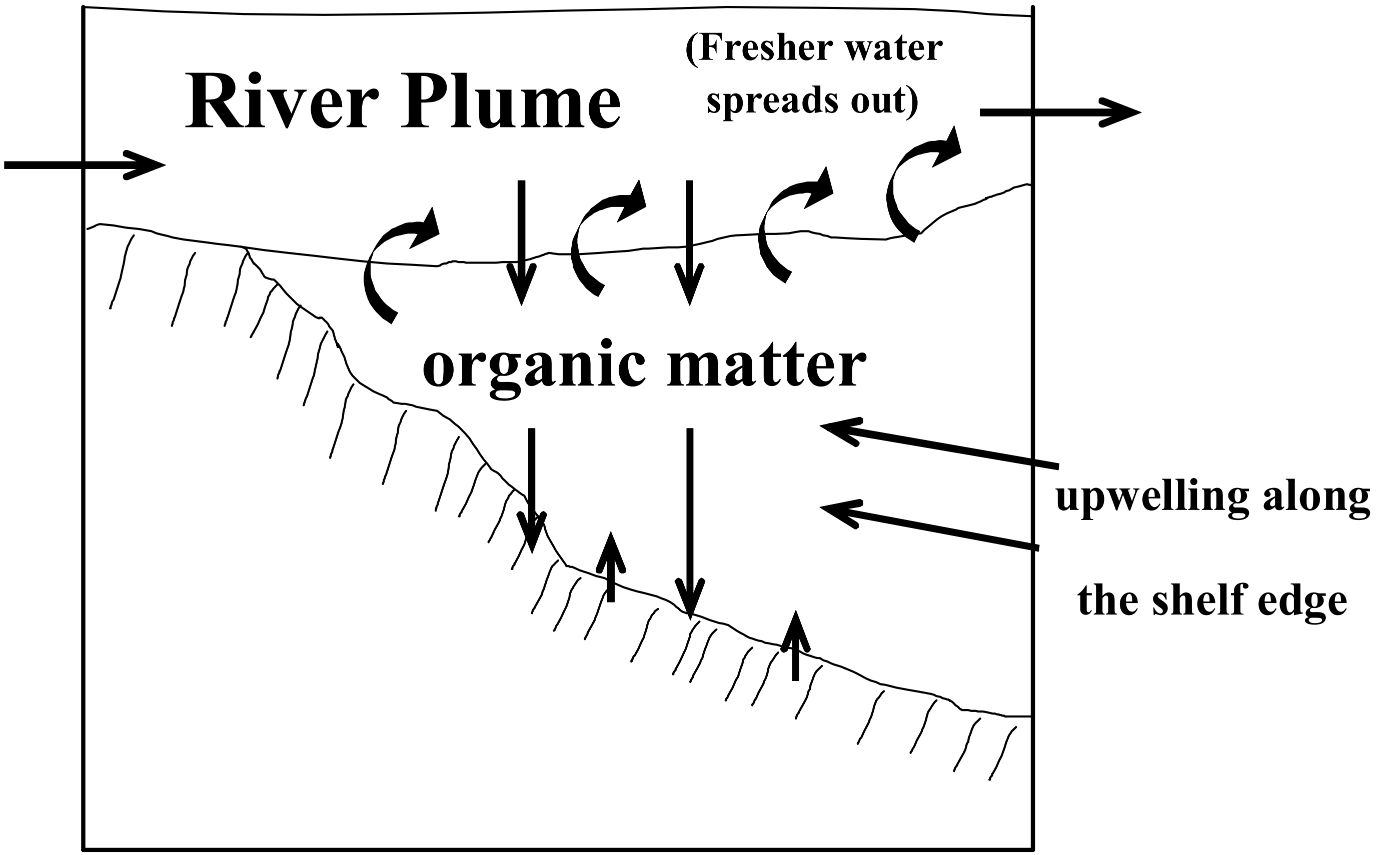
- In general, an autotrophic system absorbs CO_2 from the atmosphere, but intensive upwelling regions may be autotrophic and still release CO_2 to the atmosphere. This is attributed to the upwelled water being much too supersaturated with CO_2, so the enhanced nutrient supply does not support enough productivity to consume enough CO_2; hence, the water remains supersaturated even though biological productio is higher than respiration.



