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ABSTRACT

Nine biological-oceanographic SEFCAR (South East Florida and Caribbean Recruitment) cruises were conducted over a 2-year period, spring 1989 to spring 1991, along the continental shelf off southeast Florida between the Dry Tortugas and the Upper Florida Keys. A total of 1,140 discrete stratified zooplankton samples including zooplankton biomass (ml) and fluorescence (voltages) data were collected with MOCNESS nets at 253 stations. Horizontal distributions of zooplankton biomass and fluorescence were highly variable spatially and an onshore-offshore pattern was not clearly distinguished. Zooplankton biomass by station varied from 0.05 to 1.5 ml m^{-3} with mean and standard deviation of 0.57±0.2 ml m^{-3}, and fluorescence varied from 0.35 to 11.5 vol m^{-3} (2.71±1.9 volt m^{-3}). Mean fluorescence calculated by cruise did not show a seasonal pattern or any effect with abiotic factors, except for the time of the day in which samples were collected. The lack of calibration of fluorescence to chlorophyll was a critical factor precluding the use of these fluorescence data as indicators of primary production. In contrast, a seasonal pattern was observed on the zooplankton biomass over the two-year period, decreasing from spring to summer and increasing from summer to fall. Zooplankton biomass during the winter cruises was highly variable, perhaps due to the different oceanographic conditions and transects between cruises. Mean zooplankton biomass was also useful as an indicator of oceanographic conditions. The highest biomass was registered during cruises in which cyclonic eddies were detected passing through the Lower-Middle Keys and at the Marquesas shelf. Zooplankton biomass was correlated with the presence of eddies and with the depth of the stations, supporting the hypothesis that eddies concentrated planktonic organisms in their interior, enhancing productivity and causing highly variable spatial and temporal distributions of plankton. Zooplankton biomass data may be useful for testing ecological hypotheses and validating mathematical models.

INTRODUCTION

Oceanographers and biologists from Southeast Fisheries Science Center (SEFSC/NOAA) and the Rosenstiel School of Marine and Atmospheric Science (RSMAS/UM) joined efforts from 1989 to 1994 in a cooperative project to study the effect of oceanographic processes on plankton and regional recruitment of fishes and invertebrates along the continental shelf off southeast Florida. This project called SEFCAR (South East Florida and Caribbean Recruitment) conducted biological and oceanographic surveys in the Straits of Florida between Dry Tortugas and the Upper Florida Keys (Fig. 1). Oceanographic conditions during SEFCAR cruises were described mainly by Lee et al. (1992, 1994), Limouzy-Paris et al. (1997), Lee and Williams (1999), and Yeung and Lee (2002). These contributions substantially augmented knowledge of oceanographic variability in the Straits of Florida and its implications for larval recruitment. The Loop Current and Florida Current define the offshore circulation of South Florida. Large cyclonic eddies with diameters of 100-200 km are also identified as dominant features in the circulation within the southern Straits of Florida (Lee et al. 1992, 1994). These eddies propagate downstream from the Tortugas area toward the Florida Keys at 5-17 km·d^{-1} along the edge of the shelf inshore of the Florida Current (Fratantoni et al. 1998).

The Florida Keys, a 356-km island chain of great ecological and recreational importance, ends at the islands of Dry Tortugas. The Dry Tortugas islands are also known for their relatively unspoiled marine richness and for serving as nursery grounds of many commercially important species. The Keys coastal zone is divided into three main subregions (Upper, Middle and Lower Keys) based on differences associated with the curving coastline, the narrowness of the shelf, and the degree of interaction with the nearby Florida Current (Lee et al. 2001). In the Upper Keys the coastline is aligned north-south, onshore winds prevail, and the Florida Current is close to the edge of the shelf. The Middle Keys is a transitional region in terms of the extent of wind and Florida Current forcing where most of the coastline curvature occurs. In the Lower Keys, the coastline is aligned east-west, and southeast and east winds favor onshore Ekman surface transport increasing the potential for larval retention and concentration at those sites (Lee et al. 1992, Lee and Williams 1999, Lee et al. 2001). The Lower Keys section is frequented by coastal cyclonic eddies (Fratantoni et al. 1998; Yeung et al. 2001). Once the eddies pass the Middle Keys, they begin to deform and shrink due to the narrowing and curving of the channel and before reaching the Upper Keys, the eddy disintegrates and Florida Current downstream flow again dominates (Lee et al. 1994, 2001).

Significant contributions were made to the understanding of hydrodynamic processes affecting locally spawned larvae of coral reef fishes (Cha et al. 1994, Limouzy-Paris et al. 1994, 1997, Richards et al. 1994, Graber and Limouzy-Paris 1997), penaeid shrimps (Criales and McGowan 1993a, 1994, Criales and Lee 1995), stomatopods (Diaz 1995) and cephalopods (Goldman and McGowan 1991); and remote upstream transported larvae of the spiny lobster (Yeung and McGowan 1991, Yeung et al. 1993, 2000, Yeung and Lee 2002). The high diversity of fishes and invertebrates in the region and the scarcity of larval stage descriptions stimulated efforts to describe early life history stages of several taxa (Goldman 1995, Diaz 1998, Diaz and Manning 1998, Criales and McGowan 1993b). A significant contribution was made to early larval stages of fishes by Richards (2004) (book in press).

The aim of this report is to provide zooplankton and fluorescence data collected during nine SEFCAR cruises, and describe their horizontal and seasonal distributions. These data can be useful in plankton ecology and trophic and mathematical models of the Florida Keys and Dry Tortugas region.

MATERIALS AND METHODS

Biological/oceanographic surveys in the Straits of Florida were conducted from 1989 to1994 in different oceanographic vessels, *R/Vs Calanus, Long Horn, Sea Expedition, Oregon II*, and *Columbus Islin* (Table 1). Quarterly seasonal zooplankton/hydrographic surveys were conducted over a 2-year period during spring, summer, fall and winter 1989-90 and 1990-91. After the spring 1991 survey, cruises were conducted yearly, in early summer 1992, late summer 1993, and late spring 1994. Stations were sampled along transects running perpendicular to and seaward of the reef tract along the Florida Keys (Fig. 1). During each of the five surveys from spring 1989 to spring 1990, seven standard transects were sampled: Carysfort (CR) and Davis Reef (DR) in the Upper Florida Keys; Tennessee (TR) and Sombrero Reef (SR) in the Middle Florida Keys; Looe Reef (LR) and Key West (KW) in the Lower Florida Keys; and Marquesas (MQ) further west. The Dry Tortugas (DT) transect was introduced in the summer cruise of 1990. During the spring-summer 1991 cruise sampling was concentrated around the Dry Tortugas with two new transects, Western Tortugas (WT) and Halfmoon Key (HK), and two new stations, one west of Dry Tortugas (NW Patch) and another to the east (Rebecca). Sampling was conducted both in the daytime and at night, depending on the time that the ship arrived at the station. During spring, summer, and fall cruises in 1989, a series of 24 h experiments were conducted at fixed stations (Table 2-10).

Hydrographic measurements were made with a Sea Bird CTD and expendable bathythermographs (XBTs) (Lee et al. 1992, 1994). Satellite-tracked ARGOS drifter buoys were deployed during some cruises near the Marquesas and Dry Tortugas to trace the near-surface circulation (Lee and Williams 1999). Plankton samples were collected using a 1-m^2 and a 10-m^2 MOCNESS (Multiple Opening/Closing Net and Environmental Sampling System) (Wiebe et al. 1976). The 1-m^2 MOCNESS had nine nets of 0.333 mm mesh and the 10-m^2 MOCNESS had up to five nets of 3-mm mesh (*e.g.* Yeung and Lee 2002). The MOCNESS net was deployed obliquely down to the maximum depth, so each net opened and closed sequentially to sample target depth intervals as it was towed up to the surface at about 5 m/min. The depth intervals and maximum depths sampled varied among cruises (Tables 2-10). A fluorometer and conductivity-temperature depth (CTD) sensors were attached to the net frame and recorded continuously vertical profiles of depth (m), volume of water filtered (m^3), temperature (^{0}C), salinity (psu), and fluorescence (voltages) at each depth strata.

Zooplankton biomass for each depth stratum was determined by the method of displacement of volume (Beer 1976). Non-planktonic organisms (*e.g.* seaweed, large fishes) and large planktonic organisms (e.g. large gelatinous coelenterates) were removed from samples. On board, plankton samples were concentrated in a 0.250 mm mesh sieve and volume displacement of filtrated samples was read in a burette (0.1 ml measuring interval and ±0.05 ml of precision). No filter apparatus was used to drain the samples. Methodological errors by displacement of volume are usually in the range of 7% to 9%, depending on the draining method, the range of reading intervals of the burette, and the displacement volume determinations by different readers (Omori and Ikeda 1984, Postel et al. 2000). Zooplankton biomass (ml) and fluorescence (voltages) in each net *i* were standardized to m^3 of sea-water filtered. Zooplankton biomass (Z) (ml m^{-3}) per station was the volume displaced by zooplankton in all nets divided by the volume of seawater filtered by all nets:

$$Z = \frac{\sum_{i=1}^{n} D_i}{\sum_{i=1}^{n} V_i}$$

Z = zooplankton biomass in ml m^{-3} per station

i = net 1, 2, 3 ..., n fished during a MOCNESS tow

D_i= volume displaced by zooplankton in net i (ml)

V_i = volume filtered by net i (m^3)

Total fluorescence at each station was likewise calculated. Fluorescence readings are proportional to chlorophyll *a* (Yentsch and Menzel 1963, Strickland and Pearson 1968) and can be considered as an index of cellular fluorescence (Kiefer 1973). However, continuous fluorometer readings are presented here rather than chlorophyll *a* because the calibration constant for fluorescence against chlorophyll fluorescence was not properly determined during some of these cruises. For the cruises in which 24-hour experiments were performed, a mean value was calculated per station.

