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Temporal and spatial characteristics of the diatom *Eucampia zodiacus* in the Western Isles region of the Bay of Fundy

by

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ABSTRACT

Martin, J. L., Hastey, C. D., LeGresley, M. M., and Page, F.H. 2007. Temporal and spatial characteristics of the diatom *Eucampia zodiacus* in the Western Isles region of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2705: iii + 22 p.

The abundance of the diatom *Eucampia zodiacus* has been monitored at five locations in the Bay of Fundy, eastern Canada, at weekly to monthly intervals since 1987. *E. zodiacus* was observed at very low cell densities prior to 1999 and not detected at any of the sampling stations during the years 1988 and 1996. The date for the first appearance of *E. zodiacus* in a given year was inter-annually variable and ranged from April to September. Maximum concentrations occurred anywhere between April and December and tended to be earliest in the offshore and latest in the more inshore sheltered Passamaquoddy Bay stations. The more inshore stations in Passamaquoddy Bay had the highest concentrations, suggesting that this region was more conducive to the higher cell densities and blooms of *E. zodiacus*. The annual maximum concentration varied among stations and between years by up to five orders of magnitude. The median maximum value (in chains of cells•L^{-1}) was 800 (Station 3), 240 (Station 15), 320 (Station 16), 550 (Station 17) and 16,300 (Station 25). The annual duration of the presence of *E. zodiacus* ranged from April to December and had a mean of 37 d, whereas the duration of the bloom containing the annual maximum concentration varied from 1-120 d. The characteristics of the annual *E. zodiacus* blooms vary between years and stations with the number of blooms or high abundance periods varying from one to two per year.

RÉSUMÉ

Martin, J. L., Hastey, C. D., LeGresley, M. M., and Page, F.H. 2007. Temporal and spatial characteristics of the diatom *Eucampia zodiacus* in the Western Isles region of the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 2705: iii + 22 p.

Depuis 1987, l'abondance de la diatomée *Eucampia zodiacus* a été suivie à cinq sites situés dans la baie de Fundy, est du Canada soit à chaque mois ou à chaque semaine. Antérieurement à 1999, *E. zodiacus* a été observée en faible concentration, en effet elle était absente de toutes les stations en 1988 et 1996. La date de la première observation de l'année d' *E. zodiacus* était variable entre années et s'étalait de avril à septembre. Les concentrations maximales ont lieu entre avril et décembre et ont tendance à se produire plus tôt au large et plus tard dans les sites abrités de la baie de Passamaquoddy. Les stations de la baie de Passamaquoddy étant plus près de la côte et ayant les concentrations plus élevées suggèrent que cette région est plus favorable aux proliférations intenses d'*E. zodiacus*. La concentration maximale annuelle variait entre stations et aussi entre années par cinq ordres de grandeur. La médiane maximale en chaînes de celluele·L^{-1} sétait 800 (Sta 3), 240 (Sta 15), 320 (Sta 16), 550 (Sta 17) et 16,300 (Sta 25). La moyenne de la durée annuelle de la présence d' *E. zodiacus* était de 37 jours tandis que la durée de l'efflorescence ayant la plus grande concentration variait d'un jour à 120 jours. Les caractéristiques des efflorescences annuelles d' *E. zodiacus* diffèrent entre années et entre stations et varient d'une à deux proliférations par année.

INTRODUCTION

Although the majority of phytoplankton species occur in the environment without causing adverse effects, there are a few that are known to cause harm. When these harmful algal blooms (HABs) occur in areas where Atlantic salmon (*Salmo salar*) farming is conducted, the health of the caged salmon can be compromised. Farmed fish are particularly vulnerable to harmful phytoplankton blooms because they do not have the luxury of being able to swim away to avoid blooms, and heavy mortality can occur within hours. The salmonid mariculture industry in southwest New Brunswick consists of more than 90 active farms which could potentially be impacted by HABs.

Impacts to fisheries from HABs have been observed in various regions of the world (White 1980; Anderson et al. 2001; Landsberg 2002; Kim et al. 2004; Doucette et al. 2006), and particularly to salmon in regions such as: Atlantic Canada - Bay of Fundy: *Alexandrium fundyense,* and *Mesodinium rubrum* (Martin et al. 2001, 2006a), Nova Scotia: *Alexandrium tamarense* (Cembella et al. 2002); Faroe Islands – *Alexandrium* (formerly *Gonyaulax*) *excavata* (Mortensen 1985); Northwest Pacific - *Chaetoceros convolutus*, *Chaetoceros concavicornis* and *Corethron* sp. (Gaines and Taylor 1986; Rensel et al. 1989; Speare and Ferguson 1989; Horner et al. 1990, 1997; Albright et. al.1993; Rensel 1993); Europe - *Gyrodinium aureolum* (Dahl and Tangen 1990, 1993; Romdhane et al. 1998), Chile - *Leptocylindrus minimus* (Clément and Lembeye 1993).

HABs have been known to affect fish through either of the following methods: neurotoxins, gill irritation/damage (mechanically or through the production of hemolytic substances) or asphyxiation (oxygen depletion). Farmed fish are particularly vulnerable to harmful phytoplankton blooms. The result may be mortality or stress in both smolts and market size salmon and loss of growth during a severe bloom event. These effects have caused millions of dollars of lost revenue to the affected salmon farmers and insurance companies are interested in knowing what farmers are doing to mitigate potential phytoplankton related losses. In cases where there is an anticipation of a problem, introduction of fall smolts into cages may need to be delayed due to sensitivity to phytoplankton blooms.

Salmon operations in the southwestern New Brunswick region of the Bay of Fundy have been impacted by HABs several times within the past decade. Those farms located within the Passamaquoddy and Bocabec Bay areas have been impacted more so than those elsewhere. Although HABs occur less frequently in regions outside Passamaquoddy Bay, blooms only occurred in the Grand Manan area in 2003 and caused severe economic losses at several farms in eastern Grand Manan. In 2004, blooms occurred in the region between Letang and Seeleys Cove, affecting salmon farms in that area as well.

A phytoplankton monitoring program was initiated in the Western Isles region of the Bay of Fundy in 1987 due to growing concerns that the incidents involving HABs seemed to be increasing in intensity, frequency and geographic distribution throughout the world (Anderson 1989; Smayda 1990; Hallegraeff 1993, 1995). The purposes of the phytoplankton study when it was initiated were: to establish baseline data on phytoplankton populations in the lower Bay of Fundy, since little detailed work had been published since studies by Gran and Braarud (1935);

to identify harmful algal species that could potentially cause harm to the aquaculture industry; to provide an early warning to the aquaculture industries by sorting and identifying samples soon after collection; and to determine patterns and trends in phytoplankton populations. Another purpose of the study was to determine whether there were environmental changes, such as changing trends in phytoplankton populations as a result of the salmon industry. Incidences of fish mortalities, especially those held captive in net pens, had also been increasing in other regions of the world. Some of these increases can be attributed to increased awareness, both in the scientific and public communities, as well as the increased use of inshore coastal waters for aquaculture, tourism and other activities.

It is well known that phytoplankton blooms are notoriously difficult to predict. Scientists in various parts of the world have been working on this for decades with little success to date. Two decades of monitoring phytoplankton within the southwestern New Brunswick area of the Bay of Fundy have indicated that the general seasonal timing of the blooms of some species is quite consistent and hence predictable to this extent. Some initial statistical analyses have indicated that sophisticated time series analysis techniques have potential for forecasting of phytoplankton abundance.

A research program was funded under the Department of Fisheries and Oceans (DFO) Aquaculture Collaborative Research Development Program (ACRDP) to study data analysis strategies to provide information concerning (Chang et al. 2005):

1) the temporal and spatial scales of variability in the concentration of potentially harmful phytoplankton species,
2) the effectiveness of sampling and data analyses approaches for detecting the presence of potentially harmful phytoplankton species,
3) the effectiveness of the sampling and data analyses approaches for detecting and projecting a temporal trend in the abundance of a harmful algal species.

