Seasonal Flux and Assemblage Composition of Planktic Foraminifera from the Northern Gulf of Mexico

By Kathy A. Tedesco, Jessica W. Spear, Eric Tappa, and Richard Z. Poore

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Abstract

A year-long sediment-trap experiment was conducted in the northern Gulf of Mexico (GOM) between January and December 2008 to study the flux and assemblage composition of planktic foraminifera from the region for comparison with concurrent hydrographic and climatic measurements. Ten species, or varieties, of planktic foraminifera constitute >80 percent of the assemblage: *Globigerinoides ruber* (pink and white varieties), *Gs. sacculifer*, *Globigerina calida, Globigerinella aequilateralis, Globorotalia menardii* group, *Gt. crassaformis, Gt. truncatulinoides, Pulleniatina* spp., and *Neogloboquadrina dutertrei*. The mean daily flux is about 200 tests per meter square per day (m^{-2} day^{-1}) with the maximum fluxes of >600 tests m^{-2} day^{-1} occurring during October-March and minimum fluxes of <30 tests m^{-2} day^{-1} during April-June. The annual flux is weighted toward October-March; approximately 73.2 percent of the total annual flux is produced during this period, while the April-June and July-September fluxes make up 14 percent and 12 percent, respectively. During 2008, *Gs. ruber* (white) contributed ~1.5 percent to the total annual flux and averaged 4.5 percent during April-September, the period of highest fluxes for this species. Results from previous work in the GOM show *Gs. ruber* (white) contributing 20-30 percent of the late Holocene sediment record.

Introduction

To better anticipate future changes in the Earth's climate, natural and anthropogenic influences on the climate system must be differentiated. Paleoclimate reconstructions provide information on the rate and extent of pre-anthropogenic climate variability, which is critical to understanding natural climate-forcing mechanisms and feedbacks. The accuracy of these reconstructions depends on the reliability of the proxies used.

Quantitative analysis of planktic foraminiferal abundance and shell chemistry has improved our understanding of paleoenvironmental change in the world oceans (Imbrie and Kipp, 1971; CLIMAP, 1976; 1981; Ruddiman, 1985). The faunal assemblage composition and flux are indicators of local environmental parameters, such as temperature, salinity, nutrients, and productivity (Bé, 1959; 1960; Bé and Tolderlund, 1971; Prell and Curry, 1981; Kroon, 1990). Sediment-trap studies have greatly increased our understanding of the ecology of planktic foraminifera and, thus, our interpretation of paleoceanographic reconstructions. These studies supply key information for relating planktic foraminiferal flux and assemblage composition to overlying environmental conditions (Kemle-von Mücke and Oberhänsli, 1999; Fairbanks and Wiebe, 1980; Ravelo and others, 1990).

No sediment-trap studies and relatively few plankton tow studies that describe Gulf of Mexico planktic foraminifera populations in detail (Bé, 1982; Ravula, 2004) have been done. Previous efforts to reconstruct late Pleistocene and Holocene climate history for the Gulf of Mexico involving the abundance and shell chemistry (Mg/Ca and $\delta^{18}O$) of planktic foraminifera have based their interpretations on the sensitivity of certain species to glacial versus interglacial conditions (Leventer and others, 1982; 1983; Kennett and others, 1985; Flower and Kennett, 1990; Poore and others, 2003) or sediment-trap data from the Sargasso Sea (Flower and others, 2004; LoDico and others, 2006; Richey and others, 2007). In this paper, we present sediment-trap results from the northern Gulf of Mexico collected between January and December 2008 for direct comparison with the climatology and hydrography on seasonal scales.

Regional Setting

The Gulf of Mexico (GOM) is a semi-enclosed basin surrounded by the Gulf Coast of the United States, Mexico, and Cuba (fig. 1). Sea-surface temperature (SST) at the trap site ranges from a winter low of around 21°C to a gradually increased high of 30°C (World Ocean Atlas 2005 data cited in Locarnini and others, 2006) as the Western Hemisphere Warm Pool extends to the northern GOM. Sea-surface salinity (SSS) ranges from about 35 practical salinity units (psu) in the winter to 32 psu in the summer (World Ocean Atlas 2005 data cited in Antanov and others, 2006).

The GOM is connected to the Caribbean and tropical North Atlantic through the Loop Current (LC). The GOM, Caribbean Sea, and western tropical North Atlantic comprise the Atlantic Warm Pool (AWP), the Atlantic portion of the Western Hemisphere Warm Pool. The AWP is defined by the region covered by water warmer than 28.5ºC and constitutes a large part of the tropical heat engine, supplying moisture to the atmosphere and latent heat to North America as it evolves from early spring to early fall (Wang and Enfield, 2001; Wang and others, 2006). World Ocean Atlas 2005 climatology indicates the trap site is part of the AWP during July, August, and September (summer) (Locarnini and others, 2006). The LC is a surface current that enters the GOM between Cuba and the Yucatan Peninsula and typically loops east and south before exiting through the Florida Straits. A statistical analysis of LC frequency in the western GOM, spanning 27 years (1976-2003), suggests LC penetration to the trap site occurs minimally (4-6 percent of the time). In addition, eddies shedding off the LC, at intervals ranging from 6-17 months, were found to reach the trap site only about 5 percent of the time (Vukovich, 2005).

Figure 1. Location of the sediment trap mooring (inverted triangle) and its proximity to the Pigmy Basin (black dot) in the northern Gulf of Mexico. Bathymetric lines are in meters.

Materials and Methods

A sediment-trap mooring, equipped with a McLane Mark 78 sediment trap with 21 sample cups (fig. 2), was deployed in the northern GOM in early January 2008. The sediment mooring is located at 27.5ºN. and 90.3ºW. in ~1,150 meters (m) of water depth, and the trap is positioned at 700 m of water depth on the mooring to guarantee the collection of deeper dwelling species of planktic foraminifera (for example, *Globorotalia* spp.). Each cup contains a buffered (sodium borate) formalin solution to poison and preserve the samples (Tedesco and Thunell, 2003). Each trap sample represents a 1-week collection period, and the trap was recovered and redeployed every 3 months. During cruises to the trap site, conductivity-temperature-depth (CTD) measurements were conducted using a Sea-Bird Electronics SBE-16*plus* to provide seasonal profiles of temperature and salinity (fig. 3).

The sediment-trap samples were wet split into four aliquots using a precision rotary splitter at the University of South Carolina and then stored in buffered deionized water and refrigerated. A quarter split was wet sieved over a 150-micrometer (µm) sieve and subsequently wet picked for all foraminifera. To supplement total test counts in intervals with less than 300 foraminifera, we sieved and picked an additional one-quarter split and summed the counts. All planktic foraminifera were identified to species. The species counts are reported as flux in tests per meter square per day.

Figure 2. McLane Mark 78 automated sediment trap equipped with 21 cups.

Results and Discussion

Climatology and Hydrography

During 2008, the annual range of SSTs was about 6°C, from 24ºC in January to 29.6ºC in July (fig. 3, top panel). During January-March (winter), the surface mixed-layer depth is about 100 m. The mixed layer begins to shoal in April-June (spring) to about 75 m and by July-September (summer), a strong thermocline develops at 35 m, and the water becomes more stratified. By October-December (fall), the mixed layer deepens to 70 m. Sea-surface salinity was highest in January (36.5 psu), as expected, due to higher rates of evaporation. Sea-surface salinity began to decrease in April (36.2 psu) and was lowest during July (31.3 psu) (fig. 3, lower panel).

Figure 3. Temperature (top panels) and salinity (lower panels) depth profiles from this study (red and blue) and World Ocean Atlas 2005 climatology (Locarnini and others, 2006) for the trap site (black). The temperature and salinity profiles for January include 2008 (red) and 2009 (blue). m, meters; psu, pratical salinity units.