Taken form Chen/Zhai/Dai (submitted), Changjiang (Yangtze) Estuary

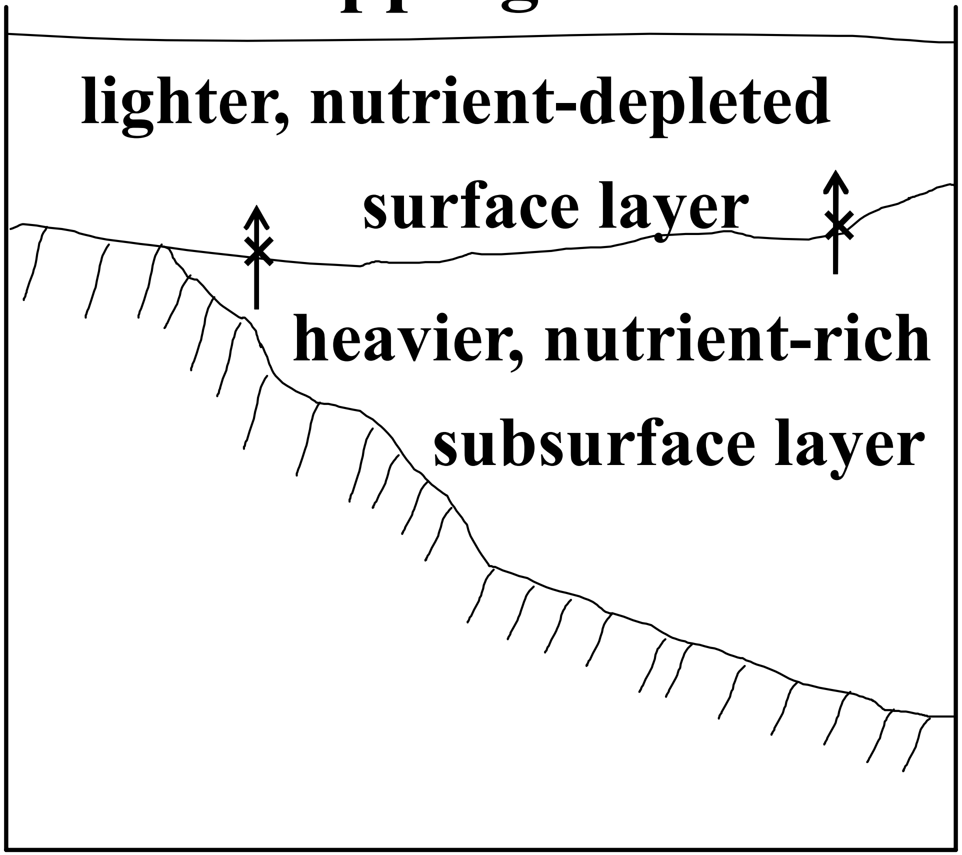

3000
2500
2000
1500
1000
500
0
$p\text{CO}_2$(µatm)
0
2
4
6
8
10
30
32
34
Sal.
The Pearl river delta
ORI-695

Buoyancy Effect



Provides nutrients to, and enhances new productivity as well as prosperity of fish, seabirds and marine mammals

Capping



lighter, nutrient-depleted

surface layer

heavier, nutrient-rich

subsurface layer

Severe consequences for new productivity as well as breeding, growth, survival, and reproduction of fish, seabirds and marine mammals

able 2 Air-Sea fluxes of CO_2 in various continental margins*

ea	Spring**	Summer	Fall	Winter	Annual	Ref.
	mmol m^{-2} d^{-1}				mol C m^{-2} yr^{-1}	
ntarctic Shelves		11-34[1]			2.2[2]	1.Chen *et al.,* 2004; 2.Carrillo and Kar 1999
ctic Sea					0.21[1], 0.51[2]	1.Anderson and Jones, 1991; 2.Bates 2006
Shelves					0.14	Anderson *et al.*, 1998
lantic Bight					0.5-1.3	De Grandpre *et al.*, 2002
ffin Bay	~0.3	0.45	~0.3	~0	0.43	Miller *et al.*, 2002
ltic Sea					0.9[1], 3.0[2]	1.Thomas *et al.*, 2003; 2.Kuss *et al.,* 2006
rrents Sea		2.7[1]			0.55[2], 3.6[3]	1.Katin *et al.*, 2002; 2.Fransson *et al* 2001; 3.Borges *et al.,* 2005
eaufort Shelves		2.9				Murata and Takizawa, 2003;
enguela Current	11			5.5	1.62	Santana-Casiano and Gonzalez-Davila 2008
ering Sea Basin					-4.7	Fransson *et al.,* 2006
ering Sea Shelf	1.2[1]	0.66[2]			4.3[3]	1.Nedashkovskij *et al.*, 1995; 2.Codispot *et al.*, 1986; 3.Walsh and Dieterle, 1994
ack Sea						
azil Shelf	-9.8[1]	-4.2[1]		-0.3[1]	-1.8[2]	1.Ito *et al.*, 2005; 2.Borges *et al.,* 2005
istol Bay					0.2	Borges *et al.,* 2005

able 2 (continued)

ea	Spring**	Summer	Fall	Winter	Annual	Ref.
	mmol m^{-2} d^{-1}				mol C m^{-2} yr^{-1}	
lifornia Coast					-2.2 -0.7	Friederich *et al.*, 2002
ukchi Sea	<0.1-1[5]	2.9[1], 13-52[2, 3], 30-90[5]	12[4]		4.8[5], 3.1[6]	1.Murata and Takizawa, 2003; 2.Wang e *al.,* 2003; 3.Li *et al.,* 2004; 4.Pipko *et al* 2002; 5.Bates, 2006; 6.Kaltin an Anderson, 2005
China Sea	1.66[1], 2.1 ± 2.8[2], 1.8[3], 5.04 ± 1.59[9]	1.2[3], -2.52 ± 1.81[9]	-0.65[1], 2.0[3], 1 ± 3[9]	3.1[3]	2.1[3], 3.3[4], 2 (1.1-2.5)[5], 3[6], 1[7], 0.03[8],	1.Ma *et al.*, 1999; 2.Peng *et al.*, 1999 3.Wang et al., 2000; 4.Tsunogai *et al* 1997; 5.Chen and Wang, 1999 6.Tsunogai *et al.,* 1999; 7.Zhang *et al* 1999; 8.Zhang, 1999; 9. Shim *et al.*, 2007
Mediterranean					$0.78\sim4\times10^{-4}$	de Madron *et al.*, 2004
glish Channel					0[1], -0.3[2]	1.Borges and Frankignoulle, 2003 2.Thomas *et al.*, 2004
nka Bay (Japan)					mean ΔpCO_2 = -75 µatm	Nakayama *et al.*, 2000
lician Coast					2.2	Borges *et al.*, 2005
ulf of Biscaye	2.01	5.51	0.51	-0.31	1.7-2.91	Frankignoulle and Borges, 2001
ulf of California		-5.4				Hidalgo-Gonzalez *et al.*, 1997
ulf of Lion					7.1	de Madron *et al.*, 2004
ulf of Mexico Shelf		2-4.2				Lohrenz and Cai, 2006

able 2 (continued)

ea	Spring**	Summer	Fall	Winter	Annual	Ref.
	mmol m^{-2} d^{-1}				mol C m^{-2} yr^{-1}	
erian	0.4^1	-0.07^1, 4.5^2	0.2^1, 0.9^2		$1.6\ (1.3\text{-}2.6)^2$	1.Perez *et al.*,1999; 2.Borges an Frankignoulle, 2002
ra Sea					0.011	Fransson *et al.*, 2001
ptev Sea					0.011	Fransson *et al.*, 2001
editerranean Sea					$0.52\text{-}2.8\times10^{-4}$	de Madron *et al.*, 2004
ew Jersey Coast	>0	<0	<0	>>0	0.44-0.84	Boehme *et al.*, 1998
orth Sea	14^1	13^1, 1.4^2	-0.9^1		1.3^3, $1.5\text{-}2.2^4$ 1.38^5	1.Frankignoulle and Borges, 200 2.Kempe and Pegler, 1991; 3.Thomas e *al.*, 2003; 4.Bozec *et al.*, 2005; 5.Thoma *et al.*, 2005
E Greenland		1.3				Yager *et al.*, 1995
khotsk Sea		2.7-5.5 $(\text{May-Sept})^1$			2.5^2, 0.83^3	1.Chen *et al.*, 2003b; 2.Otsuki *et al* 2003; 3.Wakita *et al.* (GRL, submitted)
mani Coast					-2.5	Goyet *et al.,* 1998
regon Coast		20				Hales *et al.,* 2005
oss Sea		25^1, $4\text{-}10^2$			1.5^3, $0.07\text{-}1.55^4$	1.Wang *et al.,* 1998; 2.Bates *et al.*, 1998; 3.Borges *et al.,* 2005; 4.Arrigo and Van Dijken, 2007
Prydz Bay		75^1			2.2^2	1.Wang *et al.,* 1998; 2.Borges *et al.,* 200