A series of manuscripts are being written dealing with: determining temporal and spatial characteristics of particular blooms of harmful algae in the southwestern New Brunswick area from existing phytoplankton monitoring data since 1987; evaluating the statistical potential of these time series to give an early indication of a pending HAB; and determining the similarity between time series of phytoplankton collected at individual locations. Although a number of species of phytoplankton were selected from the dataset for analyses, this particular paper focuses on the diatom *Eucampia zodiacus*. A total of 10 species are being addressed as part of the project and include species that have been suggested to have caused problems with salmon in either the Bay of Fundy or species observed in the Bay of Fundy that have been implicated in fish problems elsewhere in the world, such as *E. zodiacus*, *Ditylum brightwellii*, *M. rubrum, Chaetoceros socialis, C. concavicornis, C. convolutus, Corethron criophilum, L. minimus, A. fundyense* and *Pseudo-nitzschia* spp. Results for *A. fundyense* have been published previously (Page et al. 2004, 2005, 2006)

E. zodiacus Ehrenberg (Fig. 1) is a diatom that appears to be cosmopolitan, except in polar waters (Horner 2002). Cells are 10-61 μm along the apical axis and joined by flattened, apical elevations or horns into long helical chains. It is a chain forming diatom described as having

"bands not ribbed, scarcely visible, cells curved in broad girdle view, chains helically coiled, horns low, broad, apertures angular elliptical to square, labiate process central" (Syvertsen and Hasle 1983; Hasle and Syvertsen 1996). Although it has not been documented to have caused problems with aquaculture throughout the world, salmon appeared to be stressed and mortalities were greater than normal at a number of salmon operations in Passamaquoddy Bay in 2002 when high concentrations of *E. zodiacus* were present.

MATERIALS AND METHODS

Sampling was initiated in 1987 at Lime Kiln Bay (#3 – Letang estuary where a number of aquaculture sites are located) and at the following three stations in 1988: Brandy Cove (#17 – a brackish site influenced by the Saint Croix River estuary), Deadmans Harbour (#15 – an open bay with offshore influence), and the Wolves Islands (#16 – an offshore indicator site). An extra sampling site (#25) was added in mid-Passamaquoddy Bay in 1999 following the observation that Brandy Cove was not a good indicator site for cell densities of algal blooms within Passamaquoddy Bay (Fig. 2).

Sampling was conducted aboard the research vessel, CCGC *PANDALUS III*. Weekly samples were collected from early May to the end of September or October, depending on the decline of the fall phytoplankton blooms. Biweekly sampling was conducted in the shoulder bloom months such as April and October (when phytoplankton cell densities had begun to increase or decrease) and monthly during all other colder months.

Phytoplankton samples were collected at the surface by bucket from all five stations, and at depths of 10 m, 25 m, and 50 m with a Niskin bottle at station #16. Water samples (250 mL) were immediately preserved with 5 mL formaldehyde:acetic acid. Later, 50-mL subsamples were settled in counting chambers for 16 h. All phytoplankton greater than 5 µm were identified and enumerated (as cells or chains of cells•L^{-1}) with the Utermöhl technique using a Nikon inverted microscope (Sournia 1978). Further identification was done using either a JEOL JSM-5600 scanning electron microscope (SEM) or a Hitachi S-2400 SEM. Sample preparation for SEM was as follows: samples were rinsed with 250 mL distilled water (prefiltered 1.3 µm) onto a 3-µm (Poretics) polycarbonate filter using a 25-mm Millipore vacuum filtration apparatus. Diatoms were cleaned with the permanganate oxidation method (Hasle and Fryxell 1970) while samples with thin walls and/or unarmoured dinoflagellates were dehydrated in a series of ethanol solutions (20, 50, 70, 85, 95%) prepared with distilled water and absolute ethanol for a minimum of 10 min at each step, finishing with three rinses of 100% ethanol. For the final drying step, three changes of hexamethyldisilazane (HMDS) were used (Bray et al. 1993; Kaczmarska et al. 2000) a minimum of 10 min each, allowing the last rinse to evaporate slowly at room temperature. Filters were mounted on stubs, and then coated with gold-palladium in a Hummer sputtering system.

Counts for cells were recorded as cells•L^{-1}. As *E. zodiacus* (Fig. 1) forms chains, a chain of cells actually refers to chains of individual cells.

Following analyses for phytoplankton abundance and distribution, the results were entered into a Microsoft Access database with the following fields: survey type, sampling station, date,

organism (species name), code ("1" – dinoflagellate, "2" – diatom and "3" other which included ciliates and smaller zooplankton), and depth (only surface samples were used for this report although samples were collected at depths of 1, 5, 10, 25 and 50 m at the Wolves Islands site). The dataset was used to generate a time-series of the near surface abundance of *E. zodiacus* for each of the five primary sampling stations. Data was retrieved from Access using queries for the first occurrence, maximum occurrence, etc., and copied into an Excel spreadsheet for sorting and data manipulation. Three point running medians and logarithms were calculated using Excel. Data were then imported into SigmaPlot (2001) for plotting. SigmaPlot was used for plotting time series versus abundance, 3 point running medians and bubble plots for each station. Lattice plots showing annual first appearance versus year, date of maximum occurrence versus year, length of maximum bloom versus year and maximum concentration versus year were created using "R" (v. 2.4.0): A Program Environment for Data Analysis and Graphics.

Data from phytoplankton analyses of the total community for 1987- 2000 have been previously published (Wildish et al. 1990; Martin et al. 1995, 1999, 2001, 2006b); the data from 2001-04 is not as yet published (J.L. Martin, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, pers. commun.).

RESULTS

Table 1 shows the number of sample days for each station for each year from 1987- 2004. Sample days varied between the stations from 177 days at Station #25 to 513 days at Station #3.

Table 1. Number of sampling days/station for each year from 1987-2004. N/A means that samples were not collected.

Year	Station 3	Station 15	Station 16	Station 17	Station 25
1987	20	n/a	n/a	n/a	n/a
1988	28	23	25	25	n/a
1989	31	30	25	31	n/a
1990	31	28	25	29	n/a
1991	32	32	22	32	n/a
1992	29	29	24	29	n/a
1993	29	29	26	29	n/a
1994	27	27	19	27	n/a
1995	27	27	27	27	n/a
1996	25	24	22	24	n/a
1997	25	26	23	24	n/a
1998	29	28	27	29	n/a
1999	29	28	28	29	26
2000	29	30	31	31	31
2001	30	30	30	31	31
2002	28	25	24	27	26
2003	33	33	30	33	32
2004	31	31	31	31	31
Total	513	480	439	488	177

Variables, such as the fact that sampling occurred only at Station #3 in 1987 and the first part of 1988, resulted in the higher number of sample days at that particular location. Station #17 was sampled on a regular basis once sampling was initiated due to its easy access and close proximity to the Biological Station. Very occasionally it was not possible to sample Station #15 due to weather or the fact that the harbour was shut off for herring fishery. Sampling at Station #16 was occasionally affected by weather or sea conditions either unsafe or not conducive for working the gear. Sampling at Station #25 was initiated in 1999.

Figures 3, 4, 5, 6 and 7 show cell densities of *E. zodiacus* from 1987 to 2004 on both log and linear scales from Lime Kiln (#3), Deadmans Harbour (#15), the Wolves Islands (#16), Brandy Cove (#17) and mid-Passamaquoddy Bay (#25), respectively. *E. zodiacus* was detected at very low densities (< 2,600 cells•L^{-1}) during the study period prior to 1999, with no cells observed at station #3 in 1987 and at any of the sampling stations during 1988 and 1996.

Table 2 and Fig. 9 show the *E. zodiacus* maximum cell densities observed during each year at each of the 5 stations. During 1999, concentrations were significantly higher at all stations, with the mid-Passamaquoddy Bay site having a maximum cell density >1.14 x 10^5 cells•L^{-1}. The following year (2000) densities were again higher than prior to 1999, with the highest density (36,800 cells•L^{-1}) observed at Brandy Cove in Passamaquoddy Bay at station #17. During 2001,

Table 2. Maximum *E. zodiacus* cell densities (in cells•L^{-1}) from 1987-2004 at stations 3,15,16,17 and 25. Absent values indicate that there were no cells observed. Shaded numbers indicate maximum cell density for a particular station over the time series. N/A means that samples were not collected.