Nonparametric rank-sum Spearman's correlation tests were used to analyze fluorescence and zooplankton biomass data because distributions were not normal and variances were not homogeneous. Fluorescence and zooplankton biomass were evaluated together with month of sampling, time of day sampled, distance to offshore, number of depth strata sampled, and presence of eddies (Table 12). Time of sampling was divide in four categories, distance offshore in five, depth strata in six and presence of eddies in two.

RESULTS AND DISCUSSIONS

Horizontal distributions by stations

Horizontal distributions of fluorescence were plotted for each cruise with the superimposed concentrations of zooplankton biomass (Fig. 2-10). During the spring 1989 cruise, high values of both fluorescence and zooplankton were concentrated at some stations of Tennessee Reef, Sombrero Reef, Looe Reef and Marquesas (Fig. 2, Table 2). During the summer 1990 cruise zooplankton biomass was high at Sombrero Reef, Marquesas and Carysfort stations, and fluorescence was high at some Davis Reef and at Marquesas stations (Fig. 3, Table 3). During the fall 1989 cruise fluorescence and zooplankton values were high at some Tennessee Reef and Carysfort Reef stations (Fig. 4, Table 4). During the winter 1990 cruise, high zooplankton biomass was centered at the Upper Florida Keys stations of Carysfort Reef and Davis Reef, but also at the Middle Key stations of Sombrero Reef. Fluorescence values were high at Davis, Sombrero and Tennessee Reef stations (Fig. 5, Table 5). High zooplankton and fluorescence values were registered at Marquesas during the spring 1990 cruise (Fig. 6, Table 6). High fluorescence values were also registered in Key West, Davis Reef stations and one additional station called the Hump. During the summer 1990 cruise, high zooplankton biomass was registered in some Looe Reef stations and high fluorescence values were observed at Marquesas and Dry Tortugas but also at Davis Reef stations (Fig. 7, Table 7). High fluorescence values were detected during the fall 1990 cruise at Sombrero Reef and Looe Reef and high zooplankton biomass at Looe Reef (Fig. 8, Table 8). During the winter 1991 cruise high fluorescence and zooplankton values were both detected at Looe Reef stations (Fig. 9, Table 9). During the spring-summer 1991 cruise the highest fluorescence values were around the Dry Tortugas stations but zooplankton values were highest at the Looe Reef stations (Fig. 10, Table 10). In general horizontal distributions of zooplankton biomass and fluorescence were highly variable spatially and an onshore-offshore pattern was not clearly distinguished among stations.

Zooplankton biomass by station varied from 0.05 to 1.5 ml m^{-3} with a total mean and standard deviation of all stations combined of 0.57"0.2 ml m^{-3}. Fluorescence by station varied from 0.35 to 11.5 vol m^{-3} ml with a total mean and standard deviation of 2.71"1.9 volt m^{-3}. Fluorescence variability was higher than zooplankton biomass, which may be due to the higher patchiness of the primary production than the secondary production. Correlation coefficients of fluorescence and zooplankton biomass with some abiotic factors are shown in Table 12. Fluorescence was negatively correlated with the time of sampling, and zooplankton biomass was positively correlated with the depth strata, and with the presence of eddies. The positive correlation with depth strata is an obvious relation that may indicate a higher biomass when more strata are adding in the water column. The correlation with the presence of eddies is explained in the next section.

Seasonality and oceanographic conditions

Oceanographic conditions during each cruise were briefly summarized in Table 11. Cyclonic eddies were observed during six of the nine oceanographic cruises at different regions of the Florida shelf: at the Lower and Middle Florida Keys shelf during spring 1989, fall 1989 and 1990, and winter 1989 cruises; at the Key West and Marquesas region in spring 1990; and at the Dry Tortugas region in spring-summer 1991 (Table 11). Oceanographic conditions during the other three cruises were dominated by the main downstream flow of Florida Current.

Some seasonal trends were distinguished from total means of zooplankton biomass by cruises (Fig. 11). Mean values of zooplankton biomass from both years showed similar trend, decreasing from spring to summer and increasing to fall. The greatest difference between the two years occurred in winter. The highest zooplankton biomass was recorded during winter 1990 cruise (0.66"0.26 ml m^{-3}) and the lowest during winter 1991 cruise (0.39"0.16 ml m^{-3}). The winter 1990 cruise was conducted while an eddy was centered at the Sombrero Reef transect, and the winter 1991 cruise during normal Florida Current conditions. Transects and stations were also different between cruises. Twenty-two stations in seven transects were sampled during the winter 1990 cruise while only 12 stations in three transects (between Looe Reef and Key West) were sampled in winter 1991. The differences in oceanographic conditions, and number and location of stations between cruises might be responsible for such a highly variable biomass between the two winter-cruises.

Mean zooplankton biomass also indicated that the highest values (above the mean) were recorded during cruises in which cyclonic eddies were detected passing at the Lower-Middle Keys and at the Marquesas shelf during the spring 1989, fall 1989, winter 1990, and spring 1990 cruises (Fig. 11). Zooplankton biomass during the spring-summer cruise 1991, in which a stationary gyre was located at the Dry Tortugas region, was not particularly high; probably because the stations were farther offshore in more oceanic waters in comparison to the other cruises. Gyres and eddies are considered important mechanisms in the retention and concentration of plankton at the Florida shelf (Lee et al. 1994). This assumption has been verified during the spring 1989 cruise by a high concentration of fish, lobster and shrimp larvae during the presence of a cyclonic eddy at the Pourtales Terrace (Yeung and McGowan 1991, Cha et al. 1994, Limouzy-Paris 1994, Criales and McGowan 1994), and a high concentration of shrimp, stomatopod and lobster larvae during the development of a gyre in the Tortugas region during the spring-summer cruise 1991 (Criales and Lee 1995, Diaz 1995, Lee and Yeung 2002). The effect of eddy-induced upwelling was also clearly evident in the high nutrient concentrations at the Sombrero transect in winter 1990 when the nutricline extended between 50 and 100 m in depth while a well-developed eddy was detected at this depth (Lee et al. 1992). These eddies also serve as a mechanism for delivering fish, shrimp and lobster larvae to the Florida Keys coastal zone, favoring an onshore transport by the coastal countercurrent flow (Yeung et al. 2001, Jones et al. 2001) and causing highly variable influxes of larvae at the Middle Keys channels (Criales et al. 2003). The fact that the highest zooplankton biomass was recorded during the arrival of eddies in the coastal Florida Keys region supports the hypothesis that eddies concentrated planktonic organisms in their interior, enhancing productivity and causing highly variable spatial and temporal distributions of plankton.

In contrast, mean fluorescence by cruise did not show a clear seasonal pattern or any effect from the general circulation that dominated during each cruise. During the first year values decreased from spring to fall 1989 and increased in winter 1990 (Fig. 11). During the second year fluorescence increased from spring to summer and decreased in winter 1991. The highest fluorescence values were recorded in summer 1990 and the lowest in winter 1991, both cruises conducted during regular Florida Current conditions running nearshore. The cruises in which eddies were observed at the Florida shelf did not show particularly high fluorescence values, refuting the theory of enhancing productivity during the eddy upwelling. Multiple biotic and abiotic factors interactively influence patterns of chlorophyll in the ocean (*i.e.* light intensity, zooplankton community, patchiness, hydrographical heterogeneities), but the lack of calibration of fluorescence to chlorophyll data could be a critical factor precluding the use of these fluorescence values as indicators of primary production.

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Table 1. Biological/oceanographic SEFCAR cruises conducted between 1989 and 1994, listeded chronologically with their respective acronym, season, date, number of stations and number of nets sampled. Cruises C_1 to C_9 were analyzed for this report.