able 2 (continued)

ea	Spring**	Summer	Fall	Winter	Annual	Ref.
	mmol m^{-2} d^{-1}				mol C m^{-2} yr^{-1}	
a of Japan					3.8	Kang *et al.*, 2003
Atlantic Bight					-2.5	Cai *et al.*, 2003
China Sea		4.8[1], -0.73[2]		0.5[2]	-0.18[2], 1.0[3], -1.3[4]	1.Rehder and Suess, 2001; 2.Chen *et al* 2006; 3.Chen *et al.*, 2003a; 4.Zhai *et al* 2005
rait of Gibraltar	5.5±2	-3±8		19±6	2.5	Santana-Casiano, 2002
iwan St.	17.6					Ma *et al.*, 1999
ncouver Is. Coast					1.2	Borges *et al.*, 2005
European Shelves						Frankignoulle and Borges, 2001
eddell Sea		-0.3***				Stoll *et al.*, 2002
Florida Shelf					ΔpCO_2= -43 to -64 µatm	Wanninkoff *et al.*, 1997
Mediterranean	-	++	+	-	0.5±0.18	Begovic and Copin-Montegut, 2002
					1.5-8×10^{-4}	de Madron *et al.*, 2004
				4		Copin-Montegut and Begovic, 2002
llow Sea	4.4[1]	-1.8[1]	4.4[1]	13[1]	2.4[1], 2±0.7[2]	1.Oh *et al.,* 2000; 2.Wang *et al.*, 2001

able 2 (continued)

ea	Spring**	Summer	Fall	Winter	Annual	Ref.
	mmol m^{-2} d^{-1}				mol C m^{-2} yr^{-1}	
obal Coral Reefs 0.6×10^6 km^2)	>0[1], <0[2]	<0[3]	~0[2]	>0[3]	-0.1~ -3.2[4], -1.1 to -2.6[5]	1.Smith, 1973; 2.Kawahata *et al.,* 1997 3.Kayanne *et al.,* 2005; 4.Borges *et al* 2005; 5.Frankignoulle *et al.*, 1996
obal Coastal to~40m depth)					-1.8	Rabouille *et al.*, 2001
obal Shelves ~40m to 200m depth)					1.05	Rabouille *et al.*, 2001
LOBAL					2.2[1], 2.4[2], 0.3[3], 1.9[4], 1[5], 1.8-2.0[6],1.15[7], 0.72[8]	1.Sabine and Mackenzie, 1991; 2.Wals and Ditterle, 1994 ; 3.Liu *et al.*, 200 4.Yool and Fasham, 2001; 5.Chen *et al* 2003a; 6.Ducklow and McCallister, 2004 7.Chen, 2004; 8.Cai *et al.,* 2006

he most recent value provided by the same principal investigator is chosen, positive flux means air to sea, negative flux means sea to air.

Spring: March-May; Summer: June-August; Fall: September-November; Winter: December-February.