Year	Station 3	Station 15	Station 16	Station 17	Station 25
1987		n/a	n/a	n/a	n/a
1988					n/a
1989		60		100	n/a
1990	1,120	880	2,480	100	n/a
1991		40	80	120	n/a
1992	140	100	60	40	n/a
1993	80	240	140	20	n/a
1994	40	120			n/a
1995	240	120	120	200	n/a
1996					n/a
1997	240	120	80	460	n/a
1998	1,900	1,240	1,580	2,560	n/a
1999	27,200	26,240	30,240	20,160	113,560
2000	7,880	2,240	1,000	36,880	24,960
2001	160	160	160	640	800
2002	82,076	6,080	11,240	178,369	144,500
2003	800	578	320	23,120	3,667
2004	800	578	867	2,080	7,640

cell numbers were again reduced to levels similar to those observed prior to 1999 and the maximum concentration (800 cells•L^{-1}) was observed at station #25 in mid-Passamaquoddy Bay. Greatest abundances were observed at stations 3 (8.2 x 10^4 cells•L^{-1}), 17 (1.78 x 10^5 cells•L^{-1}) and 25 (1.45 x 10^5 cells•L^{-1}) in 2002, whereas the highest densities for stations 15 (2.62 x 10^4 cells•L^{-1}) and 16 (3.02 x 10^4 cells•L^{-1}), the more offshore and offshore exposed sites, were observed in 1999.

A bloom event for *E. zodiacus* is characterized as an event where *E. zodiacus* cells are detected in the water, or an unbroken sequence of two or more samples with *E. zodiacus* present. Fig. 8 shows bubble plots indicating the presence of *E. zodiacus* at the five stations since 1987. The size of the circle reflects the number of cells observed – the larger the circle, the larger the bloom or concentration of cells. It shows that cells are rarely observed prior to day 140 (mid May) but can often persist at least until day 325 (mid November) or occasionally to day 355 (late December). There can be one or more bloom events or unbroken sequences in a given year, but generally the bloom with the highest cell density occurs in the latter bloom event, or in the fall between days 155-325 or between June and November (Table 3, Fig. 10). The only stations and year that had a later occurrence was in December of 1998 at station 16 (1,580 cells•L^{-1}) and station 3 (1,900. cells•L^{-1}). Highest concentrations for the five stations during the sampling period were observed during the months of October for stations 3, 15, 17, and 25 and November at station 16.

Table 3. Month of the year where the maximum cell concentration of *E. zodiacus* occurred at the five stations: 3, 15, 16, 17 and 25. Shaded months indicate years of maximum cell density during the sampling period for a particular station.

Year	Station 3	Station 15	Station 16	Station 17	Station 25
1987					
1988					
1989		April		July	
1990	September	September	September	September	
1991		June	May	June	
1992	June	June	May	August	
1993	June	June	June	November	
1994	June	June			
1995	August	August	August	September	
1996					
1997	June	June	June	October	
1998	December	June	December	November	
1999	October	October	November	September	November
2000	October	September	October	November	October
2001	September	May	September	October	September
2002	October	July	November	October	October
2003	September	July	July	September	September
2004	October	September	July	July	November

The duration for the bloom events that had the maximum cell densities for *E. zodiacus* for each year varied from 1-120 d (Table 4, Fig. 11). The bloom with the longest duration (120 d) of the time series occurred in 1998 at station 17. The bloom with the next longest length (113 d) occurred at station 3 in 1998, whereas maximum bloom lengths for stations 15, 16 and 25 were 84 (2000), 98 (1999) and 106 (1999), respectively. Interestingly, Station 16 was the only location where the maximum bloom length occurred in the same year as the longest bloom duration.

Table 4. Length (in days) of the maximum bloom for each station in each year. Shaded numbers indicate the longest bloom period for a given station during the study period. N/A means that samples were not collected.

Year	Station 3	Station 15	Station 16	Station 17	Station 25
1987	0	n/a	n/a	n/a	n/a
1988	0	0	0	0	n/a
1989	0	1	0	1	n/a
1990	35	35	35	13	n/a
1991	0	1	1	21	n/a
1992	21	8	1	1	n/a
1993	6	1	20	1	n/a
1994	14	21	0	0	n/a
1995	7	21	7	7	n/a
1996	0	0	0	0	n/a
1997	14	1	14	29	n/a
1998	113	1	79	120	n/a
1999	112	77	98	119	106
2000	56	84	77	97	77
2001	1	7	1	40	23
2002	98	42	56	112	98
2003	27	21	6	34	27
2004	29	1	6	42	77

The date of first occurrence for *E. zodiacus* varied considerably between years and stations (Table 5, Fig. 12) and ranged from Day 103 (April 13) to Day 245 (September 2). It tended to occur later in the Passamaquoddy Bay stations (17 and 25) than in the offshore and exposed sites. The mean day of the first occurrence ranged from 155-185 (June 4 – July 4) and the median day ranged from 148-168 (May 28-June 17).

Table 5. Ranges of days for first occurrences of *E. zodiacus*, including mean and median days of occurrences for the five stations.

	Station 3	Station 15	Station 16	Station 17	Station 25
Range for 1st occurrence	103 - 221	115 - 236	121 - 234	139 - 213	145 - 245
Mean	157	173	155	162	185
Median	155	168	148	156.5	168

Further information on the description of the blooms of *E. zodiacus* indicate that the median day of the maximum cell abundance ranged from 179–289 d or from June 28–October 17 (Table 6). Median duration of the blooms ranged from 8-77 d; and the median maximum cell abundance ranged from 240-16,300 cells•L^{-1}. The mean annual duration of the presence of *E. zodiacus* for each station ranged from days 29-52 (occurring from April to December) and had a mean of 37 d.

Table 6. Summary of descriptive analyses from data on *E. zodiacus* including: median day of first occurrence, median day of maximum cell abundance, median duration in days of the bloom with the greatest cell abundance, median of the maximum cell abundance for all years, and the mean for the annual duration of the presence of cells.

Variable (units)	Station 3	Station 15	Station 16	Station 17	Station 25
Median day of first appearance (Day of year)	155 June 4	168 June 17	148 May 28	156.5 June 5 or 6	168 June 17
Median day of maximum cell abundance (Day of year)	258 Sept 15	179 June 28	241 Aug 29	265 Sept 22	289.5 Oct 16 or 17
Median maximum bloom duration (days)	27	8	14	31.5	77
Median maximum cell abundance (cells•L^{-1})	800	240	320	550	16,300
Mean duration (days)	31	29	32	52	51

DISCUSSION

The phytoplankton monitoring program was initiated in 1987 following concerns that the local salmon industry might experience problems that were happening elsewhere in the world where the industry has been established for a longer period. Although more than 48 species of dinoflagellates, 94 species of diatoms and 21 other species (including smaller zooplankton and

ciliates), have been observed from the region, the majority do not cause harm. Results from monitoring of phytoplankton cell densities from 1987-2004 show that occurrences of phytoplankton species have seasonal, inter-annual and decadal variations in abundances, and all species in the Bay of Fundy behave differently. Earlier analyses of *A. fundyense* populations further emphasize this variation, but on a different scale and magnitude (Page et al. 2004, 2005, 2006).

E. zodiacus was observed in the Bay of Fundy in the early 1930s and is therefore not a new species to the area (Gran and Braarud 1935). Their records indicated that during 1931 and 1932: it was observed from April to June; it was rarely present in August; it was never abundant; and the maximum cell density (2,000 cells•L^{-1}) was observed in May along the coast of the Gulf of Maine. Their report showed its occurrence in April-June, whereas this study showed that it did occur during that time period, but the fall was the usual time for the high counts. This study revealed that *E. zodiacus* was observed at very low cell densities (<2600 cells•L^{-1}) at all of our sampling sites prior to 1999 and was absent in 1987, 1988 and 1996. It is a very distinct (and relatively large) species, so it would not have been easily missed during either our counts or earlier counts by Gran and Braarud. As the appearances and abundances of *E. zodiacus* appear to vary greatly between years, and the study in the early 1930's was only for a 2-yr period, we do not know whether there have been periods of higher cell density in the interim. It was interesting to see that in 2002, cell concentrations were almost five times higher than previously observed.