Cruises and Seasons	Date	No of stations	N of nets
C_1= CA8906, spring 89	May 26-Jun 4, 1989	29	133
C_2= CA8910, summer 89	August 15-23, 1989	34	189
C_3= CA8914, fall 89	Nov 12-18, 1989	31	179
C_4= CA9002, winter 90	Feb 12-16, 1990	23	119
C_5= LH9005, spring 90	May 22-28, 1990	28	133
C_6= LH9007, summer 90	Jul 25-Aug 2, 1990	28	166
C_7= SEX9011, fall 90	Nov 11-14, 1990	19	123
C_8= OII9101, winter 91	Jan 13-16, 1991	13	80
C_9= LH9105, spring 91	May 29-Jul 1, 1991	84	438
C_{10}= CI9206, summer 92	Jun 13-16, 1992	17	119
C_{11}= CI9309, summer 93	Sep 12-13, 1993	8	57
C_{12}= OII9405, spring 94	May 21-25,1994	34	100

Table 2. Spring 89 SEFCAR cruise, May 26-June 5 1989. n=night, d=day,tw=twilight, dw=dawn, 24h=experiment of 24 hours.

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
2	Carysfort	-80.15	25.15	7.96	n	50	2	5.19	0.58
3	Carysfort	-80.77	24.71	4.10	d	50	2	5.19	0.72
5	Tennessee	-80.71	24.62	13.15	n	175	7	10.19	1.14
7	Tennessee	-80.64	24.54	22.15	d	175	7	3.47	0.58
11	Looe Key	-81.40	24.53	1.73	d	25	2	2.25	0.25
13	Looe Key	-81.36	24.45	10.61	d	150	7	5.21	1.27
15	Looe Key	-81.32	24.36	21.02	d	175	7	1.77	0.48
16	Looe Key	-81.28	24.28	30.59	n	200	8	1.86	0.62
18	Key West	-81.79	24.31	19.85	d	200	8	1.61	0.48
20	Key West	-81.80	24.37	12.64	d	175	7	1.17	0.53
22	Key West	-81.80	24.44	3.06	d	25	2	3.00	0.70
23	Marquesas	-82.20	24.42	5.56	d	50	2	4.34	1.04
25	Marquesas	-82.20	24.36	14.20	d	150	6	0.75	0.36
27	Marquesas	-82.20	24.29	22.21	n	200	8	1.52	0.65
30	Looe Key	-81.40	24.53	1.83	d	25	1	2.15	0.20
33	Looe Key	-81.36	24.44	11.90	d	150	6	0.58	0.75
38	Looe Key	-81.35	24.41	15.55	24h-n	150	6	1.95	0.47
39	Looe Key	-81.35	24.41	15.55	24h-n	150	6	1.49	0.52
40	Looe Key	-81.34	24.41	15.55	24h-d	150	6	1.37	0.41
42	Sombrero	-81.09	24.61	2.01	d	25	1	1.61	0.23
44	Sombrero	-81.05	24.53	10.44	d	125	5	1.81	1.27
46	Sombrero	-81.01	24.46	17.93	d	175	7	1.23	0.51
48	Sombrero	-80.93	24.41	24.44	n	175	7	2.11	0.60
49	Davis	-80.38	24.81	13.97	dw	175	7	1.81	0.48
50	Davis	-80.41	24.82	11.96	n	125	5	0.49	0.59
51	Davis	-80.51	24.90	3.28	n	25	1	1.93	0.50
52	Carysfort	-80.20	25.20	2.32	d	50	2	1.10	0.34

Table 3. Summer 89 SEFCAR cruise, August 15-23, 1989. n=night, d=day,tw=twilight, dw=dawn, 24h=experiment of 24 hours.

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
37	Key West	-81.80	24.44	3.40	d	40	2	4.69	0.31
38	Key West	-81.80	24.37	11.95	d	125	4	1.79	0.39
39	Key West	-81.82	24.31	21.26	d	200	7	1.63	0.39
41	Marquesas	-82.21	24.42	6.81	n	50	2	3.99	0.56
42	Marquesas	-82.19	24.35	13.76	dw	150	6	5.99	1.09
43	Marquesas	-82.21	24.28	23.92	d	200	7	1.61	0.62
44	Looe Reef	-81.27	24.27	30.55	d	200	8	1.04	0.57
45	Looe Reef	-81.32	24.36	20.80	d	175	7	1.06	0.51
46	Looe Reef	-81.36	24.44	11.84	d	150	6	1.49	0.47
47	Looe Reef	-81.41	24.53	2.39	n	25	1	2.20	0.13
48	Sombrero	-81.11	24.60	1.87	d	25	1	1.45	0.19
49	Sombrero	-81.05	24.53	9.95	d	150	6	2.66	1.11
50	Sombrero	-81.00	24.47	17.14	d	200	8	0.35	0.42
51	Sombrero	-80.96	24.39	25.97	d	200	8	1.16	0.42
52	Tennessee	-80.63	24.53	23.19	n	175	7	1.26	0.32
53	Tennessee	-80.72	24.62	13.10	n	175	7	4.15	0.54
58	Tennessee	-80.74	24.66	8.49	24h-n	150	6	1.78	0.45
59	Tennessee	-80.74	24.67	8.08	24h-n	150	6	2.43	0.42
60	Tennessee	-80.74	24.66	8.53	24h-d	150	6	2.29	0.54
61	Tennessee	-80.74	24.66	8.84	24h-d	150	6	1.48	0.50
62	Tennessee	-80.74	24.66	8.54	24h- d	150	6	3.80	0.42
63	Tennessee	-80.74	24.67	8.16	d	125	5	1.76	0.56
64	Davis	-80.48	24.90	2.54	n	50	2	1.82	0.37
65	Davis	-80.43	24.85	8.15	n	100	4	3.77	0.67
66	Davis	-80.38	24.81	13.11	n	150	6	6.50	0.69
67	Carysfort	-80.10	25.16	10.30	d	175	7	2.59	0.62
69	Carysfort	-80.14	25.19	6.58	d	125	5	1.36	0.86
71	Carysfort	-80.18	25.21	2.91	d	25	1	0.87	0.14
73	Carysfort	-80.10	25.16	10.15	24h-d	175	7	1.33	0.58
74	Carysfort	-80.10	25.16	10.15	24h-d	175	7	0.46	0.41
75	Carysfort	-80.10	25.16	10.19	24h-tw	175	7	2.18	0.53
76	Carysfort	-80.10	25.16	10.31	24h-n	175	7	3.73	0.62
77	Carysfort	-80.10	25.16	10.16	24h-n	175	7	2.67	0.47
78	Carysfort	-80.11	25.17	9.02	d	175	7	1.19	0.44

Table 4. Fall 89 SEFCAR cruise, November 12-20, 1989. n=night, d=day,tw=twilight, dw=dawn, 24h=experiment of 24 hours.

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
37	Key West	-81.80	24.44	3.29	d	50	2	0.78	0.47
38	Key West	-81.80	24.40	8.15	d	125	5	1.50	0.74
39	Key West	-81.80	24.31	19.77	n	200	8	1.75	0.83
40	Marquesas	-82.20	24.29	22.65	n	200	8	1.75	0.47
41	Marquesas	-82.18	24.36	12.33	n	150	6	1.84	0.75
42	Marquesas	-82.20	24.42	6.25	d	75	3	2.37	0.31
43	Looe Reef	-81.40	24.51	4.89	d	50	2	0.55	0.26
44	Looe Reef	-81.36	24.44	11.64	d	100	7	1.21	0.67
45	Looe Reef	-81.31	24.36	21.28	n	200	8	1.78	0.66
46	Looe Reef	-81.27	24.27	30.47	n	200	8	0.92	0.65
47	Sombrero	-80.95	24.39	26.17	n	200	8	0.93	0.57
48	Sombrero	-80.99	24.47	17.28	d	175	7	1.56	0.68
49	Sombrero	-81.05	24.53	10.47	d	175	7	0.89	0.87
50	Sombrero	-81.10	24.62	1.53	d	50	2	0.53	0.24
51	Tennessee	-80.77	24.72	2.62	d	50	2	0.91	0.61
52	Tennessee	-80.71	24.62	13.33	d	175	7	1.22	0.75
53	Tennessee	-80.63	24.58	18.97	n	200	8	1.64	1.00
54	Tennessee	-80.67	24.59	17.27	24h-n	200	8	1.39	0.47
55	Tennessee	-80.67	24.59	16.81	24h-n	200	8	1.30	0.61
56	Tennessee	-80.68	24.58	17.78	24h-d	200	8	1.33	0.82
57	Tennessee	-80.67	24.58	17.51	24h-d	200	8	1.87	0.98
58	Tennessee	-80.74	24.66	8.50	24h-n	125	5	2.40	0.71
59	Tennessee	-80.74	24.67	8.04	24h-n	150	6	6.78	0.69
60	Tennessee	-80.74	24.66	8.49	d	150	6	6.24	0.54
61	Tennessee	-80.74	24.66	9.17	d	150	6	1.76	0.83
62	Davis	-80.48	24.89	3.32	t	75	3	0.54	0.37
63	Davis	-80.42	24.86	7.85	n	100	4	3.13	0.75
64	Davis	-80.37	24.83	12.76	n	150	6	0.92	0.36
65	Carysfort	-80.09	25.17	10.55	dw	200	8	2.57	1.03
66	Carysfort	-80.15	25.19	5.77	d	100	5	1.40	0.74
67	Carysfort	-80.18	25.22	2.65	d	50	2	0.77	0.34