*austral summer

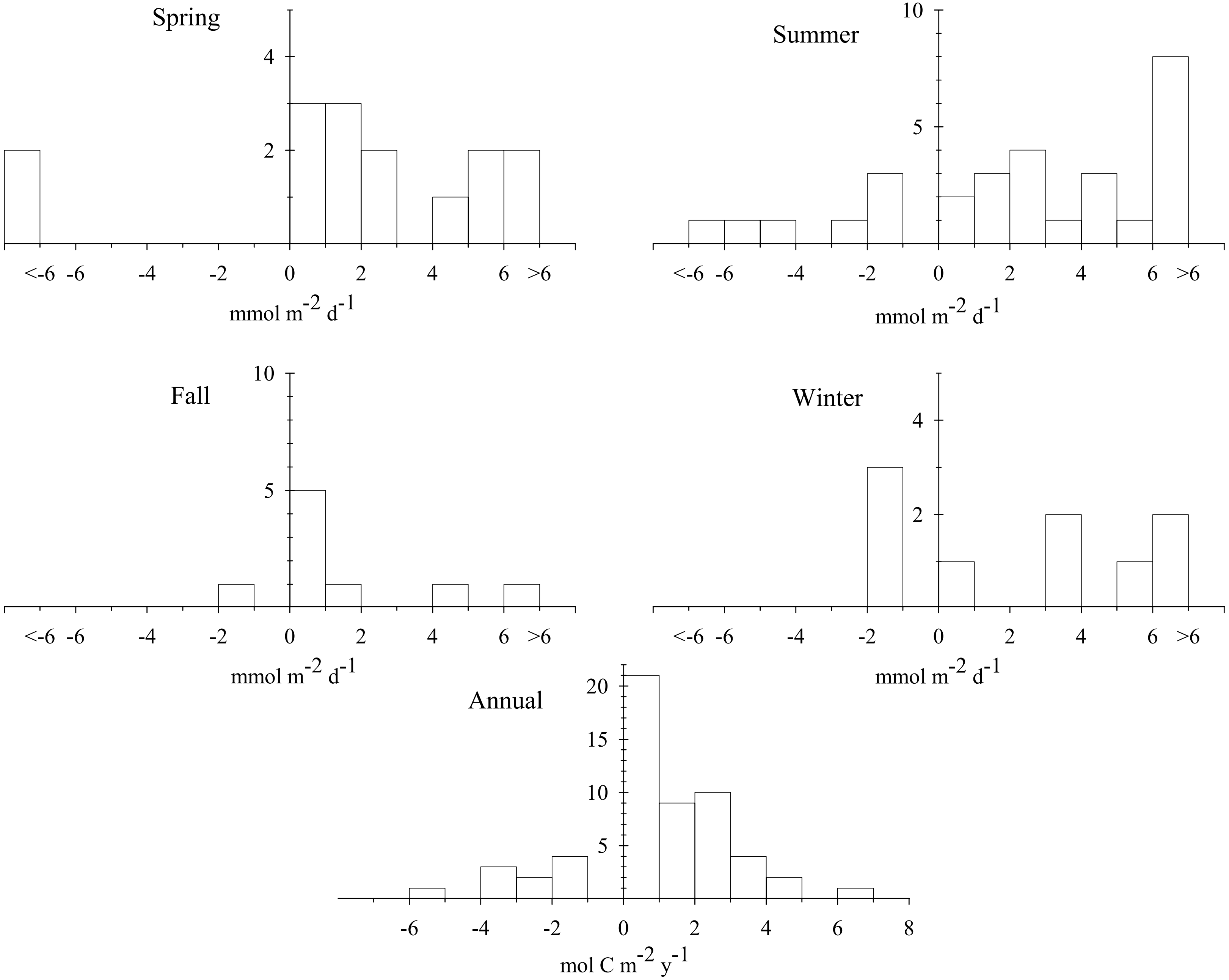

Spring
4
2
<-6 -6 -4 -2 0 2 4 6 >6
mmol m-2 d-1
Summer
10
5
<-6 -6 -4 -2 0 2 4 6 >6
mmol m-2 d-1
Fall
10
5
<-6 -6 -4 -2 0 2 4 6 >6
mmol m-2 d-1
Winter
4
2
<-6 -6 -4 -2 0 2 4 6 >6
mmol m-2 d-1
Annual
20
15
10
5
-6 -4 -2 0 2 4 6 8
mol C m-2 y-1

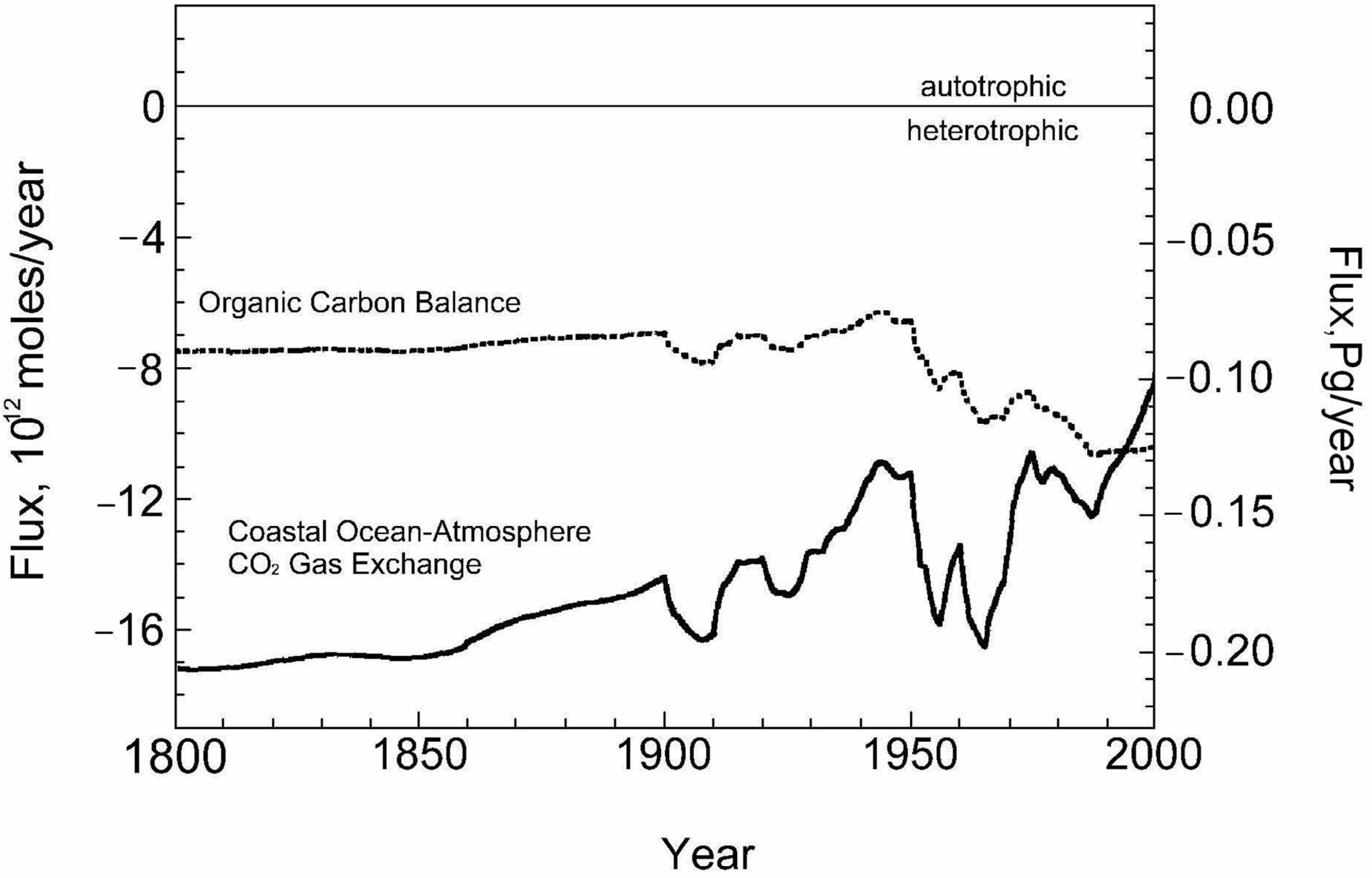
Fig. 2

Table 3. Air-sea primary production and air-sea exchanges of CO_2 on the continental shelves