A comparison of World Ocean Atlas climatology 2005 (WOA05) with temperature data from the National Data Buoy Center (NDBC), Moderate Resolution Imaging Spectroradiometer (MODIS), and our CTD casts showed that both the NDBC and MODIS data agreed well with the CTD data (fig.4). In addition, NDBC, MODIS, and CTD records indicate that SSTs were 1.5-2ºC warmer between January and April 2008 than the WOA05 climatology would predict. World Ocean Atlas (2005) climatology also suggests the trap site experienced higher than average SSS during most of 2008. The increase in salinity relative to climatological means ranged from as large as +3.6 psu in April to +0.8 psu in July.

Figure 4. Comparison of sea-surface temperature data from the NDBC, MODIS, and World Ocean Atlas 2005 (Locarnini and others, 2006) from 2005 to early 2009 with SST measurements from conductivity-temperature-depth (CTD) casts at the trap site.

Planktic foraminifera flux and assemblage composition

More than 25 species of planktic foraminifera were identified in the sediment-trap material. Ten species, or varieties, of planktic foraminifera constitute >80 percent of the assemblage: *Globigerinoides ruber* (d'Orbigny) (pink and white varieties), *Gs. sacculifer* (Brady), *Globigerina calida* (Parker), *Globigerinella aequilateralis* (Brady), *Globorotalia menardii* group (The *Gt. menardii* group includes *Gt. menardii* (Parker, Jones, and Brady), *Gt. tumida* (Brady), and *Gt. ungulata* (Bermudez), *Gt. crassaformis* (Galloway and Wissler), *Gt. truncatulinoides* (d'Orbigny), *Pulleniatina* spp., and *Neogloboquadrina dutertrei* (d'Orbigny) (table 1, figs. 5 and 7). The seasonal range of several of these species has important implications for paleoceanographic reconstructions of the region (for example, *Gs. ruber*, *Gs. sacculifer*).

Table 1. Planktic foraminifera flux (tests per square meter per day, m^{-2} d^{-1}) and percent contribution (in parentheses) to the total assemblage for the 10 dominant species.

The mean daily flux of planktic foraminifera recovered from the sediment trap in 2008 was about 200 tests m^{-2} day^{-1} (fig. 5 and table 1). The fall and winter assemblages, combined, account for 73.2 percent of the total annual flux and dominate the annual flux. The spring and summer contribute ~14 percent and 12 percent, respectively, to the annual flux. The mean winter seasonal flux is ~300 tests m^{-2} day^{-1} with a maximum daily flux of ~600 tests m^{-2} day^{-1}. The mean seasonal flux in the spring decreases to ~110 tests m^{-2} day^{-1} with the lowest average flux in the summer of about 94 tests m^{-2} day^{-1}. The fall mean flux is close to that of winter, ~288 tests m^{-2} day^{-1}, with a daily maximum flux of ~640 tests m^{-2} day^{-1} in late fall as well.

Figure 5. Weekly flux (tests per meter square per day, m^{-2} day^{-1}) of all planktic foraminifera and the 10 most abundant species/groups during 2008. Note the scale changes in the y-axes.

The diversity of species was measured as the total number of species identified for each interval (that is, species richness) (fig. 6). Diversity ranged from 11 to 20 different species and averages 15.1 ±2.4 throughout 2008. The average number of species did not change substantially from winter (15.1 ±2.2) to spring (15.4 ±2.7). Diversity in the summer (14.7 ±3.1) was not significantly different from the winter and spring. However, there was a sharp decrease in diversity in mid-June, from 18 species to 11 species, when the deeper dwelling species (for example, *Globorotalia* spp.) are absent. Species diversity remains low, averaging 11.6 ±0.9 species, until mid-July when it increases for 2 weeks to 16.5 species before decreasing to an average of 13.3 ±1.9 until mid-September. Diversity increases to 19.5 species for the last 2 weeks of September before lowering back down to an average of 15.6 ±1.3 during the fall.

Figure 6. Species diversity during 2008. The x-axis is the mid-week day for each 7-day collection period. On average, species diversity is lowest during the majority of the summer. There is a large decrease in diversity in mid-June and the end of July, when the deeper dwelling species are absent.

Globorotalia truncatulinoides dominates the winter assemblage with fluxes up to 450 tests m^{-2} day^{-1} and contributing 46 percent to the assemblage (fig. 7). In the spring, total fluxes begin to decrease. The abundance of the shallow-dwelling, symbiont-bearing species *Gs. ruber* (white and pink varieties) increases, whereas the deeper dwelling, omnivorous species *Gt. truncatulinoides*, *Pulleniatina* spp., and *N. dutertrei* decrease. As SST increases during summer and the water becomes more stratified, the seasonal average flux reaches its lowest values. The deeper dwelling foraminifera disappear during late spring and summer, causing a sharp decline in species diversity in mid-June. *Globigerinoides ruber* (pink) dominates the summer assemblage with fluxes as high as 102 tests m^{-2} day^{-1}. This species contributes between 13 and 55 percent to the assemblage, while *Gs. ruber* (white) rarely exceeds 10 percent. By the fall, *Gs. ruber* (white and pink varieties) fluxes decrease, fluxes of *Gl. aequilateralis*, *Gt. crassaformis*, *Gt. menardii* group, *N. dutertrei* increase, and the assemblage is dominated by *Pulleniatina* spp. with fluxes up to 322 tests m^{-2} day^{-1} and contributing 37 percent to the assemblage.

The seasonal variations in total foraminiferal flux and assemblage composition relate to changes in hydrographic conditions in the overlying surface waters. The winter assemblage in the GOM sediment trap is most abundant in the deep-dwelling species *Gt. truncatulinoides*, a finding similar to those of other sediment-trap studies from the Sargasso Sea (Deuser and others, 1981; Deuser and Ross, 1989). Lohmann and Schweitzer (1990) have suggested that *Gt. truncatulinoides* needs deep mixing and low-density stratification to introduce juvenile specimens from the deep into surface waters. In subtropical waters, the primary calcification of *Gt. truncatulinoides* begins in weakly stratified winter surface waters (Hemleben and others, 1985; Deuser and Ross, 1989; Lohmann and Schweitzer, 1990). This may explain the high abundance of *Gt. truncatulinoides* in the winter in the northern GOM, when SSTs are lower and the water column is less stratified.

Figure 7. Total planktic foraminifera flux (tests m^{-2} day^{-1}) (top panel) and weekly percent abundance of the 10 most abundant species/groups of planktic foraminifera during 2008. Note the scale changes in the y-axes.

Globigerinoides ruber is a subtropical to tropical species that lives in the upper 50 m of the photic zone and is often used in low-latitude paleoceanographic reconstructions (Keigwin, 1996; Flower and others, 2004; Schmidt and others, 2004; Richey and others, 2007). It occurs in two forms, pink and white, distinguished by the presence of pink pigmentation that ranges in coverage from the proloculus to the entire test. Numerous studies over the past four decades demonstrate the difference in ecology between the two varieties including temperature tolerance (Bijma and others, 1990), seasonality (Bé, 1960; Deuser and others, 1981), depth preference (Bé, 1982; Anand and others, 2003), latitudinal distribution (Bé, 1959; Bé and Hamlin, 1967; Bé and others, 1971; Bé and Tolderlund, 1971; Zaric and others, 2005), seasonal average weights (Deuser and others, 1981), and stable-isotope ratios of carbon and oxygen (Deuser and Ross, 1989). In fact, recent RNA analyses on the two varieties reveal an adequate genetic difference for species-level distinction (Darling and Wade, 2008).