Table 5. Winter 90 SEFCAR cruise, February 12-16, 1990. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
37	Key West	-81.79	24.44	2.75	d	50	2	1.95	0.20
38	Key West	-81.78	24.37	11.84	d	175	7	2.55	0.57
39	Key West	-81.80	24.32	19.30	d	200	8	2.63	0.79
40	Marquesas	-82.20	24.29	22.73	n	200	8	1.72	0.63
41	Marquesas	-82.19	24.36	12.75	n	150	6	1.19	0.29
42	Marquesas	-82.22	24.42	7.06	d	75	3	2.29	0.70
43	Looe Reef	-81.28	24.28	29.85	d	200	8	0.85	0.64
44	Looe Reef	-81.31	24.37	19.44	n	125	5	2.03	0.46
45	Looe Reef	-81.35	24.45	10.87	n	175	7	2.60	0.79
47	Sombrero	-81.10	24.60	2.16	n	50	2	1.01	0.36
48	Sombrero	-81.05	24.53	9.90	tw	175	7	2.91	0.92
49	Sombrero	-80.99	24.46	17.83	n	175	7	3.74	0.92
50	Sombrero	-80.96	24.38	26.20	n	200	8	3.82	0.89
51	Tennessee	-80.66	24.59	16.99	dw	175	7	3.51	0.85
52	Tennessee	-80.71	24.63	12.54	d	175	7	1.72	0.87
53	Tennessee	-80.74	24.66	8.83	d	125	5	1.47	0.61
54	Tennessee	-80.78	24.70	5.19	d	50	2	1.11	0.32
55	Davis	-80.47	24.90	3.14	d	75	3	1.90	0.81
56	Davis	-80.43	24.88	12.60	n	100	4	1.74	0.54
57	Davis	-80.38	24.84	11.41	n	125	5	3.90	1.17
58	Carysfort	-80.13	25.20	7.62	n	125	5	5.51	1.00
59	Carysfort	-80.19	25.22	2.68	d	50	2	0.63	0.32

Table 6. Spring 90 SEFCAR cruise, May 22-28,1990. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	n° nets	fluoresence (volt m^{-3})	zooplankton biomass (ml m^{-3})
37	Key West	-81.81	24.43	5.31	n	40	2	4.56	0.31
38	Key West	-81.80	24.36	14.26	n	120	5	3.14	0.60
39	Key West	-81.82	24.30	22.26	n	200	8	2.74	0.81
40	Marquesas	-82.20	24.29	23.21	d	200	8	5.24	1.00
41	Marquesas	-82.20	24.36	13.78	d	140	6	5.09	1.43
42	Marquesas	-82.23	24.42	8.68	d	60	3	2.66	0.44
43	Looe Reef	-81.42	24.53	3.69	d	20	1	0.55	0.06
44	Looe Reef	-81.37	24.44	12.50	d	140	6	1.65	0.54
45	Looe Reef	-81.31	24.36	20.44	d	200	8	1.99	0.68
46	Looe Reef	-81.27	24.28	29.97	d	160	7	3.37	0.74
47	Sombrero	-80.95	24.38	26.85	tw	200	8	0.59	0.41
48	Sombrero	-80.99	24.46	18.04	d	200	8	1.46	0.54
49	Sombrero	-81.04	24.52	10.92	d	160	7	2.08	0.71
50	Sombrero	-81.11	24.60	2.55	d	40	2	2.14	0.23
51	Tennessee	-80.76	24.69	5.22	d	60	3	1.36	0.39
52	Tennessee	-80.70	24.62	13.31	d	200	8	2.68	0.93
53	Tennessee	-80.62	24.53	23.72	d	200	8	1.51	0.56
62	Davis	-80.47	24.88	4.50	d	60	3	1.64	0.38
63	Davis	-80.42	24.86	8.34	d	120	5	1.76	0.89
64	Davis	-80.37	24.83	12.48	d	160	7	2.07	0.84
65	Davis	-80.08	25.16	11.49	n	200	8	4.19	0.79
66	Davis	-80.13	25.19	7.42	tw	140	6	3.51	0.83
67	Davis	-80.17	25.21	4.21	tw	60	3	2.27	0.47
241	Davis	-81.35	24.46	9.53	d	160	7	2.90	0.71
242	Carysfort	-81.36	24.45	10.64	n	160	7	1.75	0.61
243	Carysfort	-81.36	24.44	12.23	n	160	7	2.71	0.69
244	Carysfort	-81.36	24.46	9.81	d	160	7	2.81	0.58
H1	Hump	-80.43	24.75	12.18	n	80	4	3.39	0.58
H2	Hump	-80.43	24.80	10.27	d	80	4	2.40	0.40

Table 7. Summer 90 SEFCAR cruise, July 26-31, 1990. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
1	Carysfort	-80.18	25.22	2.89	tw	40	2	1.93	0.11
2	Carysfort	-80.12	25.21	8.98	n	130	6	4.03	0.65
4	Davis	-80.46	24.92	3.52	d	40	2	8.54	0.39
5	Davis	-80.43	24.91	6.21	d	60	3	8.91	0.69
6	Davis	-80.35	24.83	13.55	n	160	7	3.16	0.64
7	Tennessee	-80.76	24.69	5.45	d	80	4	9.19	0.87
9	Tennessee	-80.71	24.61	14.14	d	200	8	5.03	0.70
11	Tennessee	-80.62	24.53	23.09	d	200	8	1.09	0.46
12	Sombrero	-81.10	24.61	1.36	d	20	1	0.91	0.13
14	Sombrero	-81.05	24.53	10.03	d	200	8	5.75	0.70
16	Sombrero	-80.99	24.46	17.56	d	200	8	6.26	0.73
18	Sombrero	-80.95	24.37	27.38	n	160	7	2.78	0.47
19	Looe Reef	-81.40	24.53	1.67	d	40	2	6.26	0.66
21	Looe Reef	-81.38	24.43	13.57	d	160	7	6.29	1.18
23	Looe Reef	-81.31	24.36	20.97	d	200	8	2.03	0.34
24	Looe Reef	-81.29	24.32	25.49	n	200	8	5.36	0.83
25	Looe Reef	-81.27	24.28	29.51	n	160	7	3.24	0.45
26	Key West	-81.81	24.44	4.61	n	40	2	3.55	0.32
28	Key West	-81.79	24.38	11.40	n	130	6	1.79	0.49
30	Key West	-81.80	24.31	19.78	n	160	7	3.09	0.62
32	Marquesas	-82.23	24.42	8.57	n	60	3	9.62	0.30
34	Marquesas	-82.21	24.36	14.33	d	130	6	1.91	0.53
36	Marquesas	-82.22	24.29	14.33	d	200	8	1.69	0.47
37	Dry Tortugas	-83.01	24.44	26.45	d	60	3	8.09	0.26
39	Dry Tortugas	-83.01	24.34	39.88	tw	200	8	2.56	0.71
41	Dry Tortugas	-83.00	24.17	60.56	n	200	8	2.73	0.74
44	Dry Tortugas	-83.00	23.88	97.94	n	200	8	3.32	0.69

Table 8. Fall 90 SEFCAR cruise, November 11-14, 1990. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
7	Tennessee	-80.76	24.71	3.06	n	80	4	2.32	0.30
9	Tennessee	-80.70	24.62	13.02	d	200	8	2.12	0.36
11	Tennessee	-80.63	24.54	22.89	d	200	8	0.96	0.22
12	Sombrero	-81.10	24.61	1.82	n	40	2	4.94	0.25
14	Sombrero	-81.05	24.53	10.32	n	200	8	4.70	0.64
16	Sombrero	-81.01	24.46	18.17	n	200	8	3.94	0.42
18	Sombrero	-80.96	24.39	26.05	d	200	8	1.95	0.34
19	Looe Reef	-81.40	24.53	2.05	n	40	2	1.32	0.22
21	Looe Reef	-81.35	24.47	8.82	d	160	7	3.84	1.50
23	Looe Reef	-81.30	24.32	24.85	d	200	8	1.39	0.63
25	Looe Reef	-81.27	24.29	28.45	n	200	8	5.07	0.86
26	Key West	-81.81	24.44	4.17	n	40	2	2.98	0.67
28	Key West	-81.80	24.38	11.44	n	160	7	1.98	0.56
30	Key West	-81.81	24.31	20.74	d	200	8	0.54	0.05
32	Marquesas	-82.21	24.41	7.71	n	60	3	2.67	0.80
34	Marquesas	-82.19	24.36	13.14	n	200	8	3.03	0.49
36	Marquesas	-82.20	24.29	13.14	n	200	8	3.36	0.56