Region	Area* 10^6 km^2	Air-sea flux mol CO_2 m^{-2} y^{-1}	Total air-sea exchange 10^{12} mol CO_2 y^{-1}
Arctic - P	3.51	2.2	7.72
Antarctic-P	2.19	2.0	4.38
NW Atlantic - SP	2.25	1.0	2.25
NW Atlantic - WB	1.54	-0.5	-0.77
W Atlantic - T	0.62	0.0	0.00
SW Atlantic - WBC	1.68	-1.0	-1.68
SW Atlantic - SP	2.33	1.5	3.50
NE Atlantic - SP	2.34	1.6	3.74
NE Atlantic - EBC	1.68	0.8	1.34
E Atlantic - T	0.18	0.0	0.00
SE Atlantic - EBC	0.22	0.5	0.11
Atlantic Subtotal	**12.84**	**--**	**8.49**
W Indian - M	0.50	-1.4	-0.70
W Indian - T	0.08	0.0	0.00
W Indian - WBC	0.18	-1.0	-0.18
E Indian - M	0.62	0.4	0.25
E Indian - T	0.23	0.0	0.00
E Indian - EBC	0.25	0.0	0.00
E Indian - SP	0.38	1.8	0.68
Indian Subtotal	**2.24**	**--**	**0.05**
NW Pacific - SP	2.91	2.5	7.28
NW Pacific - WBC	1.36	1.1	1.50
W Pacific - T	2.15	-0.1	-0.22
SW Pacific - WBC	2.01	-1.0	-2.01
NE Pacific - SP	0.22	1.8	0.40
NE Pacific - EBC	0.40	-0.5	-0.20
E Pacific - T	0.10	0.0	0.00
SE Pacific - EBC	0.20	0.0	0.00
SE Pacific - SP	0.03	1.8	0.05
Pacific Subtotal	**9.38**	**--**	**6.80**
Grand Totals	**30.16**	**--**	**27.44**

*Taken from Jahnke, 2007.

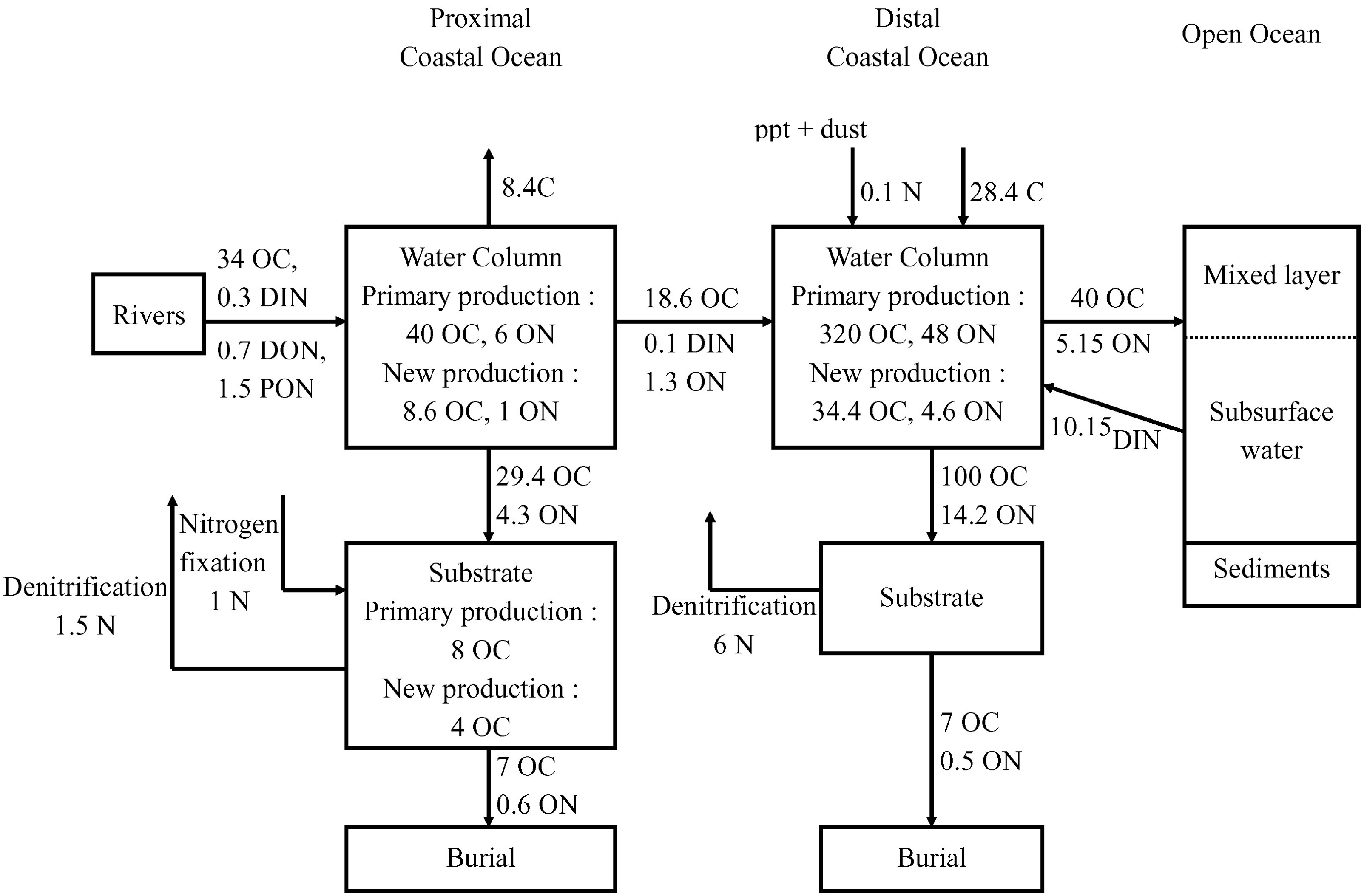
- The shelves transport
  50×10^{12} mol DOC (27 from rivers),
  45×10^{12} mol POC (18 from rivers),
  21×10^{12} mol PIC (15 from rivers),
  5×10^{12} mol DON (1 from rivers) and
  5×10^{12} mol PON (1.5 from rivers)
  to the open oceans every year.
- In addition, based on mass balance calculations, net denitrification releases about 2.5×10^{12} mol N y^{-1} into the atmosphere.



Organic carbon balance (dashed line) and net exchange flux of CO_2 across the air-seawater interface (solid line) for the coastal margin system, in units of 10^{12} moles C y^{-1} and Pg y^{-1}. Negative values indicate CO_2 flux is out of the surface waters (modified from Vet *et al*., 1999a).