Confined to the Atlantic since 120,000 years ago (Thompson and others, 1979), *Gs. ruber* (pink) is a major contributor to the assemblage in the southern subtropical to tropical waters within the North Atlantic but typically does not dominate the assemblage (Bé and Hamlin, 1967; Bé and others, 1971). In this study, however, *Gs. ruber* (pink) was much more abundant than *Gs. ruber* (white), with fluxes of 102 tests m^{-2} day^{-1} compared with a maximum flux of 13 tests m^{-2} day^{-1} for the white variety.

Sediment-trap experiments assume that the material collected in the trap is representative of that reaching the seafloor. In results from previous studies in the Gulf of Mexico (Kennett and others, 1985; LoDico and others, 2006; Poore and others, in press), *Gs. ruber* (white and pink) makes up ~30-45 percent (fig. 8) of the total assemblage, while *Gs. ruber* (pink) only contributes around 8-10 percent. However, in the trap material collected in 2008, *Gs. ruber* (white) contributes on average <2 percent to the total annual flux, while *Gs. ruber* (pink) contributes 9.75 percent which, when combined, only account for ~11 percent of the annual flux. Sediment-core and plankton-tow studies of *Gs. ruber* in the Atlantic have demonstrated that the abundances from tows show a similar pattern with those in the underlying sediments (Kemle-von Mücke and Oberhänsli, 1999). We currently do not understand the unusually low fluxes of *Gs. ruber* (white). The comparison of WOA05 regional climatology to NDBC and MODIS data back to 2005 with our CTD data from 2008 indicate 2008 was not anomalous.

Figure 8. Faunal assemblage data from nearby Pigmy Basin (Poore and others, in press) shows the abundance of *Gs. ruber* (white and pink) was on average 31 percent of the total planktic foraminifera population during the last 2000 years and rarely fell below 20 percent.

Conclusions

New sediment-trap data from the northern GOM indicate the seasonal variability in the flux of planktic foraminifera closely tracks changes in hydrography. Species diversity peaks in early spring and late summer. The highest fluxes of non-spinose species (for example, *Gt. truncatulinoides* and *Pulleniatina* spp.) occurred during the fall and winter, when the depth of the mixed layer was greatest. The highest fluxes of symbiont-bearing spinose species (for example, *Gs. ruber*) occurred during the summer, when the water column was thermally stratified and SSTs were greatest.