Table 9. Winter 91 SEFCAR cruise, January 13-16, 1991. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	no nets	fluoresence (volt m-3)	zooplankton biomass (ml m-3)
299	Key West	-81.80	24.45	2.72	d	40	2	0.86	0.20
300	Marquesas	-82.22	24.42	7.97	tw	60	3	1.99	0.37
301	Dry Tortugas	-83.00	24.44	25.35	n	40	2	1.07	0.16
302	Dry Tortugas	-83.01	24.34	38.85	n	200	8	1.57	0.23
304	Dry Tortugas	-82.98	24.16	59.77	n	200	8	1.06	0.34
307	Dry Tortugas	-82.99	23.88	97.22	d	200	7	0.51	0.31
316	Looe Reef	-81.27	24.28	29.46	n	200	7	0.95	0.29
319	Looe Reef	-81.36	24.47	8.16	n	130	6	2.79	0.39
320	Looe Reef	-81.39	24.44	13.57	n	160	7	4.18	0.73
321	Looe Reef	-81.32	24.37	20.97	n	160	7	3.55	0.52
323	Looe Reef	-81.37	24.47	16.64	d	130	6	2.13	0.50
324	Looe Reef	-81.35	24.47	8.86	d	130	6	2.50	0.54

Table 10. Spring-summer 91 SEFCAR cruise, May 29-June 30 1991. n=night, d=day,tw=twilight, dw=dawn

station	transect	longitude W	latitude N	Distance offshore (km)	time code	max. depth sampled (m)	n° nets	fluoresence (volt m^{-3})	zooplankton biomass (ml m^{-3})
15	Dry Tortugas	-82.90	24.50	13.56	d	25	1	0.58	0.73
17	Dry Tortugas	-82.91	24.41	25.06	d	60	3	1.41	0.73
19	Dry Tortugas	-82.92	24.32	36.82	d	200	8	1.61	0.47
21	Dry Tortugas	-82.90	24.22	48.65	d	200	8	1.20	0.31
23	Dry Tortugas	-82.90	24.03	73.10	d	200	8	0.39	0.42
26	NW Patch	-83.13	24.57	21.50	d	40	4	3.59	0.31
27	NW Patch	-83.14	24.56	23.99	t	40	4	5.47	0.50
29	Dry Tortugas	-82.92	24.50	13.59	d	20	2		0.26
30	Dry Tortugas	-82.91	24.41	25.32	d	60	4		0.23
31	Dry Tortugas	-82.92	24.32	37.03	tw	200	8	4.95	0.38
32	Dry Tortugas	-82.91	24.23	48.46	n	200	8	1.55	0.28
36	NW Patch	-83.13	24.57	22.33	d	40	2	3.11	0.50
38	Halfmoon	-82.50	24.23	47.29	d	160	7	1.75	0.45
39	Halfmoon	-82.50	24.10	58.03	d	200	8	2.20	0.41
40	Halfmoon	-82.50	23.97	71.39	d	200	7	3.79	0.47
42	Marquesas	-82.19	24.23	61.34	n	200	7	2.19	0.95
43	Marquesas	-82.19	24.32	51.78	n	200	7	2.71	0.60
44	Marquesas	-82.19	24.40	44.34	n	80	4	0.72	0.26
45	NW Patch	-83.12	24.57	20.18	d	40	3	4.60	0.48
46	W Tortugas	-83.36	24.83	35.80	d	60	3	2.04	0.42
47	W Tortugas	-83.41	24.63	44.96	d	60	4	3.73	0.68
48	W Tortugas	-83.44	24.52	57.06	d	120	6	3.14	0.52
49	W Tortugas	-83.48	24.40	72.29	d	200	7	2.78	0.41
50	W Tortugas	-83.52	24.28	88.52	tw	200	7	7.48	0.87
51	Dry Tortugas	-82.90	24.03	72.76	n	200	7	5.02	0.52
52	Dry Tortugas	-82.90	24.22	47.84	dw	200	7	3.00	0.74
53	Dry Tortugas	-82.92	24.32	36.46	d	200	7	1.93	0.57
54	Dry Tortugas	-82.91	24.41	24.93	dw	60	5	7.28	0.91
55	Dry Tortugas	-82.90	24.50	13.58	tw	20	2	1.16	0.20
56	Rebecca	-82.78	24.52	14.75	d	20	2	2.35	0.29
62	Marquesas	-82.19	24.40	40.84	d	60	3	1.63	0.26
63	Marquesas	-82.19	24.32	50.27	d	160	7	1.47	0.74
64	Marquesas	-82.19	24.23	59.67	d	160	7	2.04	0.78
65	Marquesas	-82.19	24.13	71.48	d	160	7	3.33	0.60
66	Halfmoon	-82.50	23.97	71.08	n	160	7	3.52	0.76
67	Halfmoon	-82.50	24.10	58.11	n	160	7	2.96	0.81
68	Halfmoon	-82.50	24.23	46.99	n	160	7	1.49	0.65
69	Halfmoon	-82.50	24.36	40.15	dw	60	4	5.49	0.47
70	Rebecca	-82.78	24.52	14.75	dw	20	2	1.52	0.25
71	NW Patch	-83.14	24.56	19.90	d	30	2	1.05	0.34
77	Dry Tortugas	-82.90	24.03	72.74	d	160	7	2.73	0.74
78	Dry Tortugas	-82.90	24.22	49.06	d	160	7	3.69	0.74
79	Dry Tortugas	-82.92	24.32	38.01	d	160	7	2.89	0.78
80	Dry Tortugas	-82.91	24.41	25.40	d	60	4	3.39	0.66
81	Dry Tortugas	-82.90	24.50	13.95	n	20	2	1.15	0.16
83	Rebecca	-82.83	24.57	13.95	n	20	2	11.00	0.57
85	Marquesas	-82.19	24.13	68.36	n	160	8	1.23	0.64
86	Marquesas	-82.19	24.23	59.62	d	160	7	1.66	0.57
87	Marquesas	-82.19	24.32	50.10	d	160	7	3.46	0.89
88	Marquesas	-82.19	24.40	41.40	d	60	4	7.82	0.59
89	Looe Reef	-81.40	24.53	2.16	n	25	2	5.75	0.30
90	Looe Reef	-81.36	24.44	11.49	n	160	7	3.34	1.11
91	Looe Reef	-81.31	24.36	20.82	d	160	7	2.96	0.81
92	Looe Reef	-81.27	24.29	28.27	n	160	7	2.80	1.24

Table 11. Brief summary of oceanographic conditions during SEFCAR cruises conducted between spring 1989 and spring-summer 1991. A full explanation of transect names and cruise dates are in materials and methods. FC=Florida Current.

Cruise-season	Oceanographic conditions	References
C_1= spring 89	Eddy at the Pourtales Terrace, westward flow at LR and TR	Lee et al. (1992,1994)
C_2= summer 89	FC front onshore position causing downstream flow	Lee et al. (1992)
C_3= fall 89	Offshore shift of FC front, coupled with the formation of an eddy	Lee et al. (1992)
C_4= winter 90	Defined FC eddy with core at SR	Lee et al. (1992)
C_5= spring 90	Eddy-induced inshore westward flow between KW and MQ	Yeung and Lee (2002)
C_6= summer 90	Downstream flows dominated, absence of eddies	Yeung and Lee (2002)
C_7= fall 90	Strong alongshore countercurrent of an eddy at LR	Yeung and Lee (2002)
C_8= winter 91	Downstream flows dominated	Lee et al. (1994)
C_9= spring-summer 91	Eddy centered c. 40 km offshore of Dry Tortugas	Lee et al. (1994)

Table 12. Summary of non-parametric rank-sum Spearman correlations of fluorescence and zooplankton biomass with some environmental variables (n=253). * in bold type are significant correlations (p<0.05).

Variables	*Fluorescence*		*Zooplankton*	
	R	p-level	R	p-level
Month sampled	-0.062	0.326	-0.013	0.836
Time sampled	-0.125	**0.047 ***	-0.022	0.722
Depth strata	-0.064	0.314	0.303	**0.000***
Distance offshore	-0.007	0.918	0.118	0.060
Presence of eddies	0.087	0.165	0.172	**0.006***

