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Seasonal Cycle of Phytoplankton in the Dunkellin Estuary, Western Ireland.

J.H.T. O'Mahony,*

Department of Oceanography, University College, Galway, Ireland.

* Current Address: Fisheries Research Centre, Department of the Marine, Abbotstown, Dublin 15, Ireland.

Summary

Phytoplankton species composition, assemblages, concentrations, distributions and sequences were studied for two and a half years in a small estuary in Western Ireland. Physico-chemical conditions (temperature, salinity, currents, meteorology, water transparency, nutrients, chlorophyll a and particulate organic carbon) were also monitored concurrently. 185 taxa were recorded from 9 major algal groups. The classical bimodal peaks in both cell concentrations and chlorophyll a concentrations were not observed in the Dunkellin estuary, rather a series of peaks were recorded throughout the growing season (late Feb-Nov). Seasonal aspects of the dominant phytoplankton groups and species are discusssed.

Introduction

Phytoplankton species composition, assemblages, distributions and sequences have been little studied in Irish estuaries. As interest focusses on the potential for urban, maricultural and industrial expansion both in and around Irish estuaries, it becomes important to document species composition and the factors that influence the phytoplankton assemblages that are currently found there. Occurrences of harmful phytoplankton in Irish waters since 1976 has raised concern about their potential impact on public health (vis a vis Diarrhetic and Paralytic shellfish toxins), and on the economics of our expanding fish and shellfisheries.

This present study is the first temporal, quantitative investigation of the phytoplankton of the Dunkellin Estuary, from February 1984 to June 1986. The aim of the resesarch was a detailed investigation of the phytoplankton species composition, abundance, distribution and sequences in the estuary with reference to both temporal (interannual & seasonal) and spatial (horizontal, depth & tidal cycle) patterns. Results are presented here for the seasonal cycle of phytoplankton recorded during that period.

Site description, Bathymetry, Topography & General Oceanography

The Dunkellin Estuary lies within the eastern portion of Galway Bay, Ireland, bounded by latitudes 53° 11'36" to 53° 13'12" N and longitudes 08° 51 to 09° 3'W. Location and station positions are shown in Figure 1. The study area encompasses circa c19 km^2. Figure 2 shows the bathymetric contours and place names. The Clarinbridge Oyster Bed located in Keave Narrows, covers an area of approximately 2 km^2. This is a very shallow area, and can be less than 1m in depth at low tide, in some places. Dunbulcaun Bay, NE of Keave, dries out at mean low water spring tides along the north and south shores. From Corraun Point westwards, the seabed gradually deepens until a maximum of 7m is reached in Tyrone Pool. South of Tyrone Pool the Yellow Rocks are exposed at low tide. The region deepens into Mweenish Strait, to a depth of 5m south of Mweenish Point. West of Mweenish Point and Island Eddy the bottom gradually deepens, reaching a depth of 10m SE of Kilcolgan Point.