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Figure 1

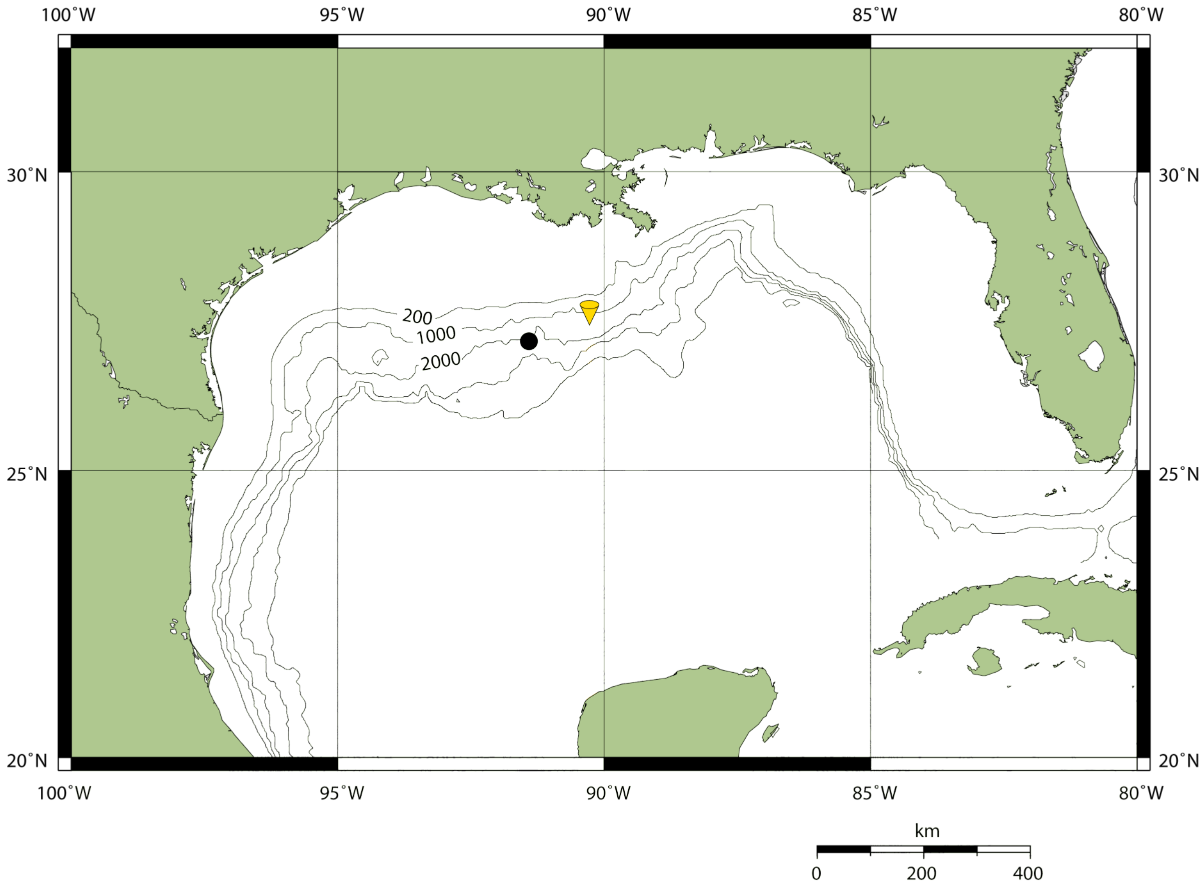


Figure 2

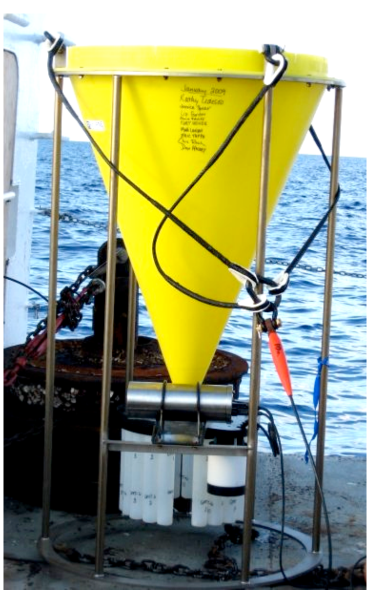
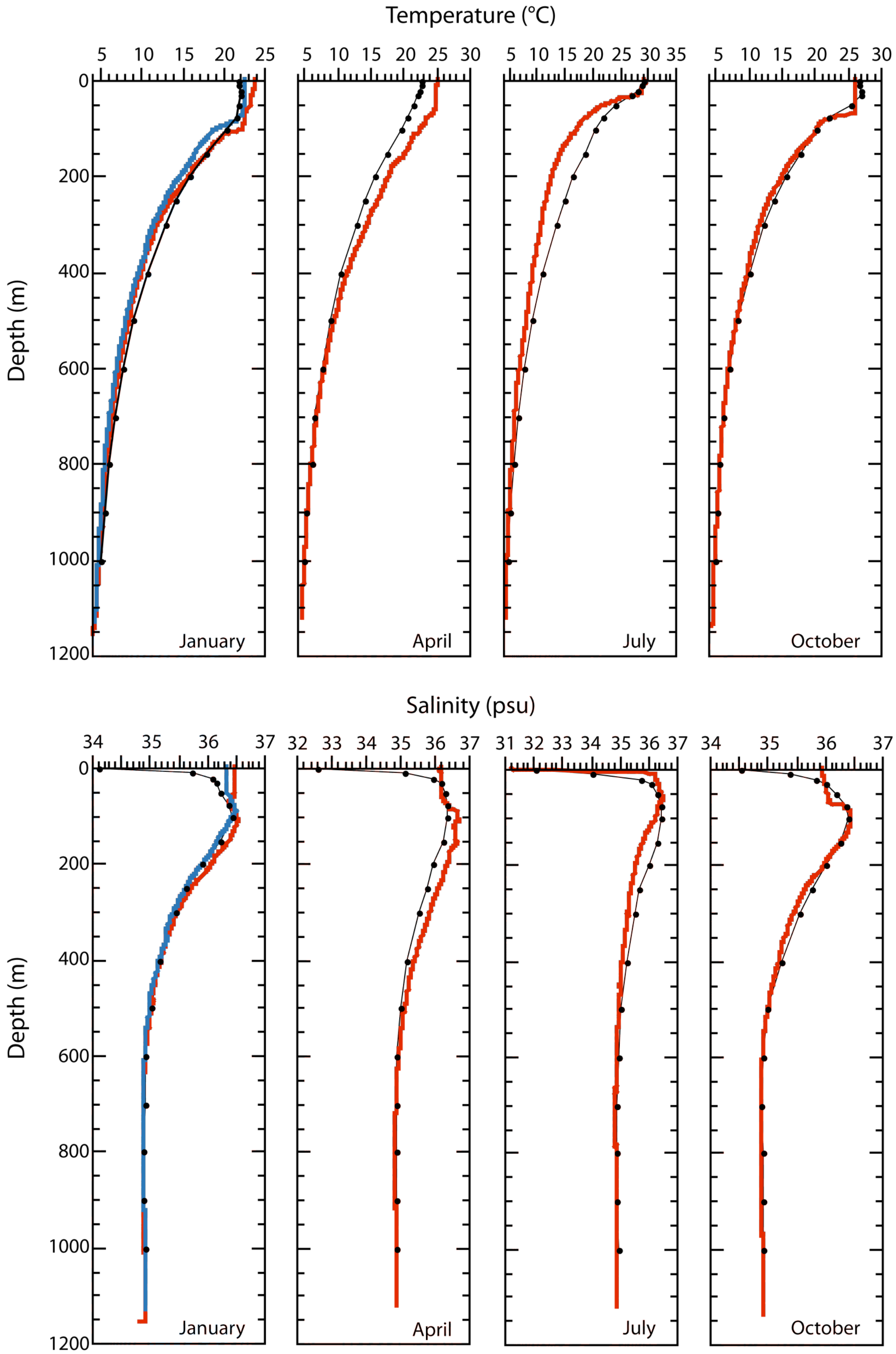


Figure 3



Temperature (°C)
5 10 15 20 25
5 10 15 20 25 30
5 10 15 20 25 30 35
5 10 15 20 25 30
Depth (m)
0
200
400
600
800
1000
1200
January
April
July
October
Salinity (psu)
34 35 36 37
32 33 34 35 36 37
31 32 33 34 35 36 37
34 35 36 37
Depth (m)
0
200
400
600
800
1000
1200
January
April
July
October

Figure 4

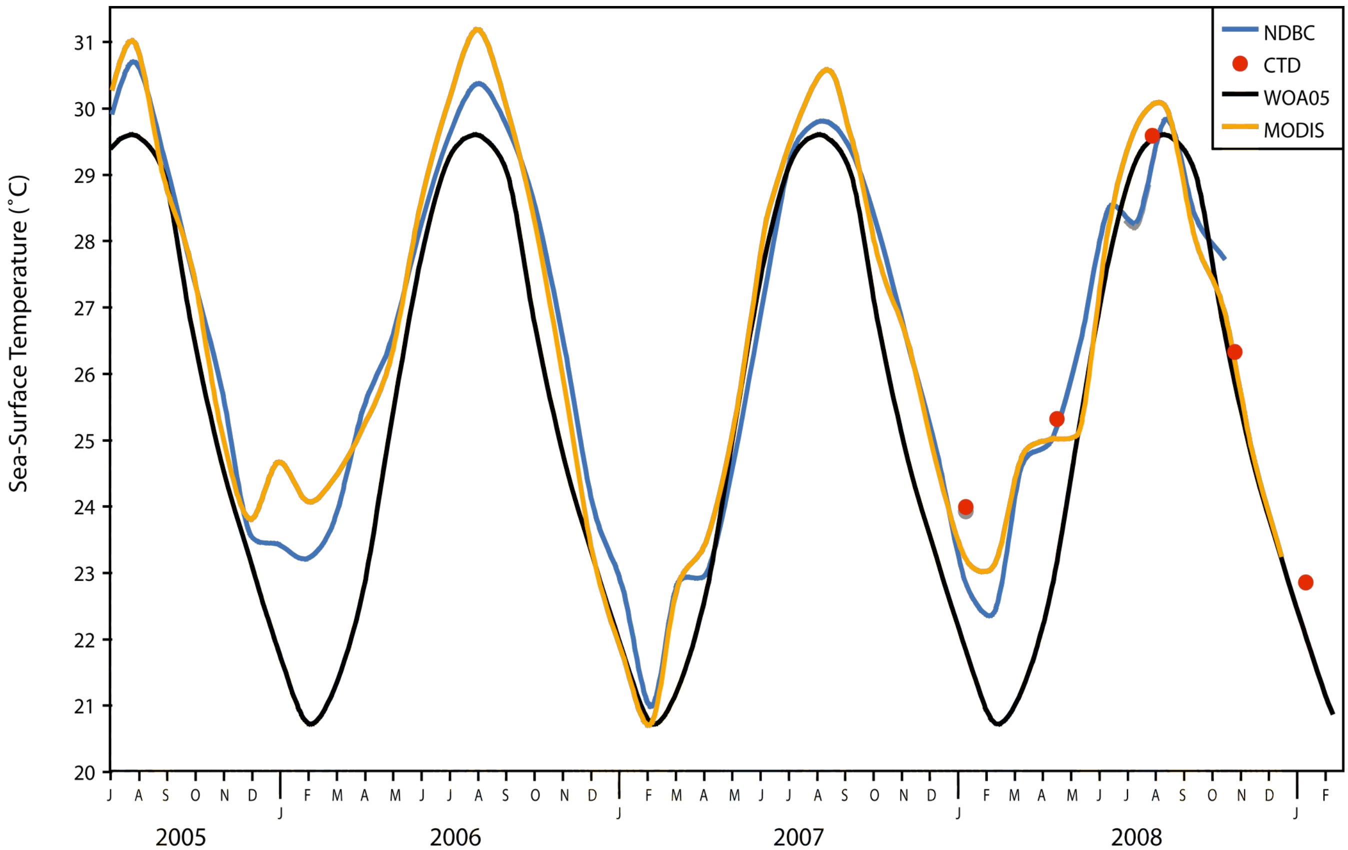

NDBC
CTD
WOA05
MODIS
Sea-Surface Temperature (°C)
31
30
29
28
27
26
25
24
23
22
21
20
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
2005
2006
2007
2008