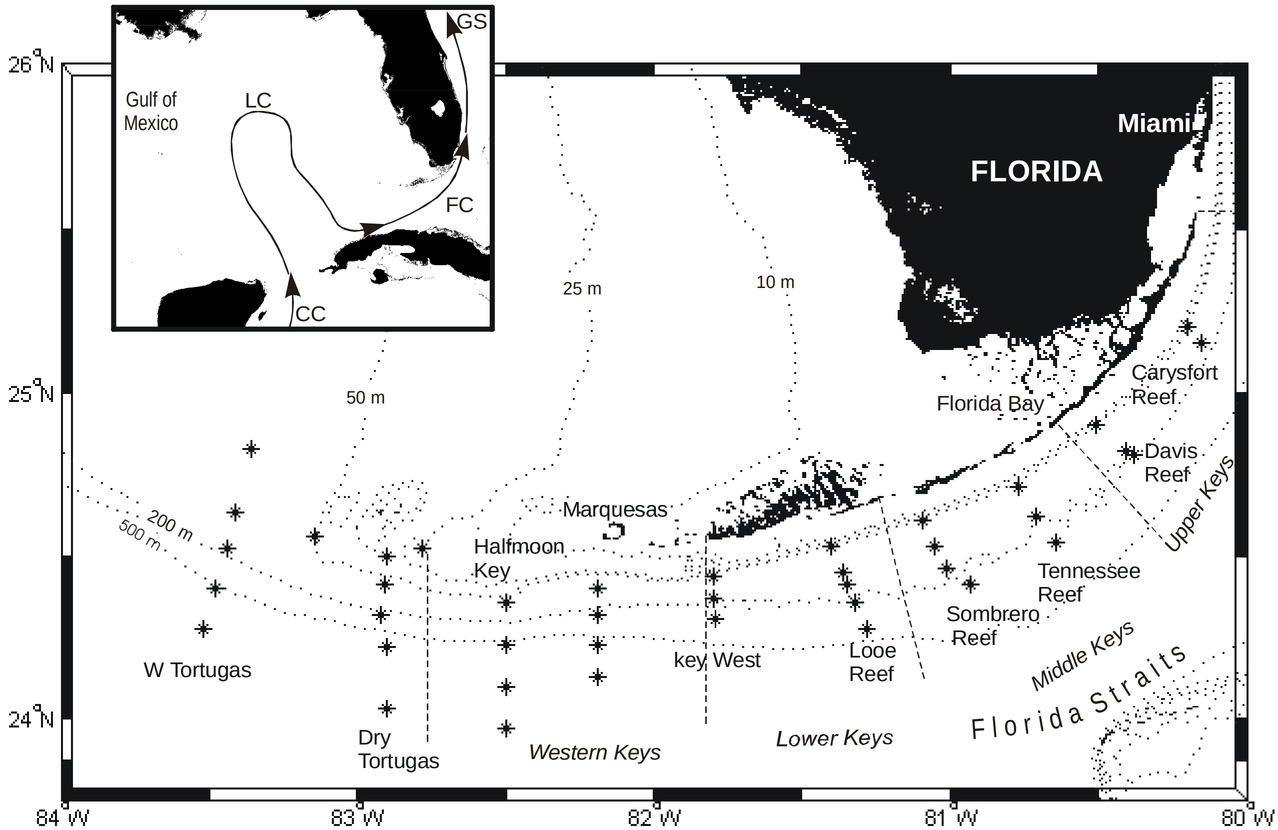
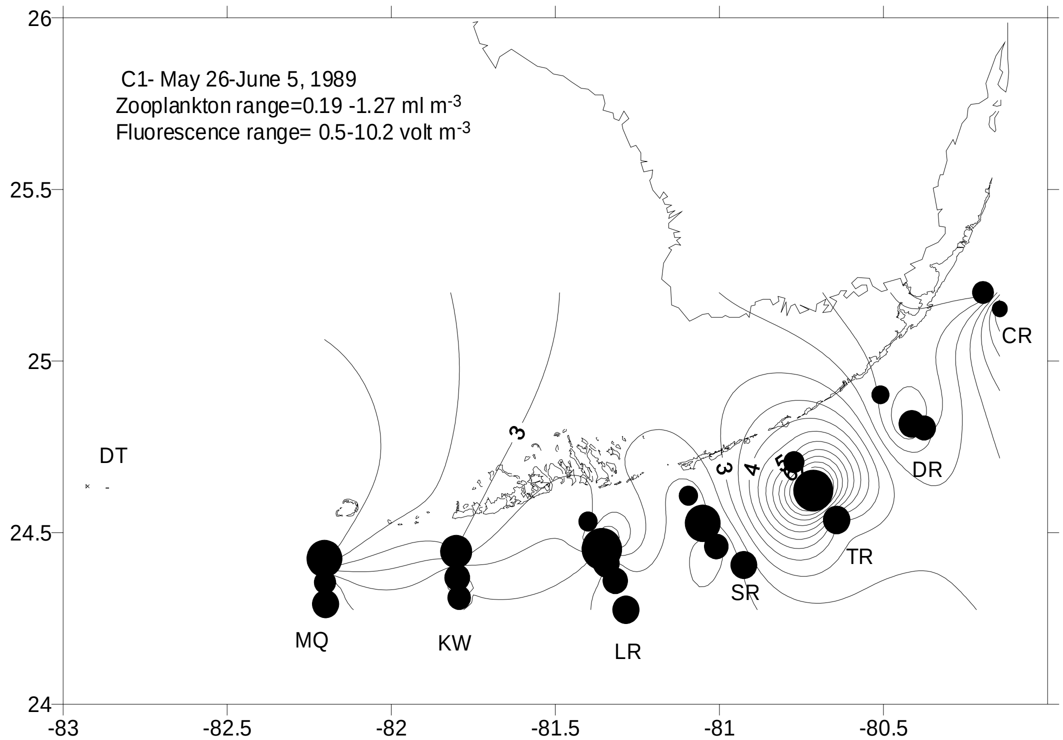
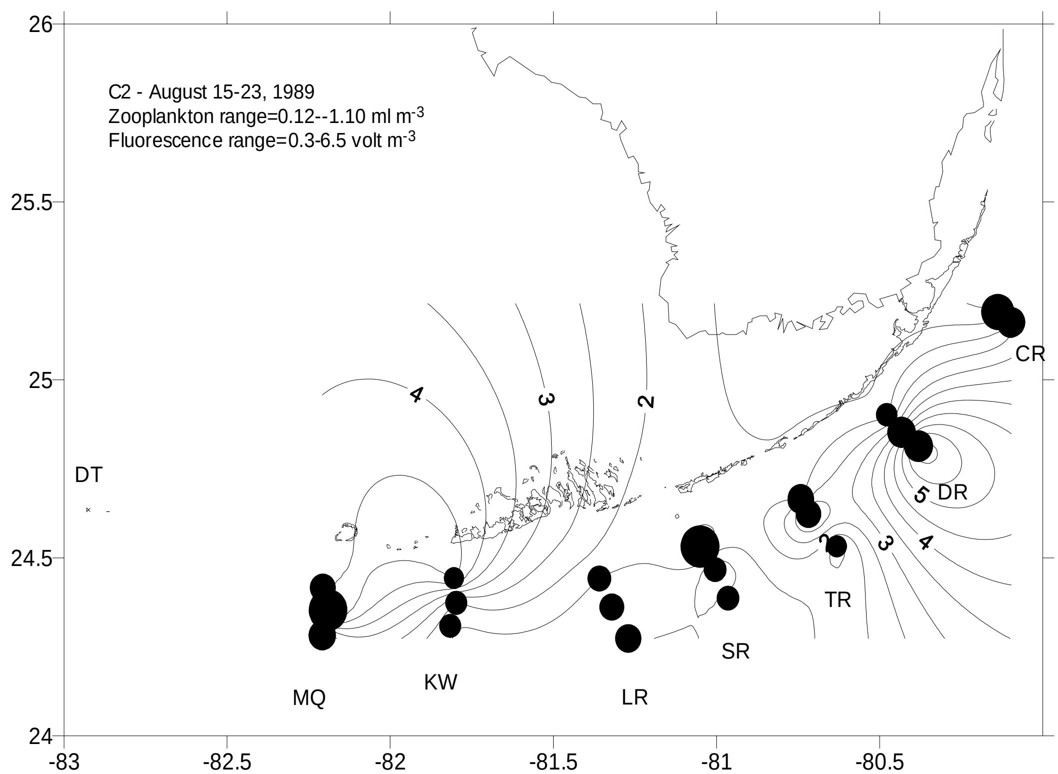
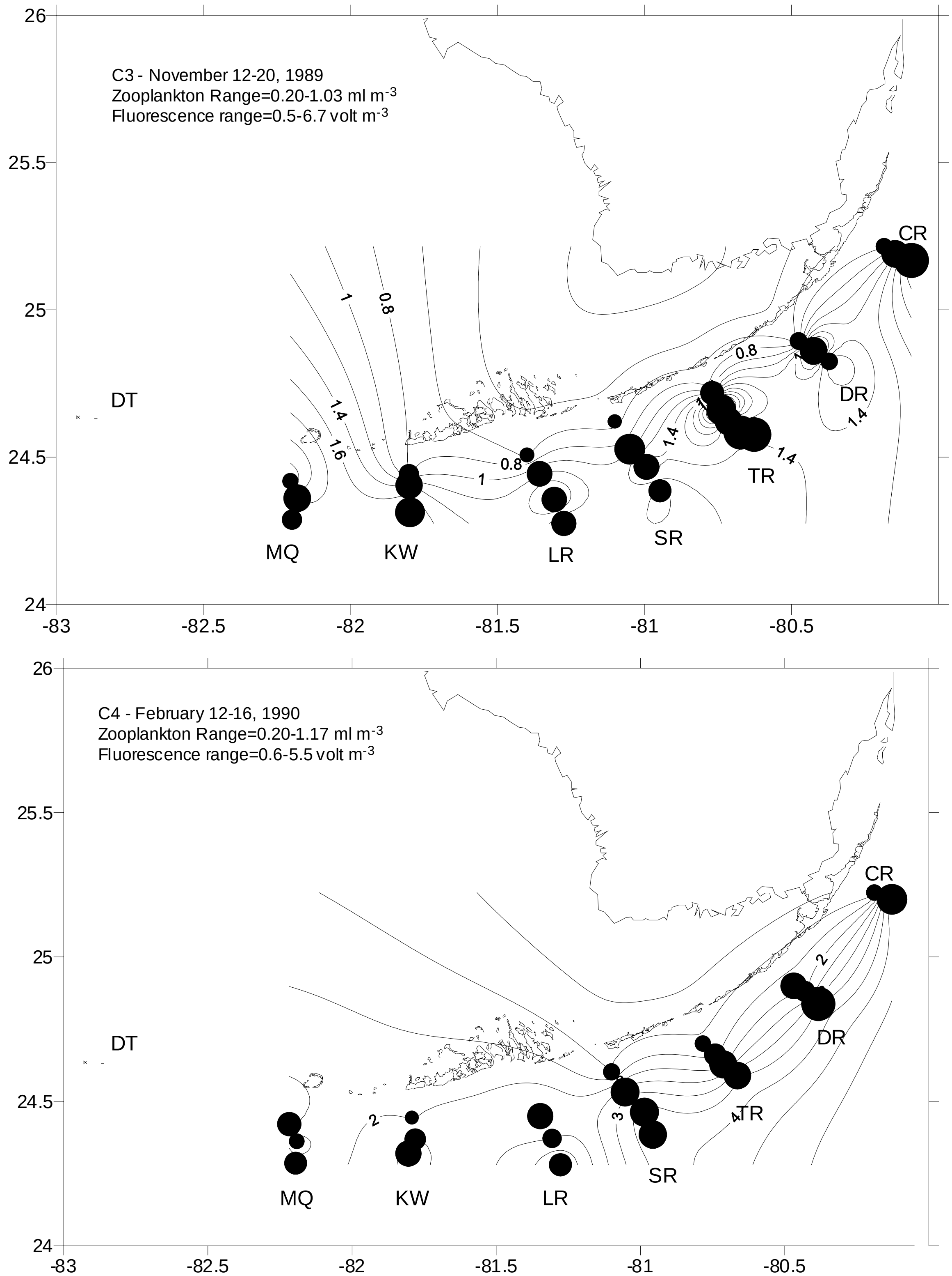