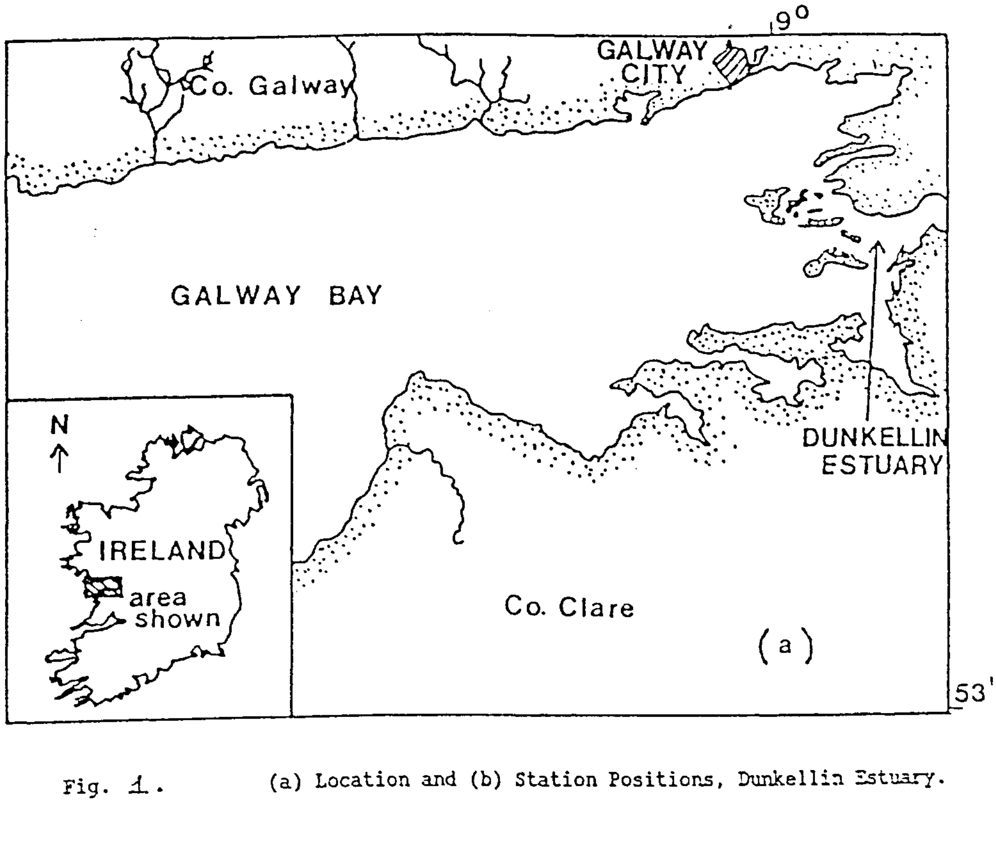

Fig. 1. (a) Location and (b) Station Positions, Dunkellin Estuary.