The more inshore stations, Brandy Cove and mid-Passamaquoddy Bay, had the highest concentrations (1.78×10^5 cells•L^{-1} and 1.44×10^5 cells•L^{-1}) in 2002 by an order of magnitude of five. Analyses from the study period suggest that the Passamaquoddy Bay region was more conducive to the higher cell densities and blooms of *E. zodiacus*. The inshore area has more freshwater influence, shallower water, and enhanced mixing and flushing. Additionally, conditions in 2002 must have been conducive to blooms of *E. zodiacus*. The high cell densities in that year were the highest recorded in the 18 yr of the phytoplankton monitoring program. These high numbers coincided with problems which were associated with salmon farms in the Passamaquoddy Bay area (J.L. Martin, unpublished). These observations suggest that if concentrations reach levels that were detected in 2002, there might be problems with salmon in adjacent net pens. Further exposure of Atlantic salmon to *E. zodiacus* under laboratory conditions would also need to be conducted as preliminary initial experiments exposing salmon to high concentrations of *E. zodiacus* (2.6×10^{-6} chains of cells•L^{-1}) for 24 h did not result in fish mortalities (Les E. Burridge, Biological Station, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, pers. commun.).

This synthesis provides information on the patterns and trends of populations of *E. zodiacus* from 1987-2004 in the southwestern New Brunswick region of the Bay of Fundy area. It is an initial phase of analysis of the data and the first documentation of the trends for this particular species from the Fundy region. This phytoplankton monitoring program is ongoing, with additional data being collected each year. Continued studies with this valuable long time series and analyses of the phytoplankton data in association with related physical, chemical and environmental data will aid and further improve our predictive/hindcasting capabilities and the search for relationships between the linkages and variables influencing the blooms.

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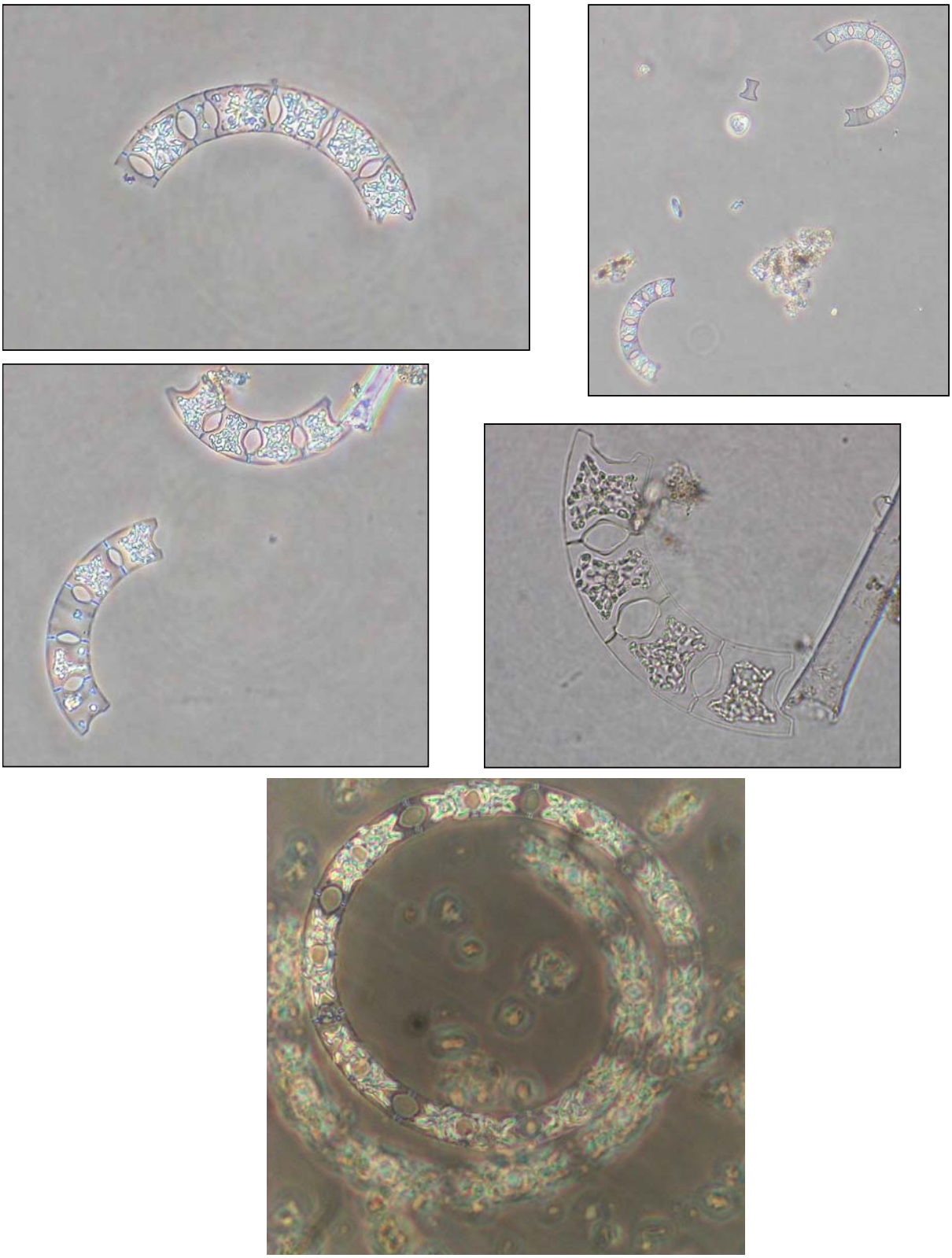

Fig. 1. *Eucampia zodiacus* from the Bay of Fundy.

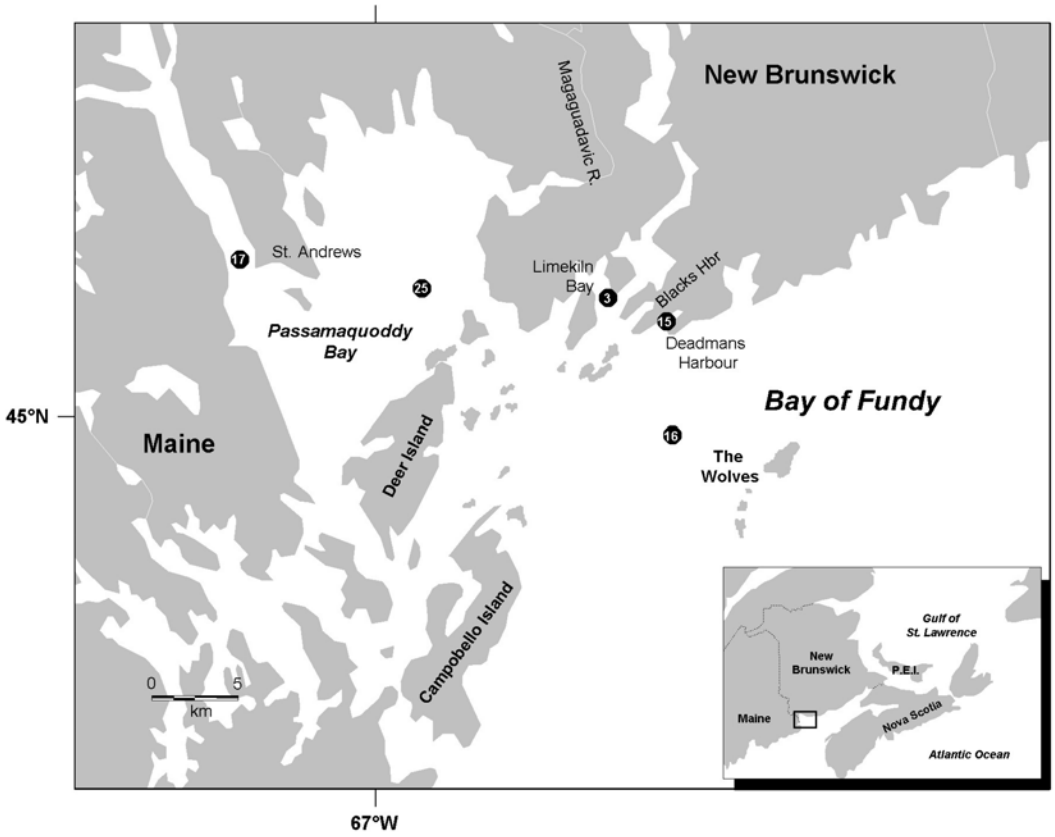

Fig. 2. Map showing sampling stations Brandy Cove (#17), Lime Kiln (#3), Deadmans Harbour (#15), the Wolves Islands (#16) and mid-Passamaquoddy Bay (#25).