Figure 1. Map of the study area showing stations (*) sampled during SEFCAR cruises between spring 1989 and spring-summer 1991. Small map at the left corner indicates the major currents at the Gulf of Mexico and off the coast of Florida: LC=Loop Current, FC=Florida Current, CC=Caribbean Current and GS=Gulf Stream.

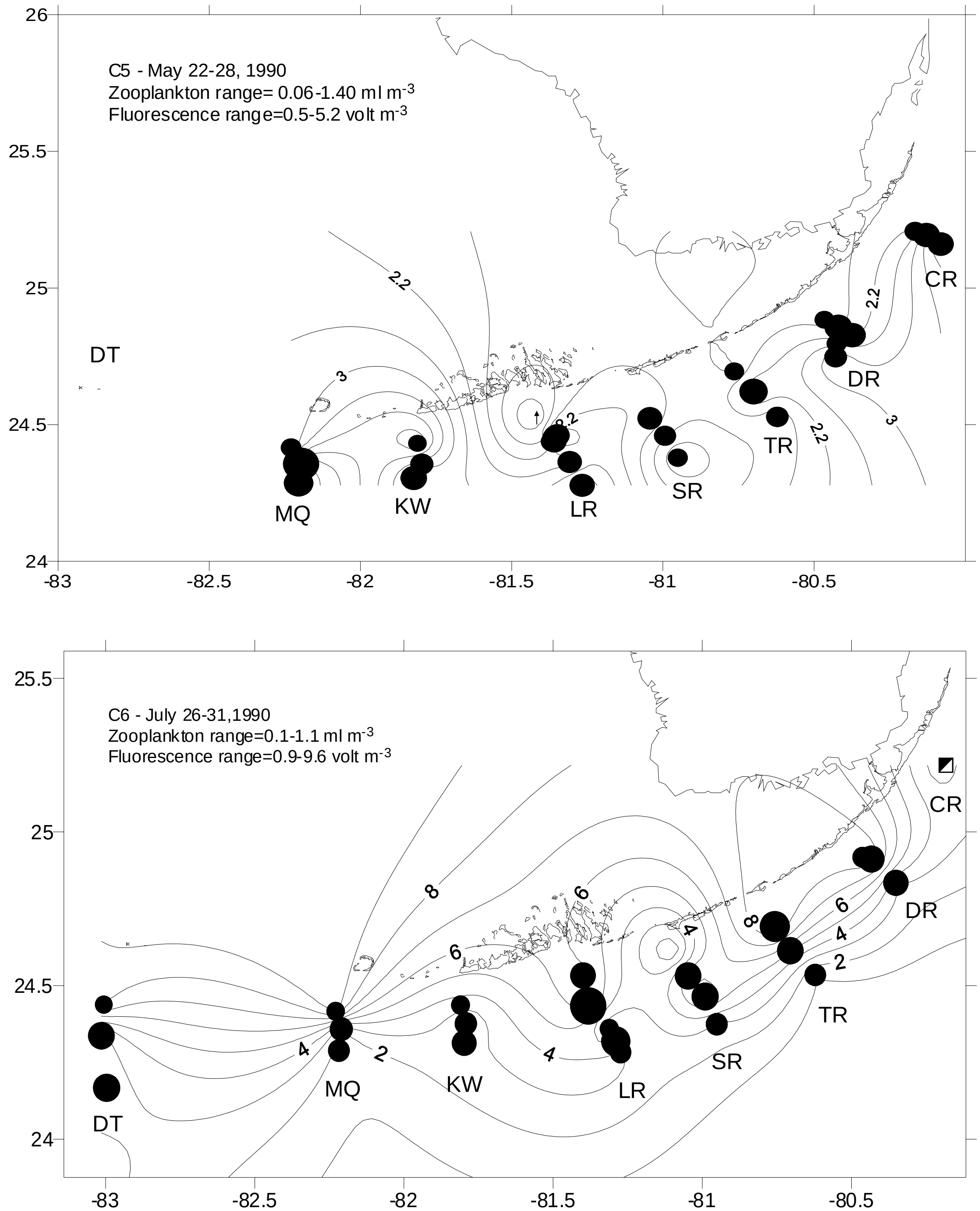




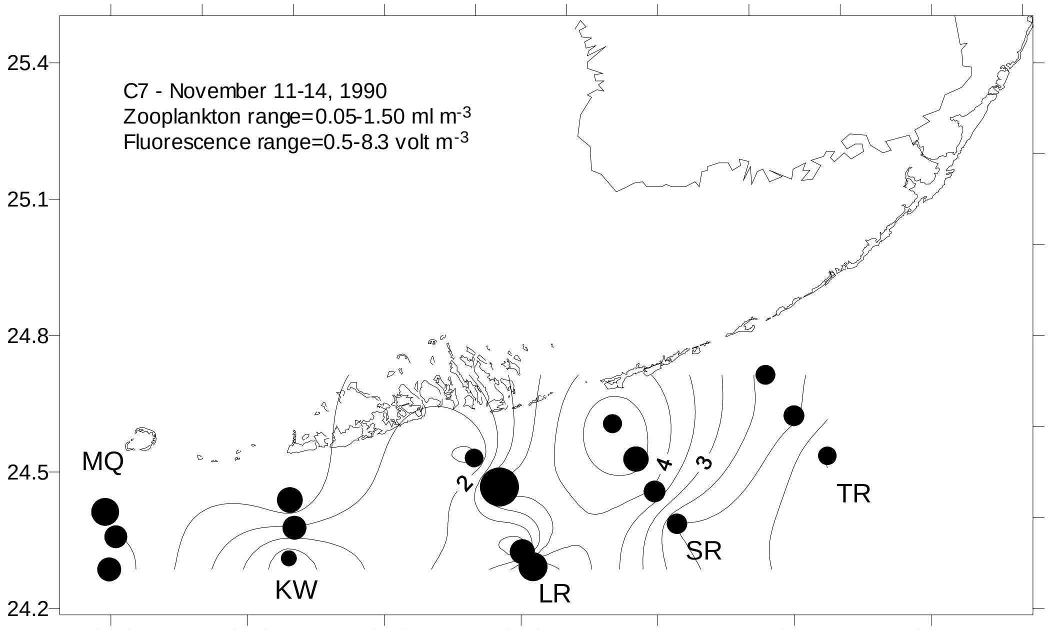
Figures 2 - 3: Horizontal distribution of zooplankton biomass superimposed over fluorescence contours during SEFCAR cruises from spring and summer 1989. Zooplankton biomass (circles) are proportional to the symbol size and centered at the sampling station. Transect names are explained in the text.