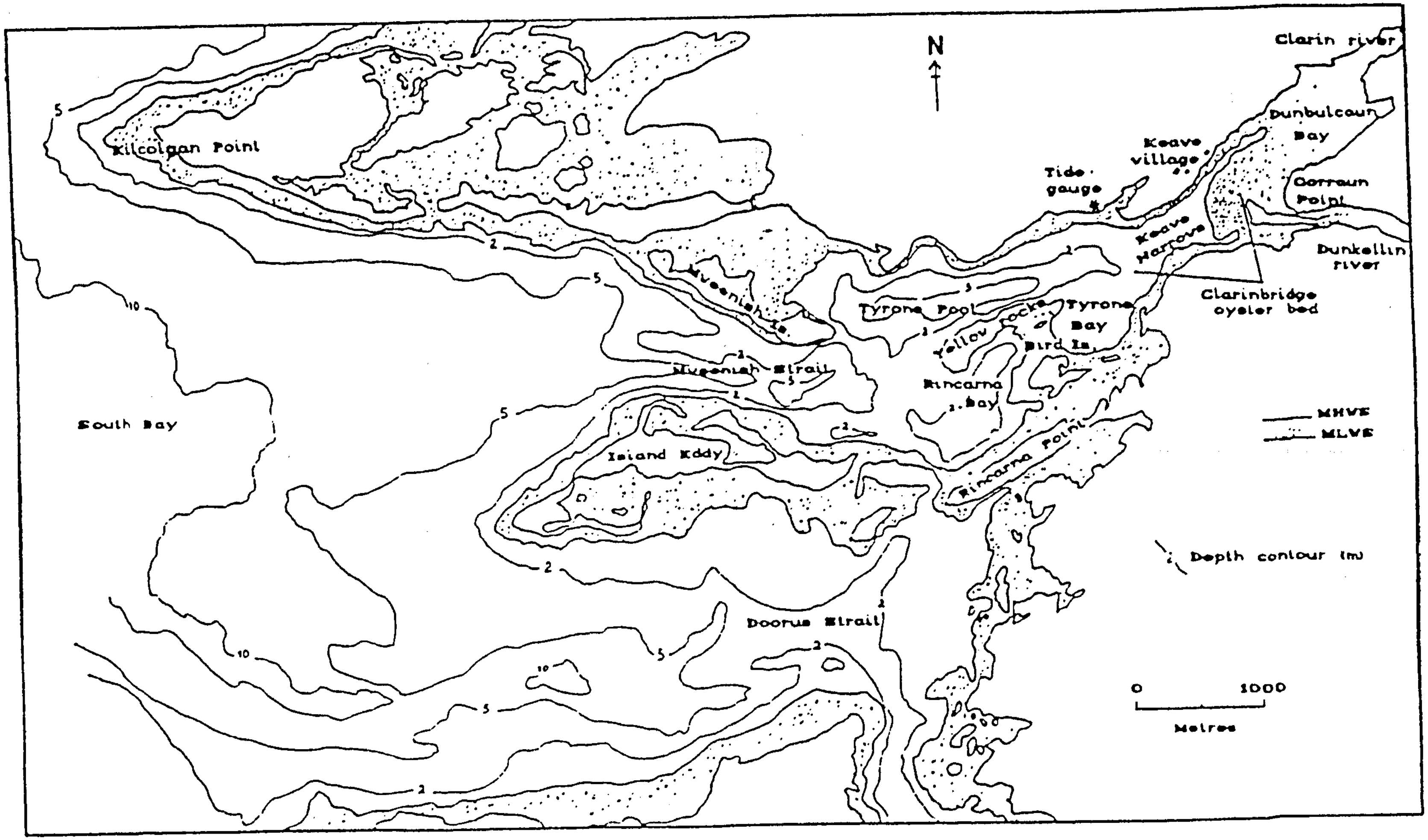

Fig. 2. Bathymetric Contours & Place Names, Dunkellin Estuary.

The surrounding land is low-lying, with bedrock composed of limestone from the Upper Carboniferous Period. The substrate types vary between the sampling stations, ranging from mud and silty clay at station 1, coarse sand and shell/gravel (station 2) to a mixture of clay, sand and maerl (remains of coralline algae) at station 4. The principal sources of freshwater are two small rivers the Dunkellin and the Clarin, with a combined catchment area of 496 km^2 approx.. These two rivers can flood circa 4000 hectares of low-lying land in winter. Due to the porous nature of the underlying Carboniferous limestone, freshwater "sinks", called swallow holes, are present and water presumably penetrates into subterranean drainage channels which may be a source of additional freswater input.

Tides in this region are semi-diurnal, and range from 4.7m - 1-9m for mean spring and neap tides respectively (Bary *et al.*, 1986). Occasional deviations do occur, events usually of a short duration of 2-3 tidal cycles and Bary (*op. cit.*), suggests that these are related to weather-induced changes occurring outside the estuary. Booth (1975) and Harte *et al.* (1982) found that the small bays at the eastern portion of Galway Bay appear to be little influenced by the general circulation within the bay itself. Berthois *et al.* (1972), considered that the surface water movements in the bay are governed by wind, and that in the southern part of the bay (which includes the Dunkellin Estuary), that wind stress is probably the major factor affecting water movement. Booth (*op. cit.)* considered the whole of Inner Galway Bay as a partial or well mixed estuary and also suggests horizontal and vertical mixing processes as the predominant form of freshwater transport in this portion of the Bay. Yip (1980), and Cronin (1987), found that water originating from outside Galway Bay can be distinguished during the summer months.

Materials & Methods

Sampling and standard analytical procedures for physico-chemical data are given in detail in O'Mahony (1992). For biological samples, quantitative duplicate 30ml samples were preserved in acidified Lugol's Iodine (Throndsen 1978), shaken gently to distribute the preservative and stored in the dark. For examination, samples were gently shaken 100 times to redistribute the phytoplankton as evenly as possible, and were poured into 10ml Hydrobios chambers and left to settle overnight (Edler 1979). The sedimented plankton were then identified and counted with a Nikon Phase Contrast Inverted Microscope using a modified Utermohl's Method (Hasle 1978). All species were identifed (or coded) and counted at the same time. The whole bottom of the base plate was counted to reduce errors even though this is a slower method.