Figure 5

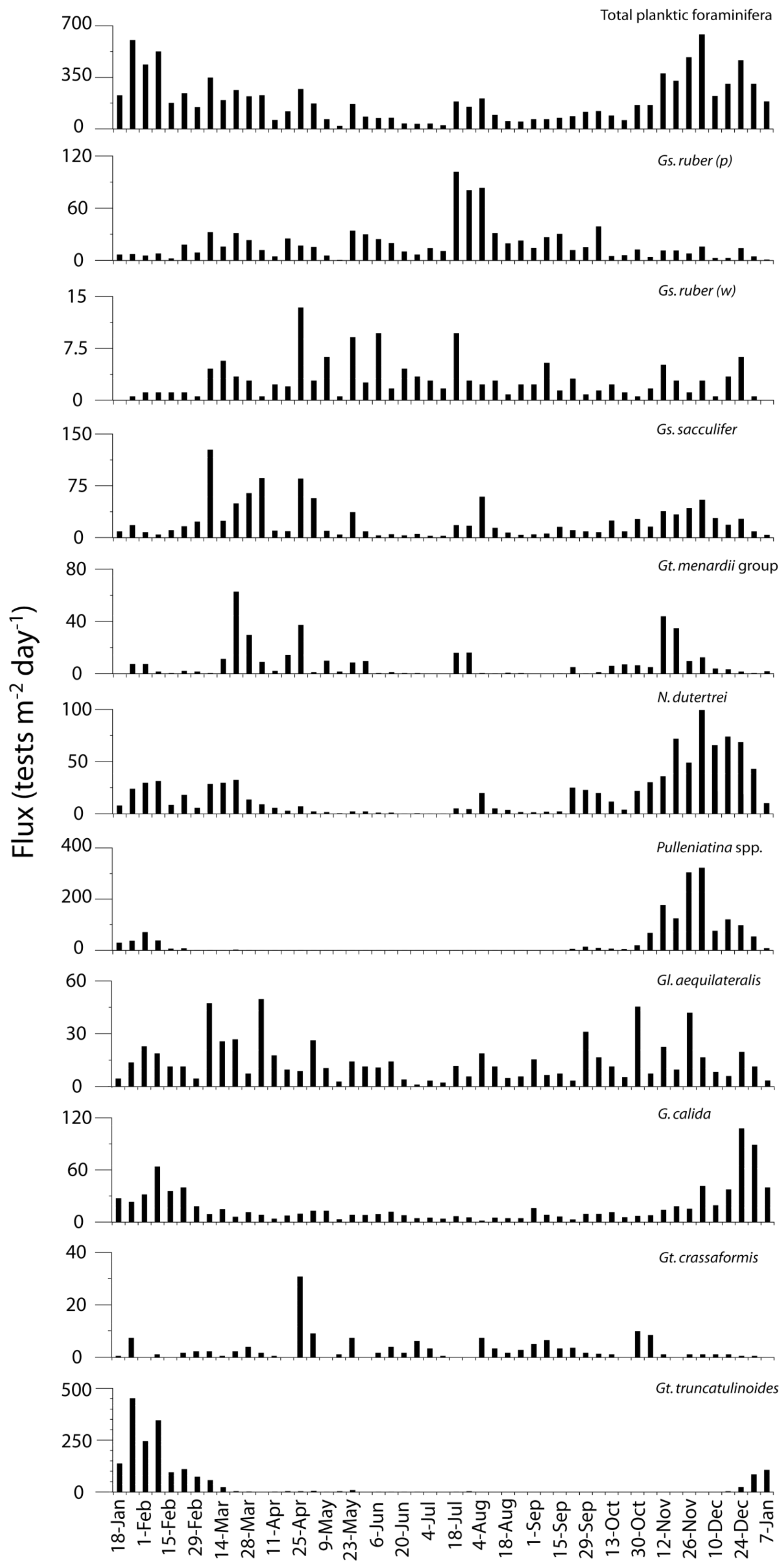
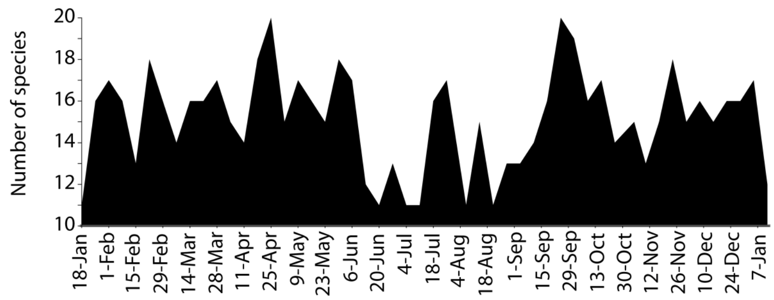
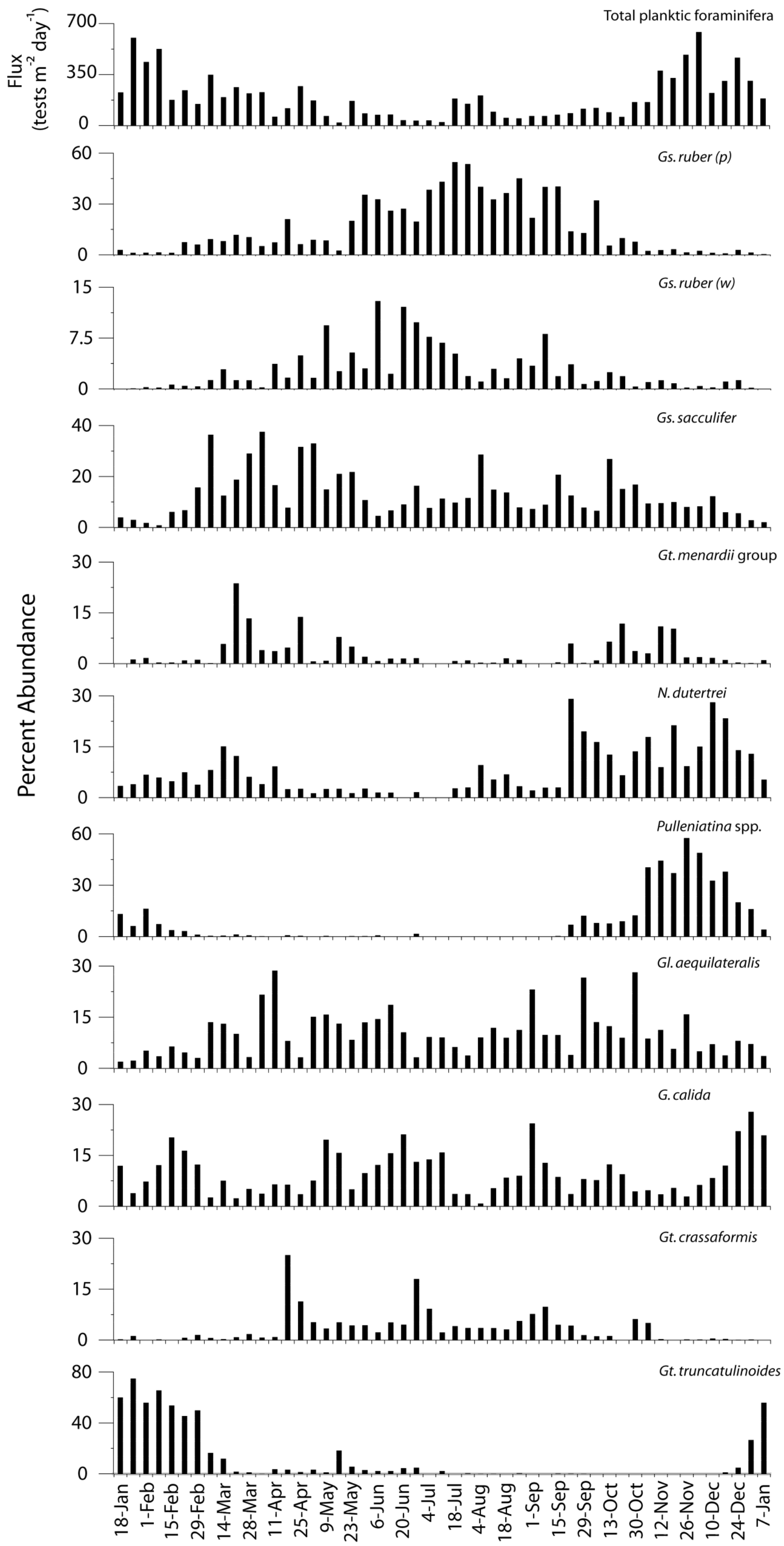