- Of interest is that the most recent estimates of Mackenzie and

  co-workers (Rabouille *et al.*, 2001) defines the continental margins as net sinks of 20×10^{12} mol C y^{-1} (0.24 Pg C y^{-1}) in the pre-anthropogenic state (see the following figure), which differs greatly from the value of -0.2 Pg C y^{-1} in the previous figure (Ver *et al.*, 1999).



Proximal
Coastal Ocean

Distal
Coastal Ocean

Open Ocean

Rivers

34 OC,
0.3 DIN
0.7 DON,
1.5 PON

8.4C

Water Column
Primary production :
40 OC, 6 ON
New production :
8.6 OC, 1 ON

18.6 OC
0.1 DIN
1.3 ON

ppt + dust
0.1 N
28.4 C

Water Column
Primary production :
320 OC, 48 ON
New production :
34.4 OC, 4.6 ON

40 OC
5.15 ON

10.15 DIN

Mixed layer

Subsurface
water

Sediments

29.4 OC
4.3 ON

100 OC
14.2 ON

Denitrification
1.5 N

Nitrogen
fixation
1 N

Substrate
Primary production :
8 OC
New production :
4 OC

Denitrification
6 N

Substrate

7 OC
0.6 ON

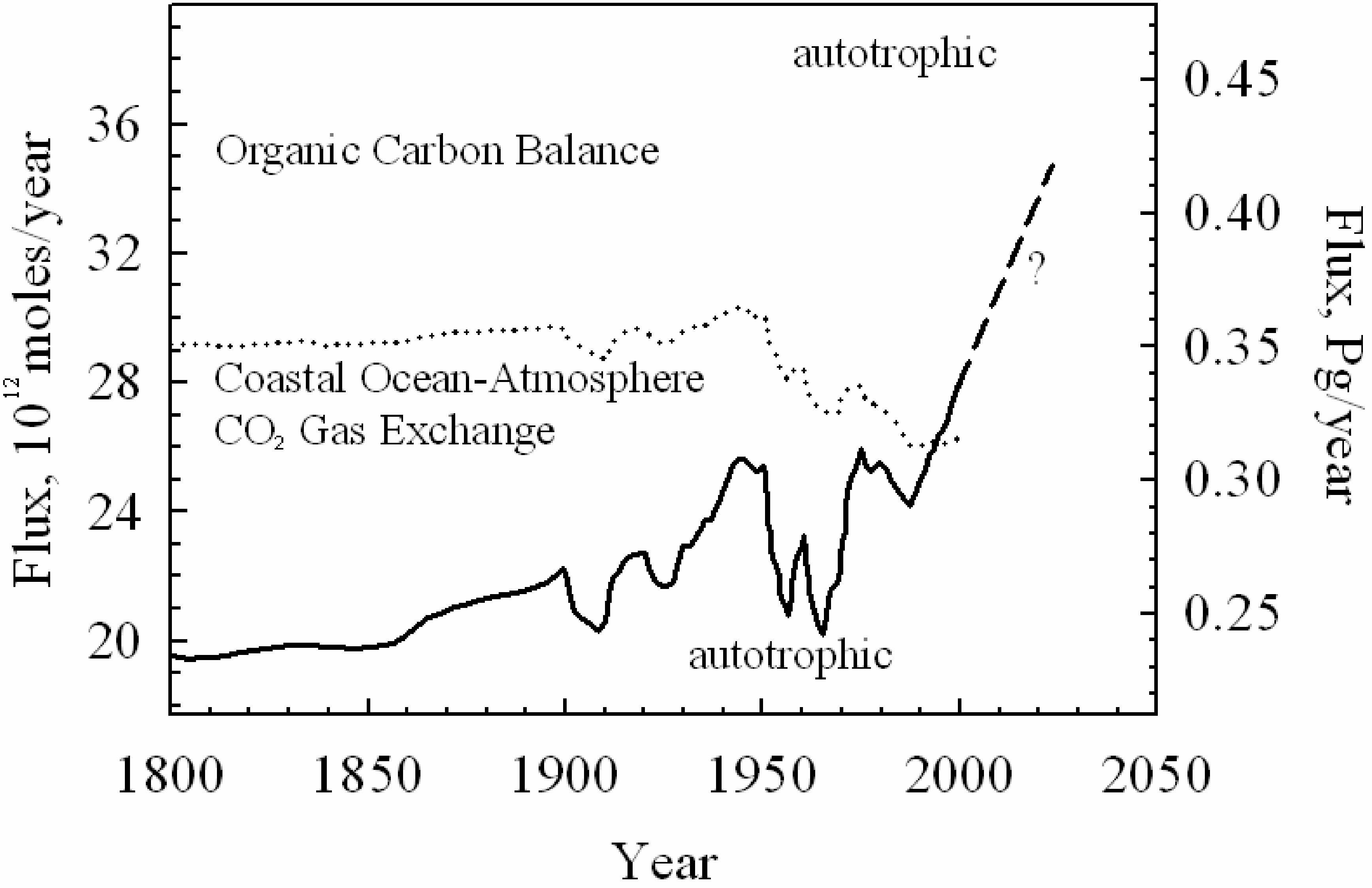
7 OC
0.5 ON

Burial

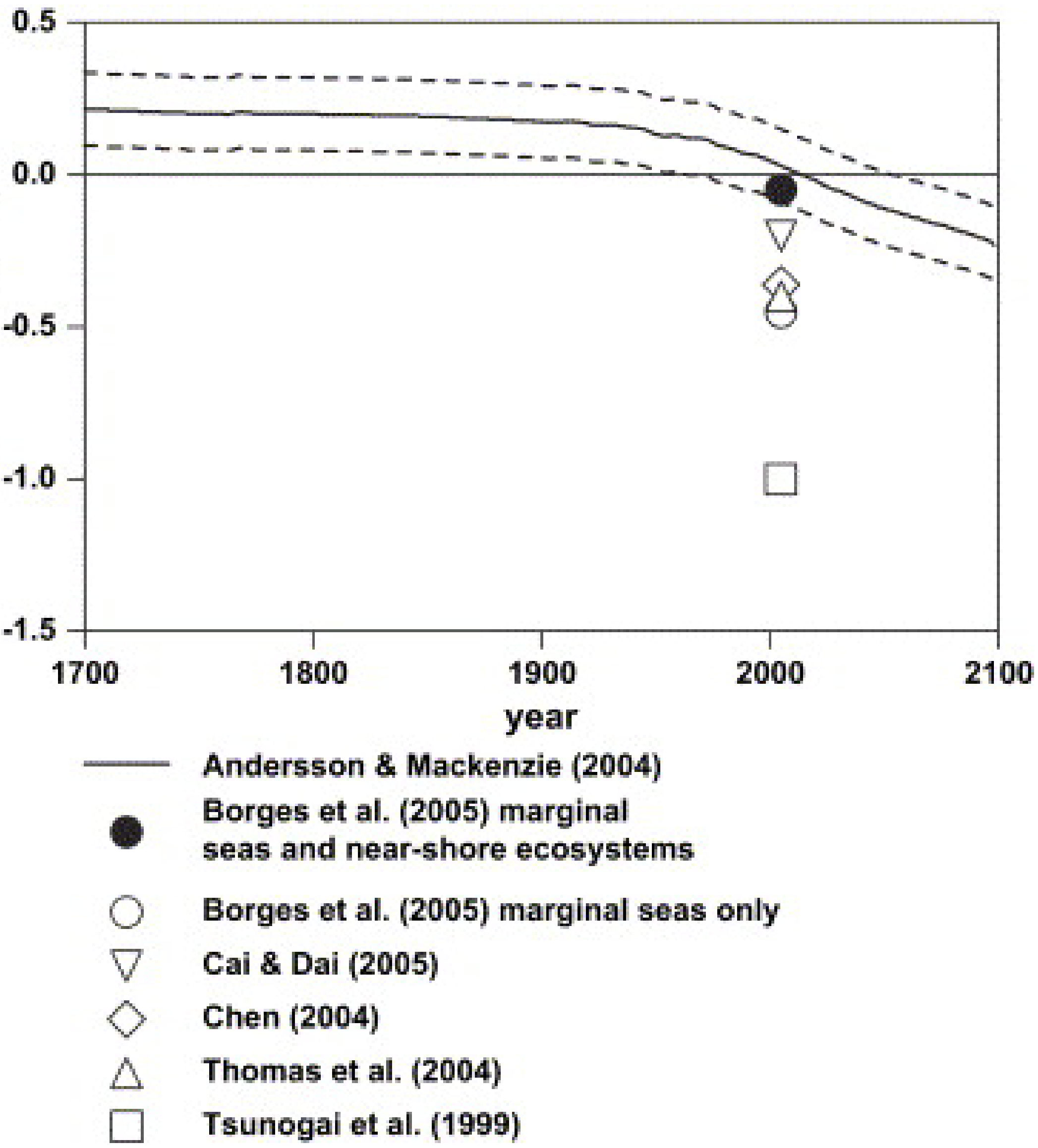
Burial

Organic carbon and nitrogen cycles (in 10^{12} mol y^{-1}) in the global coastal ocean in its pre-anthropogenic state. The boxes represent the reservoirs and the arrows represent the fluxes between the reservoirs. The air-sea fluxes do not include the net flux of CO_2 because the carbonate system is not included in the budget (data taken from Rabouille *et al.*, 2001).

- In order to make the 1999 figure correct in the pre-anthropogenic state, a value of 0.44 Pg C y^{-1} needs to be added, and as a consequence, this renders the continental margins as sinks of 0.34 Pg C y^{-1} (28×10^{12} mol y^{-1}) in the year 2000.