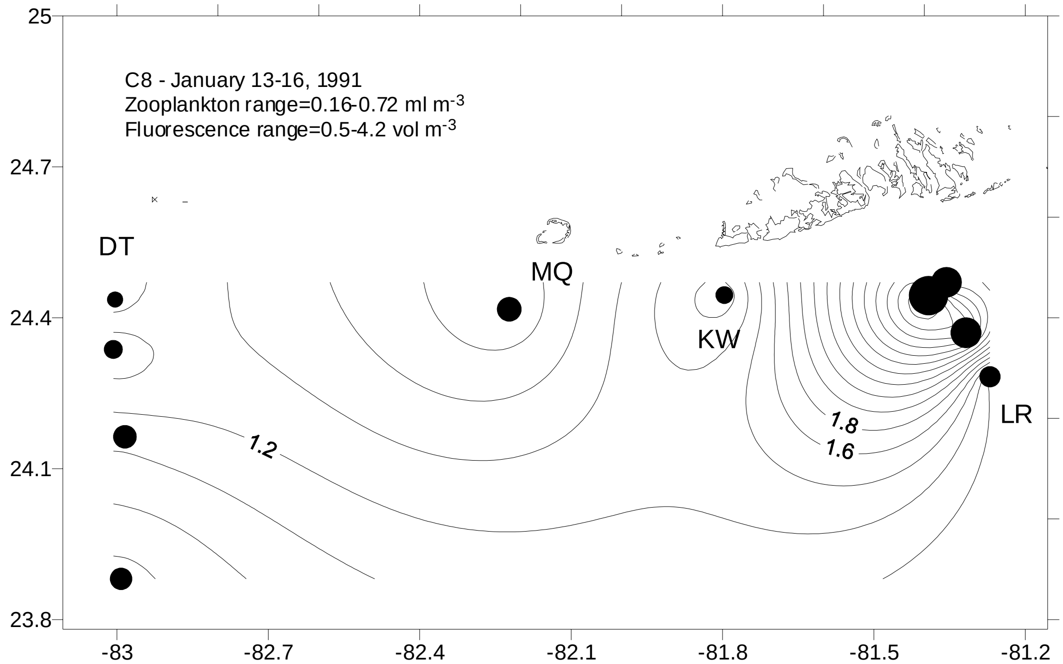


Figures 4 - 5: Horizontal distribution of zooplankton biomass superimposed over fluorescence contours during SEFCAR cruises from fall 1989 and winter 1990. Zooplankton biomass (circles) are proportional to the symbol size and centered at the sampling station. Transect names are explained in the text.



Figures 6 - 7: Horizontal distribution of zooplankton biomass superimposed over fluorescence contours during SEFCAR cruises from spring and summer 1990. Zooplankton biomass (circles) are proportional to the symbol size and centered at the sampling station. Transect names are explained in the text.





Figures 8 - 9: Horizontal distribution of zooplankton biomass superimposed over fluorescence contours during SEFCAR cruises from fall 1990 and winter 1991. Zooplankton biomass (circles) are proportional to the symbol size and centered at the sampling station. Transect names are explained in the text.

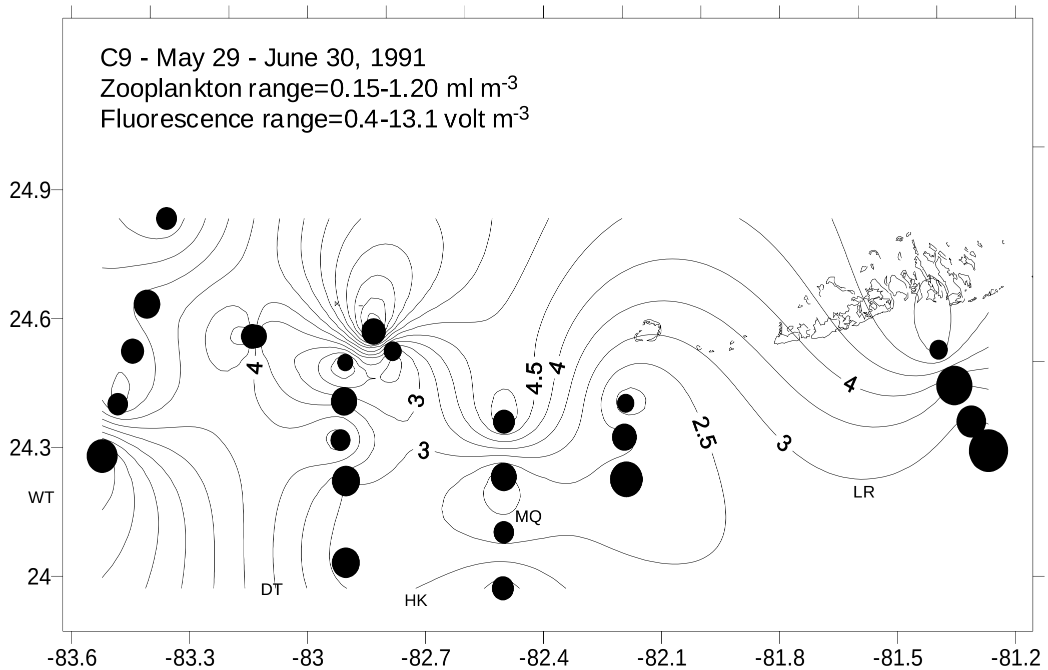


Figure 10: Horizontal distribution of zooplankton biomass superimposed over fluorescence contours during SEFCAR cruises from spring- summer 1991. Zooplankton biomass (circles) are proportional to the symbol size and centered at the sampling station. Transect names are explained in the text.

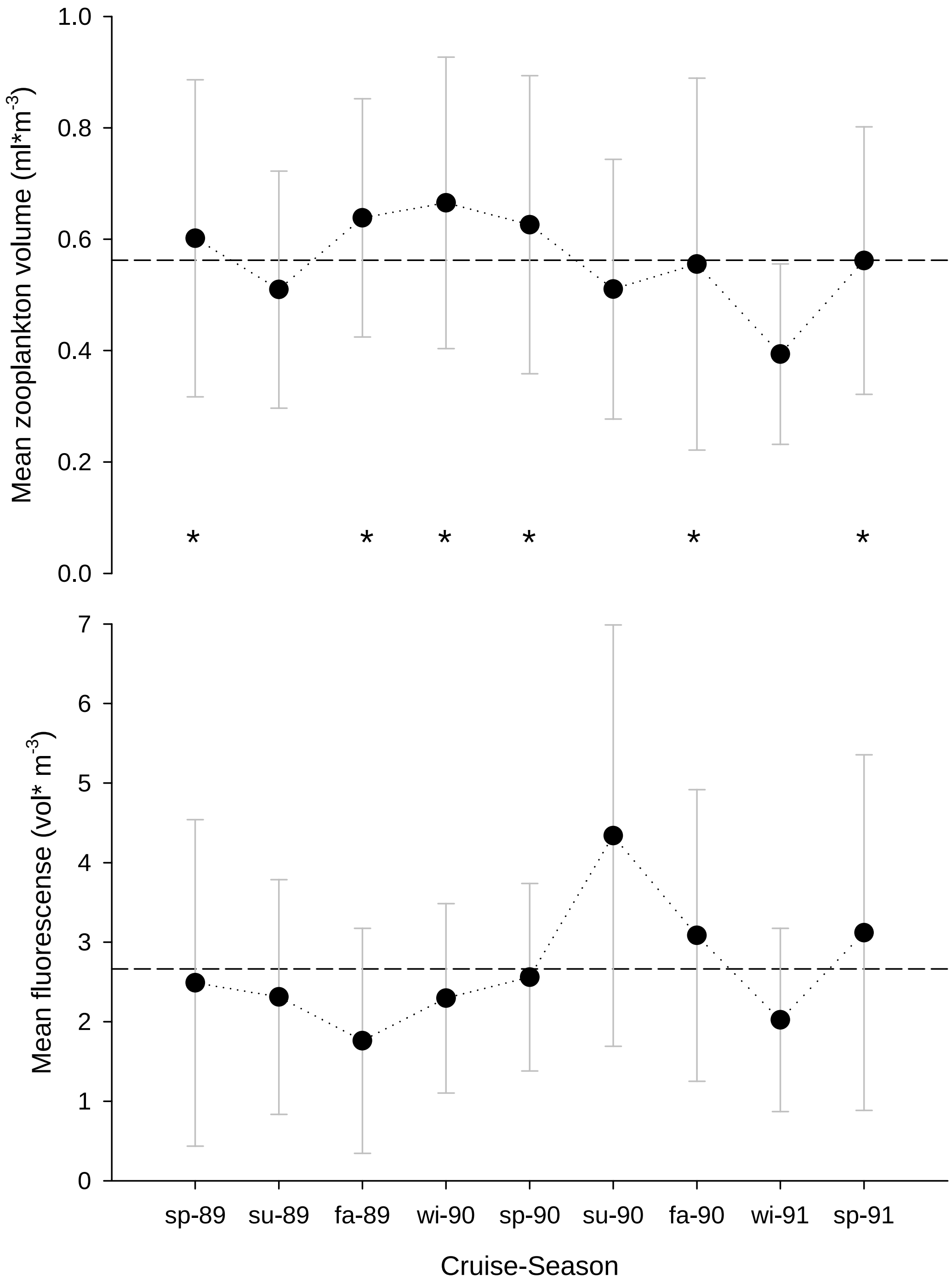


Figure 11. Mean and standard desviation of fluorescence and zooplankton biomass in each seasonal cruise. *=presence of gyre.