Total planktic foraminifera
Gs. ruber (p)
Gs. ruber (w)
Gs. sacculifer
Gt. menardii group
N. dutertrei
Pulleniatina spp.
Gl. aequilateralis
G. calida
Gt. crassaformis
Gt. truncatulinoides
Flux (tests m-2 day-1)
700
350
0
120
60
0
15
7.5
0
150
75
0
80
40
0
100
50
0
400
200
0
60
30
0
120
60
0
40
20
0
500
250
0
18-Jan
1-Feb
15-Feb
29-Feb
14-Mar
28-Mar
11-Apr
25-Apr
9-May
23-May
6-Jun
20-Jun
4-Jul
18-Jul
4-Aug
18-Aug
1-Sep
15-Sep
29-Sep
13-Oct
30-Oct
12-Nov
26-Nov
10-Dec
24-Dec
7-Jan

Figure 6



Number of species
20
18
16
14
12
10
18-Jan
1-Feb
15-Feb
29-Feb
14-Mar
28-Mar
11-Apr
25-Apr
9-May
23-May
6-Jun
20-Jun
4-Jul
18-Jul
4-Aug
18-Aug
1-Sep
15-Sep
29-Sep
13-Oct
30-Oct
12-Nov
26-Nov
10-Dec
24-Dec
7-Jan

Figure 7



Total planktic foraminifera
Flux (tests m-2 day-1)
700
350
0
Gs. ruber (p)
60
30
0
Gs. ruber (w)
15
7.5
0
Gs. sacculifer
40
20
0
Gt. menardii group
30
15
0
N. dutertrei
30
15
0
Percent Abundance
Pulleniatina spp.
60
30
0
Gl. aequilateralis
30
15
0
G. calida
30
15
0
Gt. crassaformis
30
15
0
Gt. truncatulinoides
80
40
0
18-Jan
1-Feb
15-Feb
29-Feb
14-Mar
28-Mar
11-Apr
25-Apr
9-May
23-May
6-Jun
20-Jun
4-Jul
18-Jul
4-Aug
18-Aug
1-Sep
15-Sep
29-Sep
13-Oct
30-Oct
12-Nov
26-Nov
10-Dec
24-Dec
7-Jan

Figure 8

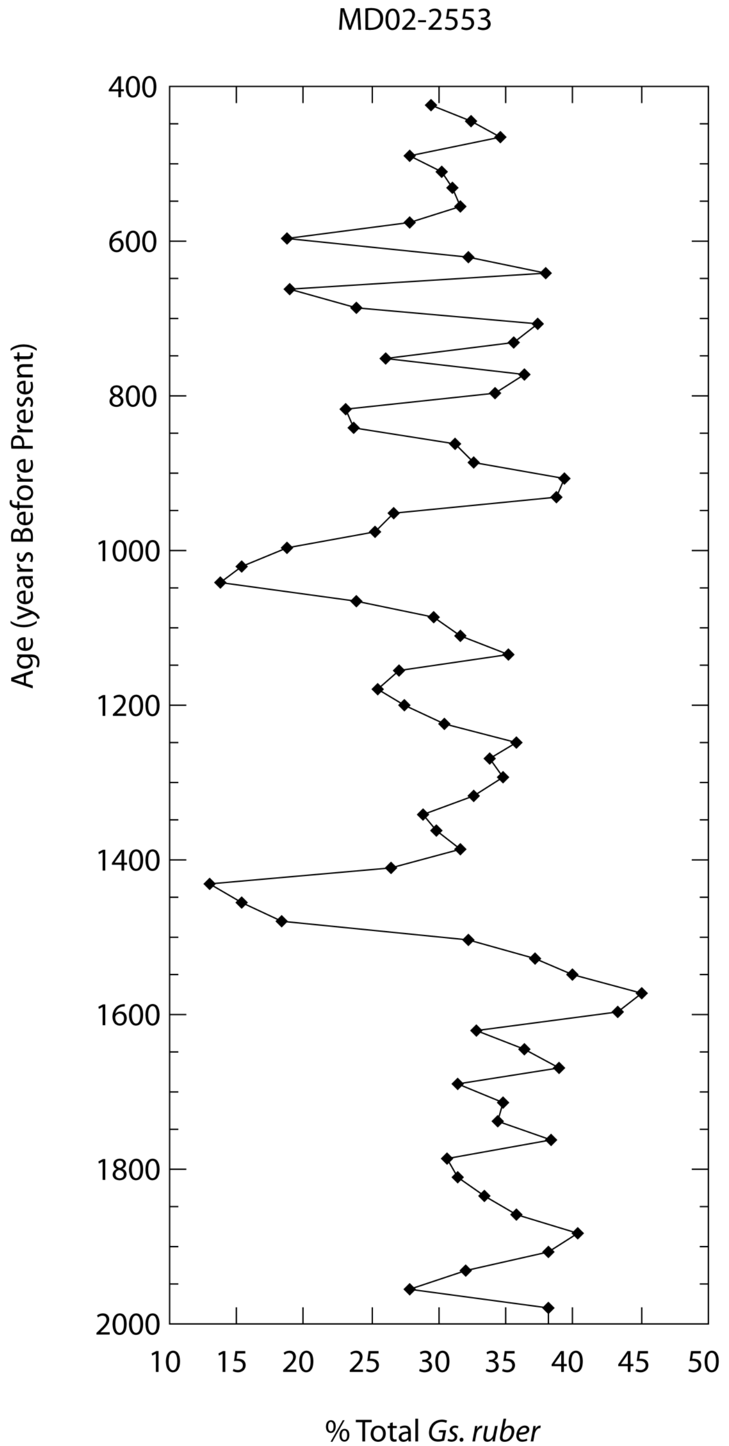

MD02-2553
Age (years Before Present)
400
600
800
1000
1200
1400
1600
1800
2000
10
15
20
25
30
35
40
45
50
% Total Gs. ruber