Organic carbon balance (dashed line) and net exchange flux of CO_2 across the air-seawater interface (solid line) for the coastal margin system, in units of 10^{12} moles C y^{-1} and Pg y^{-1}. Positive values indicate CO_2 flux is directed toward the surface waters (Modified from Vet *et al*., 1999a by adding 36.7×10^{12} mol y^{-1} or 0.44 Pg y^{-1} to their results).



Carbon dioxide fluxes between the coastal ocean and the atmosphere (PgC yr^{-1}) at global scale based on different approaches. The solid line corresponds to the output of the box model of Andersson and Mackenzie (2004) that accounts for organic and inorganic carbon fluxes (Shallow-water Ocean Carbonate Model, SOCM); dotted line corresponds to uncertainty estimate. The ope diamond corresponds to mass balance computations of organic and inorganic carbon in several marginal seas (Chen, 2004). The open square and open up-triangle correspond to globally scaled fluxes computed from field pCO_2 measurements in, respectively, the East China Se (Tsunogai *et al*., 1999), and the North Sea (Thomas *et al*., 2004). The open circle and open down-triangle correspond to globally scaled fluxe computed from field pCO_2 measurements in several marginal seas, by respectively, Borges *et al*. (2005), and Cai and Dai (2005). The full circle corresponds to globally scaled fluxes computed from field pCO_2 measurements in marginal seas and near-shore ecosystems (inner estuaries, saltmarsh and mangrove waters, coral reefs and coastal upwellings) by Borges *et al.* (2005).