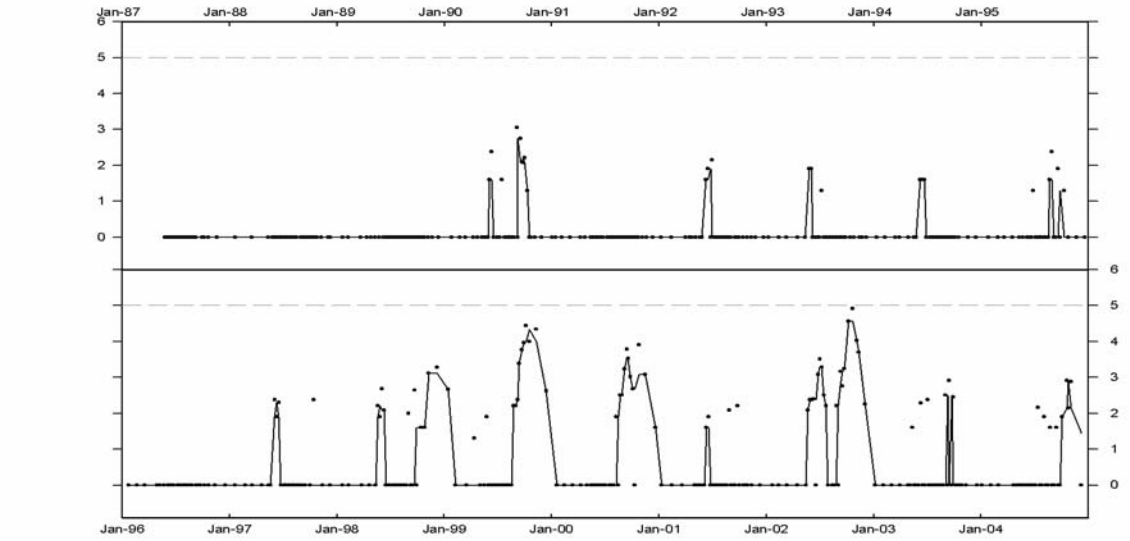

Fig. 3A. Concentrations (cells·L^{-1}) of *E. zodiacus* from Lime Kiln (#3) from 1987-2004 on a linear scale. Upper portions of figures are the 9 yr 1987-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

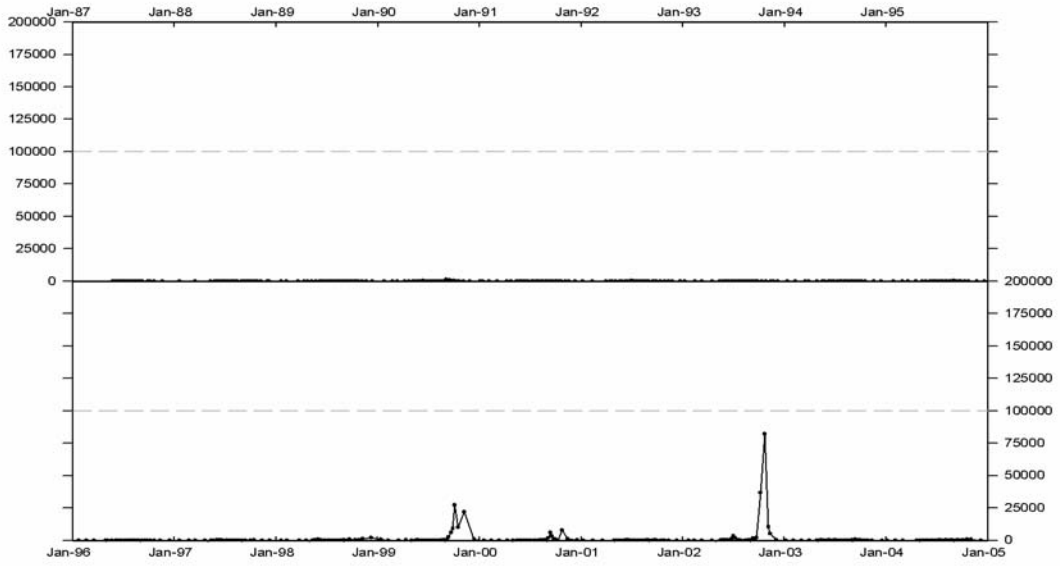

Fig. 3B. Concentrations (cells·L^{-1})of *E. zodiacus* from Lime Kiln (#3) from 1987-2004 on a log-transformed scale. Upper portions of figures are the 9 yr 1987-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

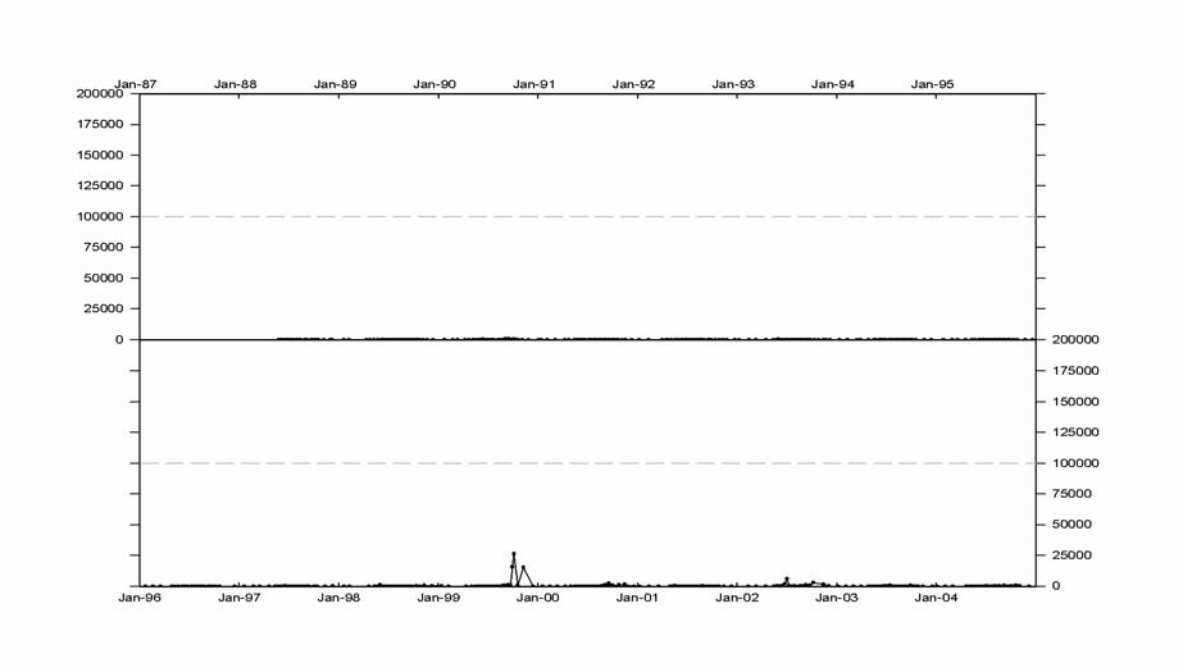

Fig. 4A. Concentrations (cells•L^{-1}) of *E. zodiacus* from Deadmans Harbour (#15) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