Table 1

Sample		Mid-week Date	*Gs. ruber* (pink)	*Gs. ruber* (white)	*Gs. sacculifer*	*Gt. menardii* group	*Pulleniatina* spp.	*N. dutertrei*	*Gl. aequilateralis*	*G. calida*	*Gt. crassaformis*	*Gt. truncatulinoides*	Total planktic flux	Percent of annual flux
GMT-4	11	7-Jan-09	1.00 (0.52)	0.00 (0.00)	4.00 (2.09)	2.00 (1.05)	8.00 (4.19)	10.00 (5.24)	3.50 (3.66)	40.00 (20.94)	0.00 (0.00)	107.00 (56.02)	187.50	
GMT-1	1	18-Jan-08	6.86 (2.99)	0.00 (0.00)	9.14 (3.99)	0.00 (0.00)	30.29 (13.22)	8.00 (3.49)	4.57 (2.00)	27.43 (11.97)	0.57 (0.25)	137.71 (60.10)	229.14	
GMT-1	2	25-Jan-08	7.43 (1.23)	0.57 (0.09)	18.29 (3.03)	7.43 (1.23)	37.71 (6.24)	24.00 (3.97)	13.71 (2.27)	23.43 (3.88)	7.43 (1.23)	452.57 (74.93)	604.00	
GMT-1	3	1-Feb-08	5.71 (1.31)	1.14 (0.26)	8.00 (1.83)	7.43 (1.70)	71.43 (16.32)	29.71 (6.79)	22.86 (5.22)	32.00 (7.31)	0.00 (0.00)	245.14 (56.01)	437.71	
GMT-1	4	8-Feb-08	8.00 (1.52)	1.14 (0.22)	4.57 (0.87)	1.71 (0.33)	38.86 (7.38)	31.43 (5.97)	18.86 (3.58)	64.00 (12.15)	1.14 (0.22)	346.29 (65.73)	526.86	
GMT-1	5	15-Feb-08	2.29 (1.29)	1.14 (0.65)	10.86 (6.13)	0.57 (0.32)	6.86 (3.87)	8.57 (4.84)	11.43 (6.45)	36.00 (20.32)	0.00 0.00	95.43 (53.87)	177.14	
GMT-1	6	22-Feb-08	18.29 (7.51)	1.14 (0.47)	16.57 (6.81)	2.29 (0.94)	8.00 (3.29)	18.29 (7.51)	11.43 (4.69)	40.00 (16.43)	1.71 (0.70)	110.86 (45.54)	243.43	
GMT-1	7	29-Feb-08	9.14 (6.15)	0.57 (0.38)	23.43 (15.77)	1.71 (1.15)	1.71 (1.15)	5.71 (3.85)	4.57 (3.08)	18.29 (12.31)	2.29 (1.54)	74.29 (50.00)	148.57	
GMT-1	8	7-Mar-08	32.57 (9.31)	4.57 (1.31)	127.43 (36.44)	0.57 (0.16)	1.71 (0.49)	28.57 (8.17)	47.43 (13.56)	9.14 (2.61)	2.29 (0.65)	57.71 (16.50)	349.71	
GMT-1	9	14-Mar-08	16.00 (8.16)	5.71 (2.92)	24.57 (12.54)	11.43 (5.83)	1.14 (0.58)	29.71 (15.16)	25.71 (13.12)	14.86 (7.58)	0.57 (0.29)	23.43 (11.95)	196.00	
GMT-1	10	21-Mar-08	31.43 (11.88)	3.43 (1.30)	49.71 (18.79)	62.86 (23.76)	3.43 (1.30)	32.57 (12.31)	26.86 (10.15)	6.29 (2.38)	2.29 (0.86)	4.57 (1.73)	264.57	
GMT-1	11	28-Mar-08	23.43 (10.54)	2.86 (1.29)	64.57 (29.05)	29.71 (13.37)	1.71 (0.77)	13.71 (6.17)	7.43 (3.34)	11.43 (5.14)	4.00 (1.80)	2.86 (1.29)	222.29	
winter		Total	162.14	22.29	361.14	127.71	218.86	232.29	198.36	322.86	22.29	1657.86	3586.93	
		(%)	(4.52)	(0.62)	(10.07)	(3.56)	(6.10)	(6.48)	(5.53)	(9.00)	(0.62)	(46.22)	(92.72)	(35.82)
GMT-1	12	4-Apr-08	12.00 (5.22)	0.57 (0.25)	86.29 (37.56)	9.14 (3.98)	0.57 (0.25)	9.14 (3.98)	49.71 (21.64)	8.57 (3.73)	1.71 (0.75)	0.57 (0.25)	229.71	
GMT-1	13	11-Apr-08	4.57 (7.41)	2.29 (3.70)	10.29 (16.67)	2.29 (3.70)	0.00 (0.00)	5.71 (9.26)	17.71 (28.70)	4.00 (6.48)	0.57 (0.93)	2.29 (3.70)	61.71	
GMT-1	14	18-Apr-08	25.33 (21.17)	2.00 (1.67)	9.33 (7.80)	14.33 (4.74)	1.00 (0.84)	3.00 (2.51)	9.67 (8.08)	7.67 (6.41)	0.00 (25.07)	4.67 (3.34)	119.67	
GMT-2	1	25-Apr-08	36.57 (12.61)	13.43 (4.63)	85.71 (29.56)	37.43 (12.91)	1.43 (0.49)	7.14 (2.46)	8.86 (3.05)	9.71 (3.35)	30.86 (10.64)	4.00 (1.38)	290.86	
GMT-2	2	2-May-08	15.43 (8.91)	2.86 (1.65)	57.14 (33.00)	1.14 (0.66)	0.00 (0.00)	2.29 (1.32)	26.29 (15.18)	13.14 (7.59)	9.14 (5.28)	5.71 (3.30)	173.14	
GMT-2	3	9-May-08	18.86 (23.57)	6.29 (7.86)	10.00 (12.50)	10.00 (0.71)	0.29 (0.36)	1.71 (2.14)	10.57 (13.21)	13.14 (16.43)	0.00 (2.86)	1.71 (1.07)	80.00	
GMT-2	4	16-May-08	0.57 (2.63)	0.57 (2.63)	4.57 (21.05)	1.71 (7.89)	0.00 (0.00)	0.57 (2.63)	2.86 (13.16)	3.43 (15.79)	1.14 (5.26)	4.00 (18.42)	21.71	
GMT-2	5	23-May-08	34.29 (20.13)	9.14 (5.37)	37.14 (21.81)	8.57 (5.03)	0.57 (0.34)	2.29 (1.34)	14.29 (8.39)	8.57 (5.03)	7.43 (4.36)	9.71 (5.70)	170.29	
GMT-2	6	30-May-08	42.86 (43.99)	2.57 (2.64)	9.14 (9.38)	9.71 (1.76)	0.29 (0.29)	2.29 (2.35)	11.43 (11.73)	8.29 (8.50)	0.00 (3.81)	1.14 (2.64)	97.43	
GMT-2	7	6-Jun-08	24.57 (32.82)	9.71 (12.98)	3.43 (4.58)	0.57 (0.76)	0.57 (0.76)	1.14 (1.53)	10.86 (14.50)	9.14 (12.21)	1.71 (2.29)	1.71 (2.29)	74.86	
GMT-2	8	13-Jun-08	20.00 (26.12)	1.71 (2.24)	5.14 (6.72)	1.14 (1.49)	0.00 (0.00)	1.14 (1.49)	14.29 (18.66)	12.00 (15.67)	4.00 (5.22)	1.71 (2.24)	76.57	
GMT-2	9	20-Jun-08	10.29 (27.27)	4.57 (12.12)	3.43 (9.09)	0.57 (1.52)	0.00 (0.00)	0.00 (0.00)	4.00 (10.61)	8.00 (21.21)	1.71 (4.55)	1.71 (4.55)	37.71	
GMT-2	10	27-Jun-08	6.86 (19.67)	3.43 (9.84)	5.71 (16.39)	0.57 (1.64)	0.57 (1.64)	0.57 (1.64)	1.14 (3.28)	4.57 (13.11)	6.29 (18.03)	1.71 (4.92)	34.86	
spring		Total	252.19	59.14	327.33	97.19	5.29	37.00	181.67	110.24	64.57	40.67	1468.52	
		(%)	(17.72)	(4.16)	(23.00)	(6.83)	(0.37)	(2.60)	(12.77)	(7.75)	(4.54)	(2.86)	(80.03)	(14.66)
GMT-2	11	4-Jul-08	14.29 (38.46)	2.86 (7.69)	2.86 (7.69)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	3.43 (9.23)	5.14 (13.85)	3.43 (9.23)	0.00 0.00	37.14	
GMT-2	12	11-Jul-08	10.86 (43.18)	1.71 (6.82)	2.86 (11.36)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.29 (9.09)	4.00 (15.91)	0.57 (2.27)	0.57 (2.27)	25.14	
GMT-2	13	18-Jul-08	102.00 (54.75)	9.71 (5.21)	18.29 (9.82)	16.00 (0.77)	0.00 (0.00)	5.14 (2.76)	11.71 (6.29)	6.86 (3.68)	0.00 (4.14)	1.71 (0.15)	186.29	
GMT-2	14	25-Jul-08	80.57 (53.61)	2.86 (1.90)	17.43 (11.60)	16.29 (0.95)	0.29 (0.19)	4.57 (3.04)	5.71 (3.80)	5.43 (3.61)	0.00 (3.61)	4.00 (0.57)	150.29	
GMT-3	1	4-Aug-08	83.43 (40.22)	2.29 (1.10)	59.43 (28.65)	0.57 (0.28)	0.00 (0.00)	20.00 (9.64)	18.86 (9.09)	1.71 (0.83)	7.43 (3.58)	0.57 (0.28)	207.43	
GMT-3	2	11-Aug-08	31.43 (32.74)	2.86 (2.98)	14.29 (14.88)	0.29 (0.30)	0.00 (0.00)	5.14 (5.36)	11.43 (11.90)	5.14 (5.36)	3.43 (3.57)	0.29 (0.30)	96.00	
GMT-3	3	18-Aug-08	19.71 (36.51)	0.86 (1.59)	7.43 (13.76)	0.86 (1.59)	0.00 (0.00)	3.71 (6.88)	4.86 (8.99)	4.57 (8.47)	1.71 (3.17)	0.00 (0.00)	54.00	
GMT-3	4	25-Aug-08	22.86 (45.20)	2.29 (4.52)	4.00 (7.91)	0.57 (1.13)	0.00 (0.00)	1.71 (3.39)	5.71 (11.30)	4.57 (9.04)	2.86 (5.65)	0.29 (0.56)	50.57	
GMT-3	5	1-Sep-08	14.57 (21.89)	2.29 (3.43)	4.86 (7.30)	0.00 (0.00)	0.00 (0.00)	1.43 (2.15)	15.43 (23.18)	16.29 (24.46)	5.14 (7.73)	0.00 (0.00)	66.57	
GMT-3	6	8-Sep-08	26.86 (40.17)	5.43 (8.12)	6.00 (8.97)	0.00 (0.00)	0.00 (0.00)	2.00 (2.99)	6.57 (9.83)	8.57 (12.82)	6.57 (9.83)	0.00 (0.00)	66.86	
GMT-3	7	15-Sep-08	30.57 (40.38)	1.43 (1.89)	15.71 (20.75)	0.29 (0.38)	0.29 (0.38)	2.29 (3.02)	7.43 (9.81)	6.57 (8.68)	3.43 (4.53)	0.29 (0.38)	75.71	
GMT-3	8	22-Sep-08	12.00 (13.91)	3.14 (3.64)	10.86 (12.58)	5.14 (5.96)	6.00 (6.95)	25.14 (29.14)	3.43 (3.97)	3.14 (3.64)	3.71 (4.30)	0.29 (0.33)	86.29	
GMT-3	9	29-Sep-08	15.14 (12.96)	0.86 (0.73)	9.14 (7.82)	0.29 (0.24)	14.29 (12.22)	22.86 (19.56)	31.14 (26.65)	9.43 (8.07)	1.71 (1.47)	0.29 (0.24)	116.86	
summer		Total	464.29	38.57	173.14	40.29	20.86	94.00	128.00	81.43	40.00	8.29	1219.14	
		(%)	(38.08)	(3.16)	(14.20)	(3.30)	(1.71)	(7.71)	(10.50)	(6.68)	(3.28)	(0.68)	(89.31)	(12.17)