Taken from Borges *et al*., 2006

Take Home Message

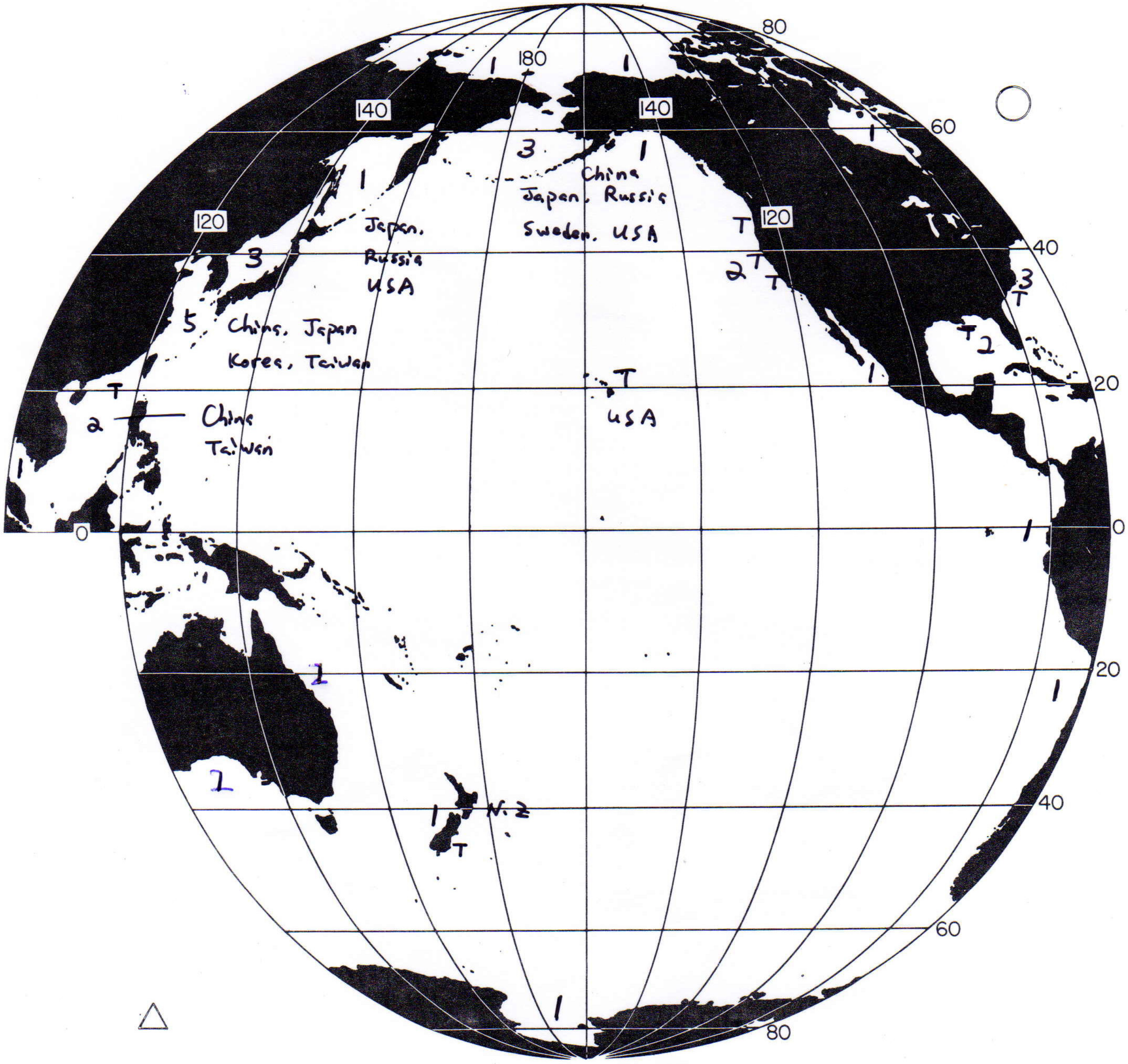
- Continental Shelves are indeed carbon sinks
- Even for large rivers such as the Amazon, pCO_2 becomes undersaturated within only a small distance outside of the estuaries.
- New Production is fueled by a net on-shore transport of 9×10^{12} mol y^{-1} of DIN (only 1×10^{12} mol y^{-1} from riverine outflow of DIN).

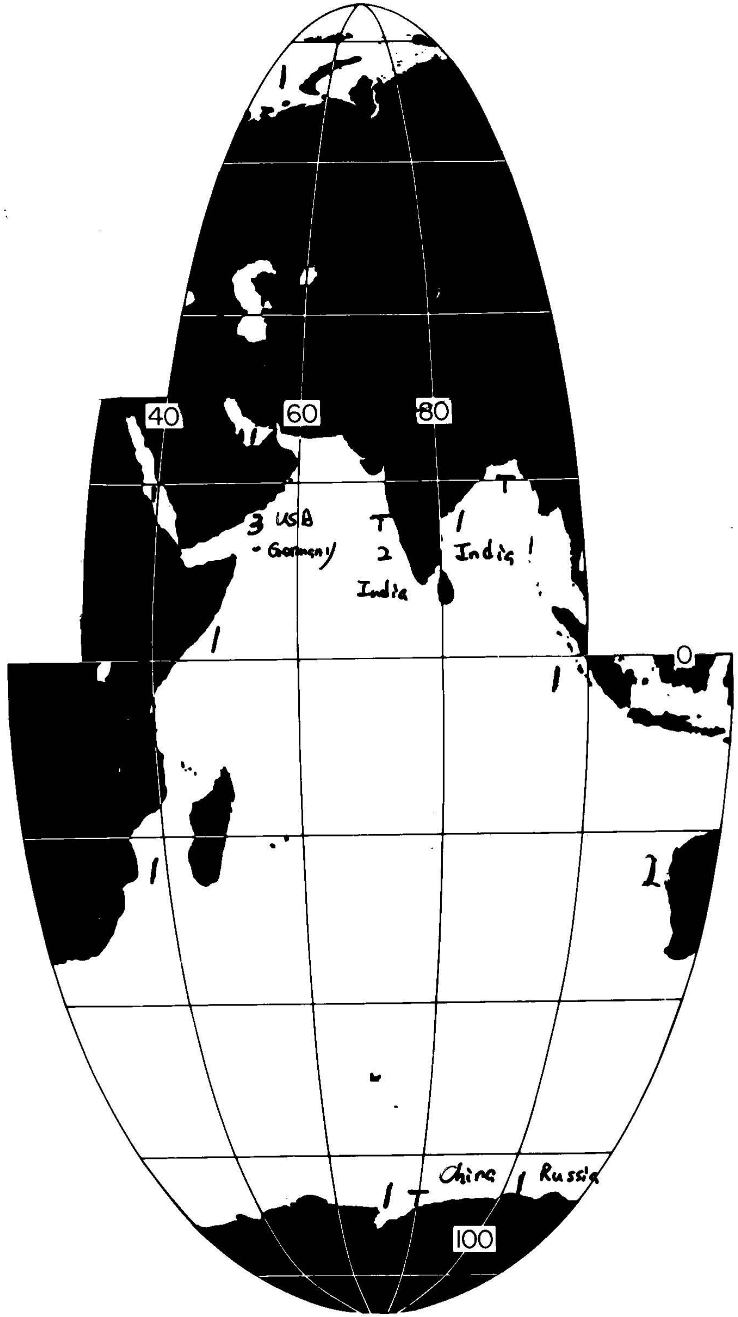
T : time series

5 : well studied

1 : poorly covered

Canada, Sweden, Russia, USA, China




40
60
80
3 USA
Germany
T
2
India
1
India !
T
1
1
0
1
2
1
1 T
China
Russia
100

△