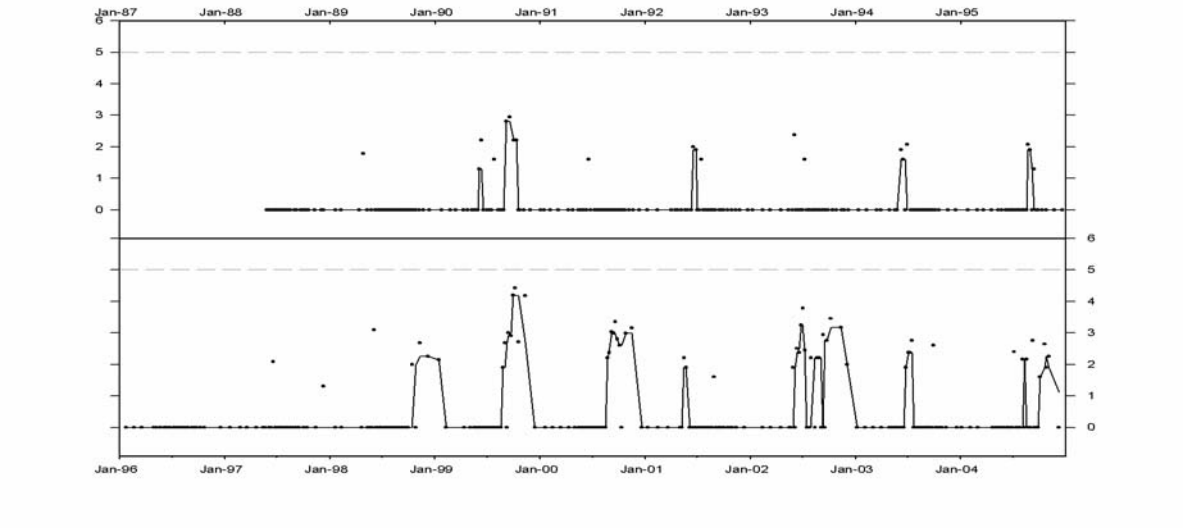

Fig. 4B. Concentrations (cells•L^{-1}) of *E. zodiacus* from Deadmans Harbour (#15) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

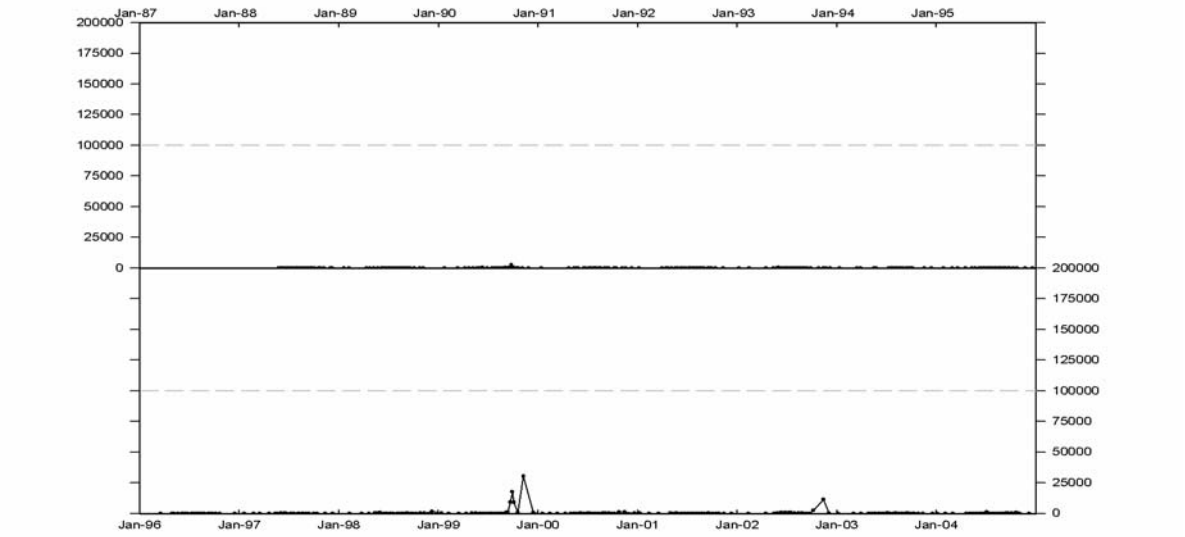

Fig. 5A. Concentrations (cells•L^{-1}) of *E. zodiacus* from the Wolves Islands (#16) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

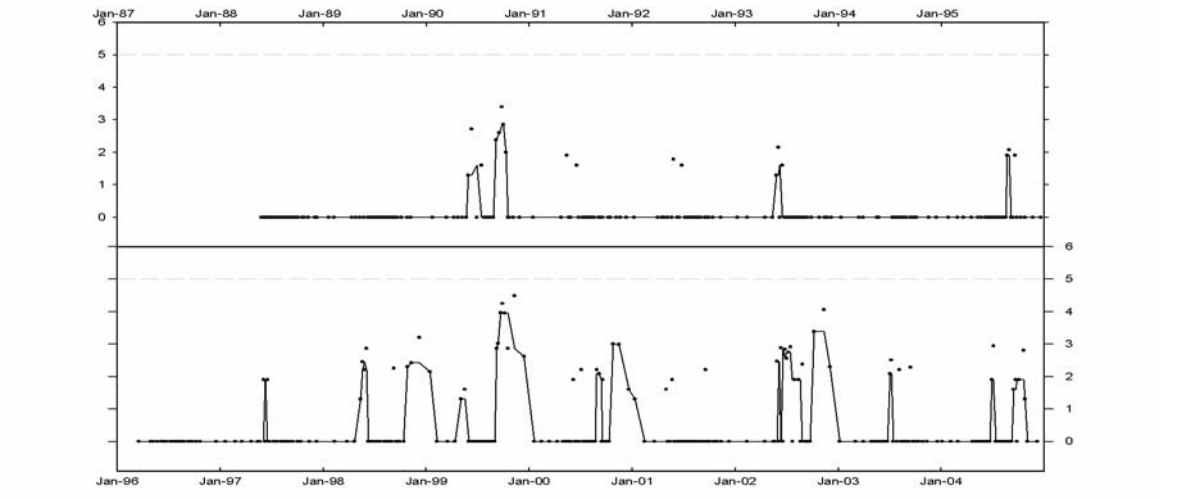

Fig. 5B. Concentrations (cells•L^{-1}) of *E. zodiacus* from Wolves (#16) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 8 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

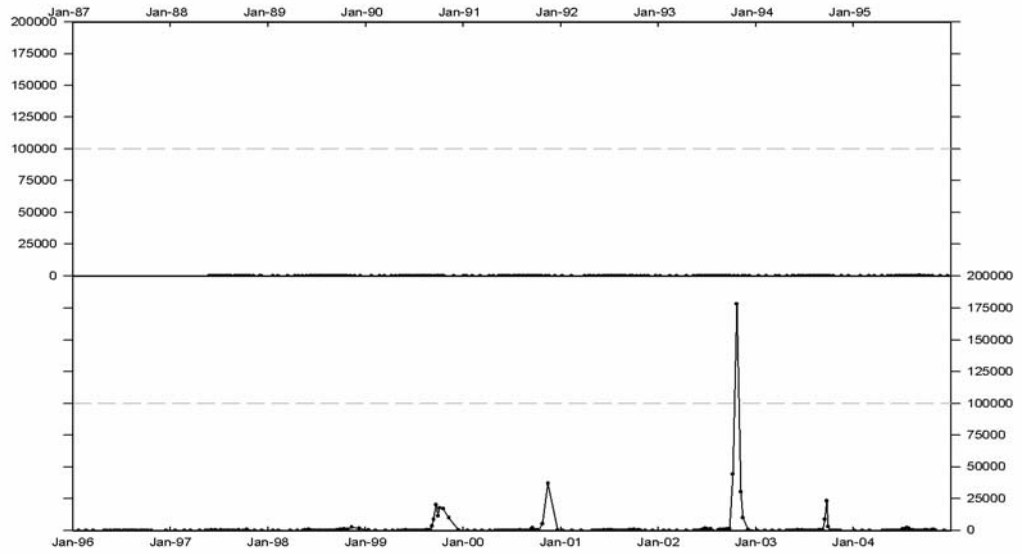

Fig. 6A. Concentrations (cells•L^{-1}) of *E. zodiacus* from the Brandy Cove (#17) from 1988-2004 on a linear scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration

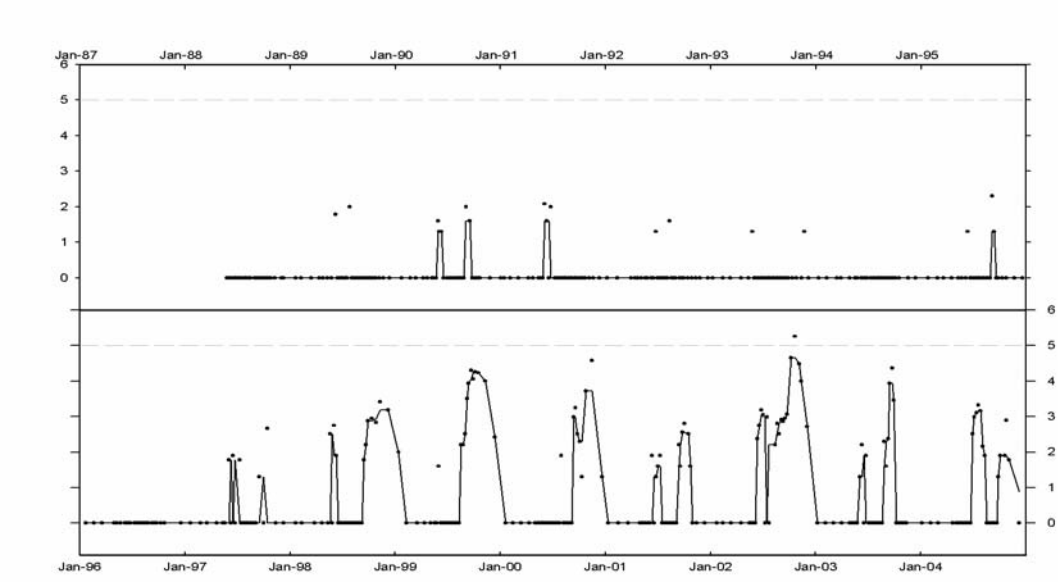

Fig. 6B. Concentrations (cells•L^{-1}) of *E. zodiacus* from Brandy Cove (#17) from 1988-2004 on a log-transformed scale. Upper portions of figures are the 8 yr 1988-95 and the lower portions are the 9 yr 1996-2004. Dotted line indicates the 100,000 cells•L^{-1} concentration.

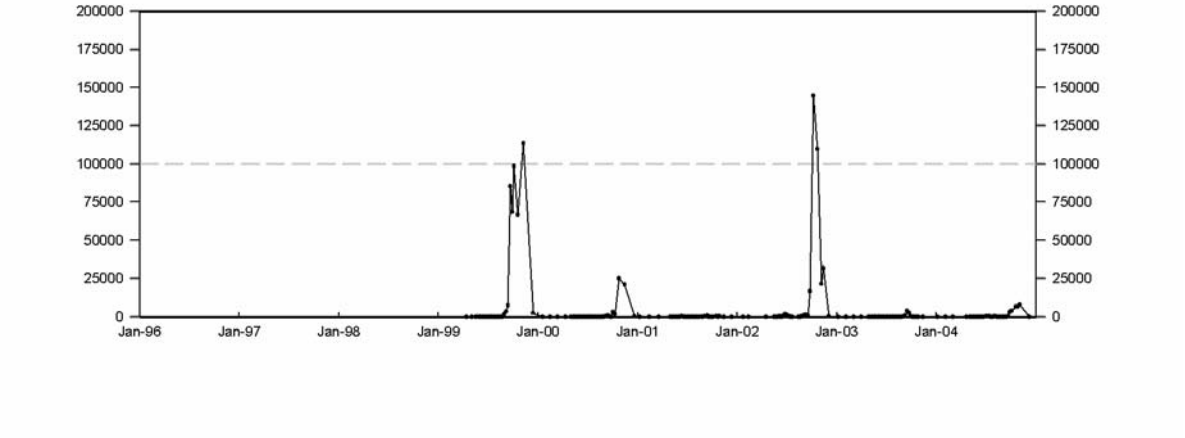

Fig. 7A. Concentrations (cells•L^{-1}) of *E. zodiacus* from mid-Passamaquoddy Bay (#25) on a linear scale (1999-2004). Dotted line indicates the 100,000 cells•L^{-1} concentration.

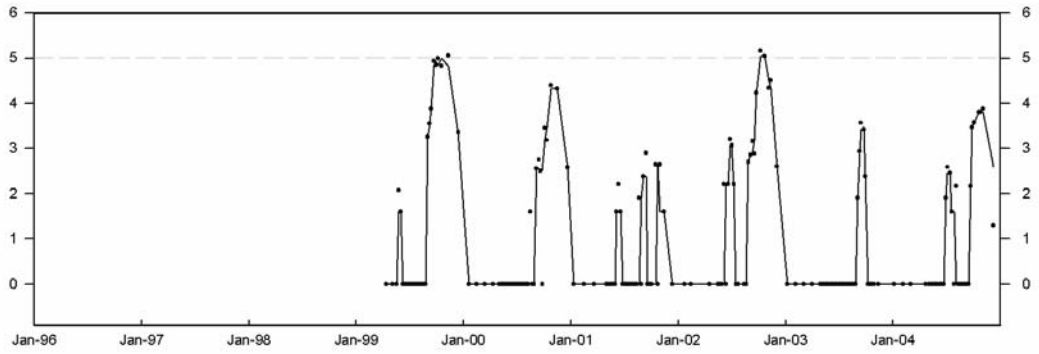

Fig. 7B. Concentrations (cells•L^{-1}) of *E. zodiacus* from mid-Passamaquoddy Bay (#25) on a log-transformed scale (1999-2004). Dotted line indicates the 100,000 cells•L^{-1} concentration.