Sample		Mid-week Date	*Gs. ruber* (pink)		*Gs. ruber* (white)		*Gs. sacculifer*		*Gt. menardii* group		*Pulleniatina* spp.		*N. dutertrei*		*Gl. aequilateralis*		*G. calida*		*Gt. crassiformis*		*Gt. truncatulinoides*		Total planktic flux	Percent of annual flux
GMT-3	10	6-Oct-08	39.14	(32.16)	1.43	(1.17)	8.00	(6.57)	1.14	(0.94)	9.71	(7.98)	20.00	(16.43)	16.57	(13.62)	9.43	(7.75)	1.43	(1.17)	0.00	(0.00)	121.71	
GMT-3	11	13-Oct-08	5.14	(5.57)	2.29	(2.48)	24.86	(26.93)	6.00	(6.50)	7.14	(7.74)	11.71	(12.69)	11.43	(12.38)	11.43	(12.38)	1.14	(1.24)	0.00	(0.00)	92.29	
GMT-3	12	20-Oct-08	6.00	(9.95)	1.14	(1.90)	9.14	(15.17)	7.14	(11.85)	5.43	(9.00)	4.00	(6.64)	5.43	(9.00)	5.71	(9.48)	0.00	0.00	0.00	(0.00)	60.29	
GMT-4	1	30-Oct-08	12.57	(7.80)	0.57	(0.35)	27.14	(16.84)	6.57	(3.72)	20.00	(12.41)	22.00	(13.65)	45.43	(28.19)	7.14	(4.43)	10.00	(6.21)	0.00	(0.00)	161.71	
GMT-4	2	5-Nov-08	4.00	(2.36)	1.71	(1.01)	16.00	(9.46)	5.14	(3.04)	68.57	(40.54)	30.29	(17.91)	7.43	(8.78)	8.00	(4.73)	8.57	(5.07)	0.00	(0.00)	161.71	
GMT-4	3	12-Nov-08	11.43	(2.86)	5.14	(1.29)	38.29	(9.57)	44.00	(11.00)	177.71	(44.43)	36.00	(9.00)	22.57	(11.29)	14.29	(3.57)	1.14	(0.29)	0.00	(0.00)	377.43	
GMT-4	4	19-Nov-08	11.43	(3.39)	2.86	(0.85)	33.71	(10.00)	34.86	(10.34)	125.14	(37.12)	72.00	(21.36)	9.71	(5.76)	18.29	(5.42)	0.00	(0.00)	0.00	(0.00)	327.43	
GMT-4	5	26-Nov-08	8.00	(1.51)	1.14	(0.22)	42.86	(8.10)	9.71	(1.84)	305.14	(57.67)	49.14	(9.29)	42.00	(15.87)	15.43	(2.92)	1.14	(0.22)	0.00	(0.00)	487.14	
GMT-4	6	3-Dec-08	16.00	(2.43)	2.86	(0.43)	54.86	(8.32)	12.57	(1.91)	322.86	(48.96)	99.43	(15.08)	16.57	(5.03)	41.71	(6.33)	1.14	(0.17)	0.00	(0.00)	642.86	
GMT-4	7	10-Dec-08	2.86	(1.23)	0.57	(0.25)	28.57	(12.29)	4.00	(1.72)	76.00	(32.68)	64.57	(27.76)	8.29	(7.13)	19.43	(8.35)	1.14	(0.49)	0.00	(0.00)	224.29	
GMT-4	8	17-Dec-08	2.86	(0.91)	3.43	(1.09)	18.86	(6.01)	3.43	(1.09)	120.00	(38.25)	72.57	(23.13)	6.00	(3.83)	37.71	(12.02)	1.14	(0.36)	4.00	(1.28)	307.71	
GMT-4	9	24-Dec-08	14.29	(2.93)	6.29	(1.29)	27.43	(5.63)	1.71	(0.35)	97.14	(19.95)	67.43	(13.85)	19.71	(8.06)	108.00	(22.08)	0.57	(0.12)	24.00	(4.93)	467.14	
GMT-4	10	31-Dec-08	4.57	(1.43)	0.57	(0.18)	9.14	(2.86)	0.57	(0.18)	53.71	(16.23)	42.29	(12.78)	11.43	(7.16)	89.14	(27.91)	0.57	(0.18)	85.14	(26.65)	308.00	
fall		Total	138.29		30.00		338.86		136.86		1388.57		591.43		222.57		385.71		28.00		113.14		3739.71	
		(%)		(3.70)		(0.80)		(9.06)		(3.66)		(37.13)		(15.81)		(5.95)		(10.31)		(0.75)		(3.03)	(90.21)	(37.34)
Annual		Total	971.48		150.00		1200.48		402.05		1795.29		781.57		730.60		900.24		154.86		1819.95		10014.31	
		(%)		(10.20)		(1.50)		(12.04)		(4.03)		(16.31)		(9.66)		(7.33)		(9.03)		(1.55)		(18.26)		