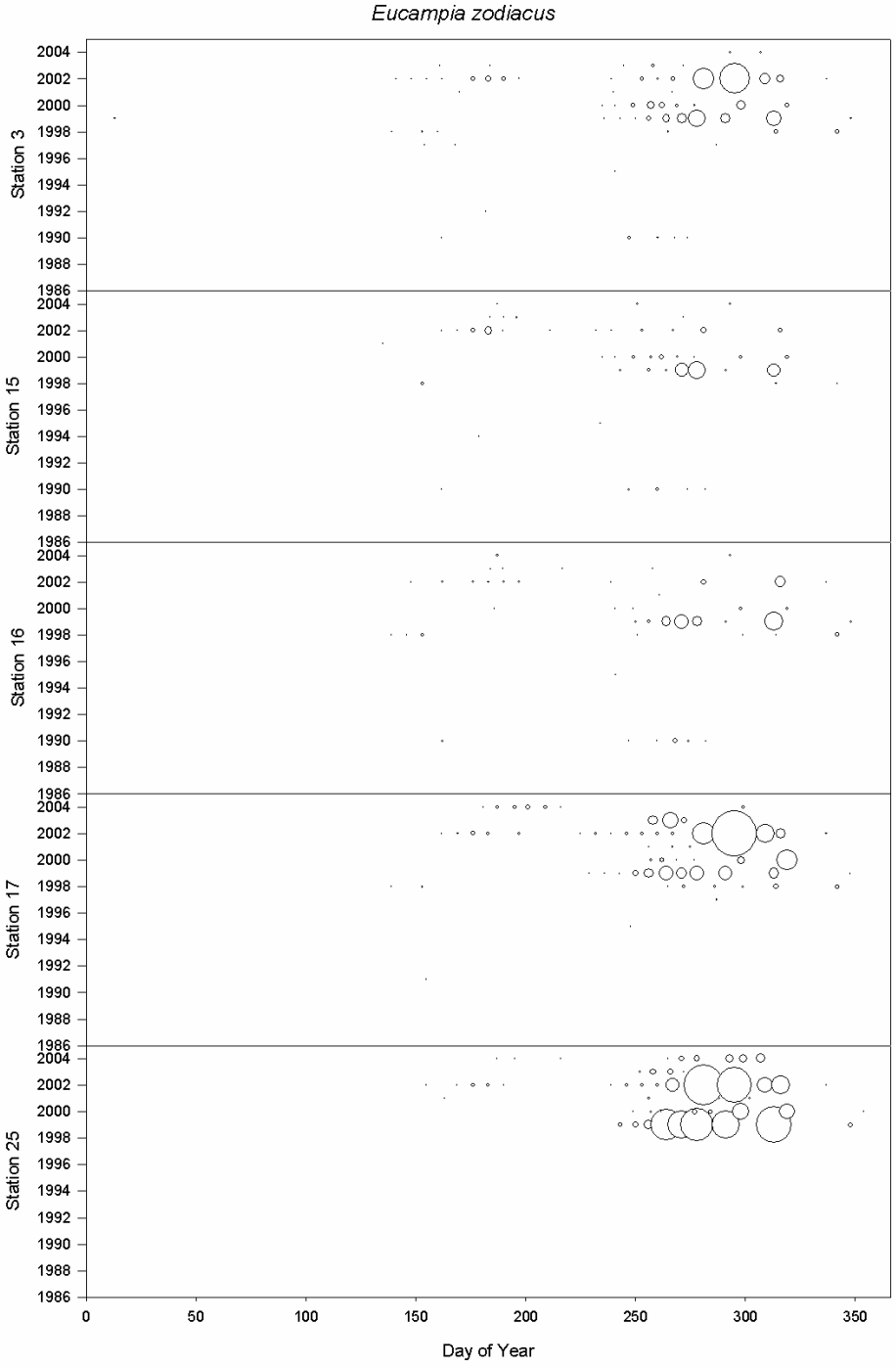

Fig. 8. Bubble graphs showing the *E. zodiacus* bloom durations from 1987-2004. Size of the circles indicates the cell concentrations (cells•L^{-1}). Station #25 was not sampled prior to 1999.

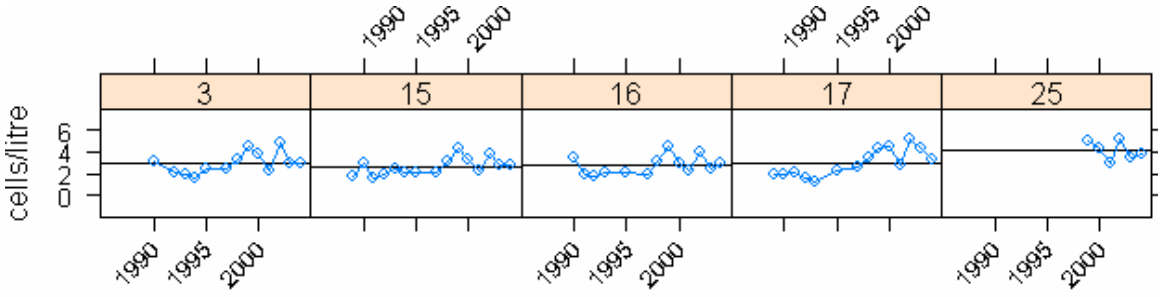

Fig. 9. Maximum density (cells•L^{-1}) of *E. zodiacus* at Stations 3, 15, 16, 17, and 27 on a log-transformed scale. Solid line indicates the mean of the log cell concentrations.

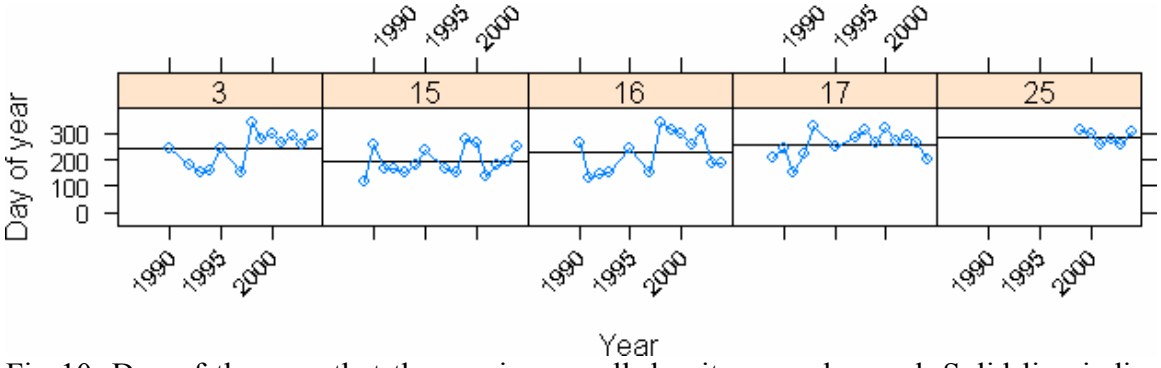

Fig 10. Day of the year that the maximum cell density was observed. Solid line indicates the mean.

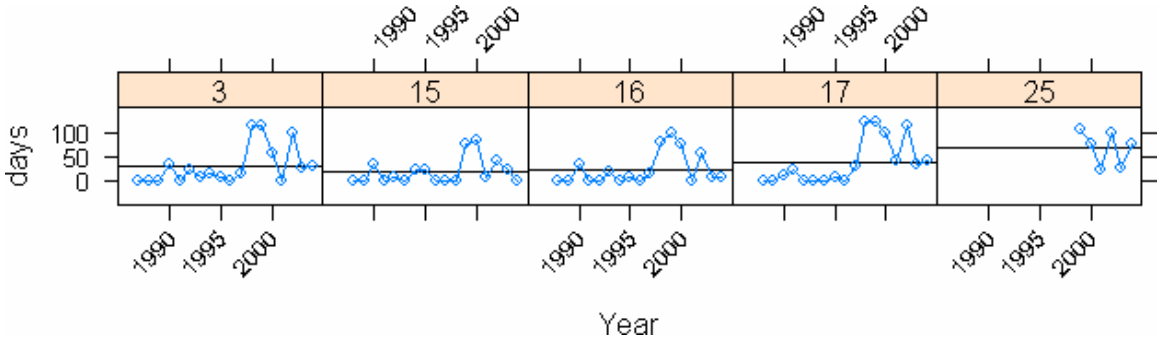

Fig. 11. Length of the bloom containing the maximum cell density for each year 1987-2004.

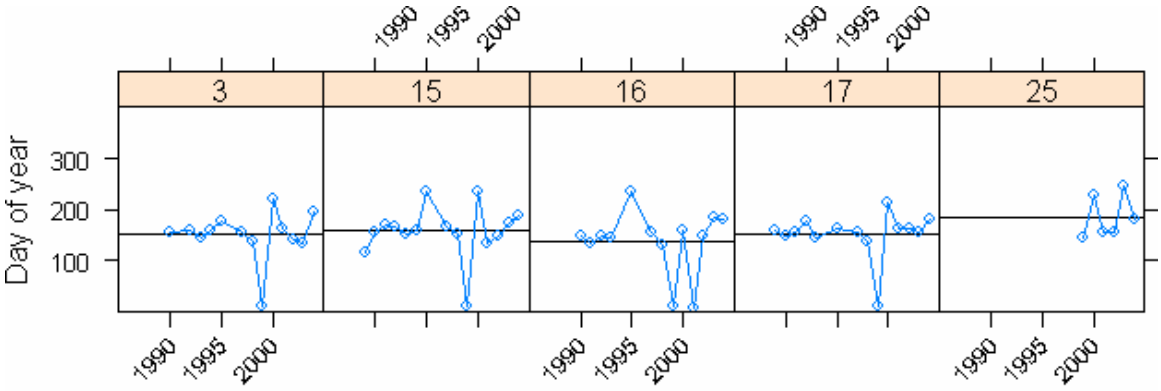

Fig. 12. Date of the first appearance of *E. zodiacus* cells in a given year.