Results

A. Meteorology

The climate on the west coast of Ireland is characterized by a small annual variation in air temperature with average winter and summer values differing by about 10°C. Maximum precipitation usually occurs between later autumn and early spring. In winter and occasionally in late summer, the Galway Bay area is subject to severe storms. Figure 3 summarizes mean air temperatures, wind force and direction, windspeeds, cloud coverage and riverflow rates (the latter an indication of rainfall) during the period of the survey. The coldest months were January 1985 and February 1986, with the warmest periods occurring between June to September. 1984 was warmer and dryer than either of the following two years. The prevailing wind was southwesterly and on most sampling dates winds were greater than Beaufort force 2. Windspeeds were higher in 1985 and 1986 than in 1984. August 1985 was notable for particularly severe storms. Cloud coverage values of 0/8 octres were never

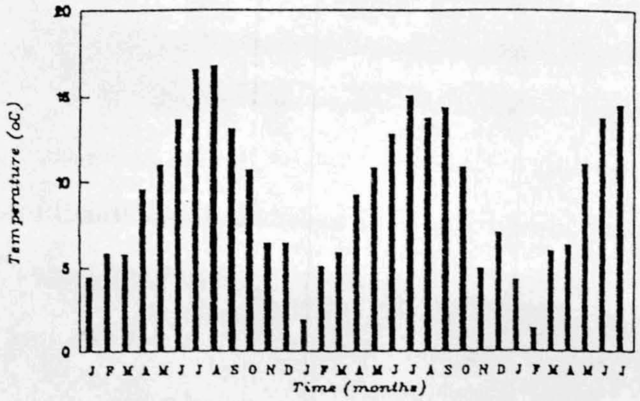

Fig. 3.1. Mean Monthly Air Temps., Galway, 1984–1986

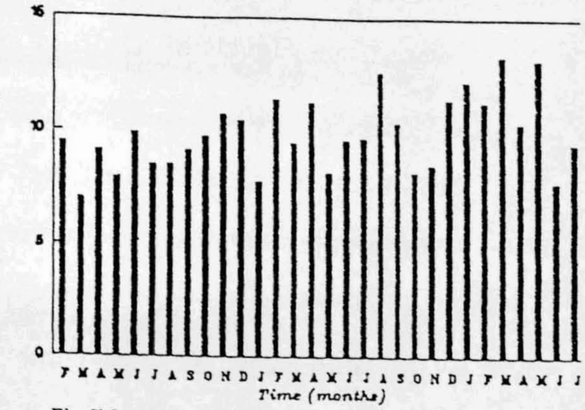

Fig. 3.3. Windspeeds, Dunkellin Estuary, 1984–1986

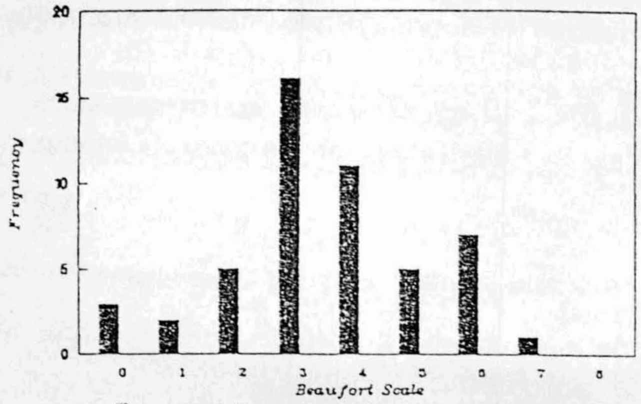

Fig. 3.2a Wind Force, Dunkellin Estuary, 1984–1986

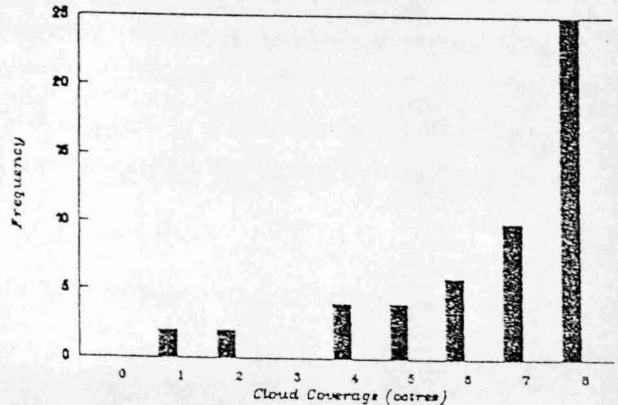

Fig. 3.4. Cloud Coverage, Dunkellin Estuary, 1984–1986

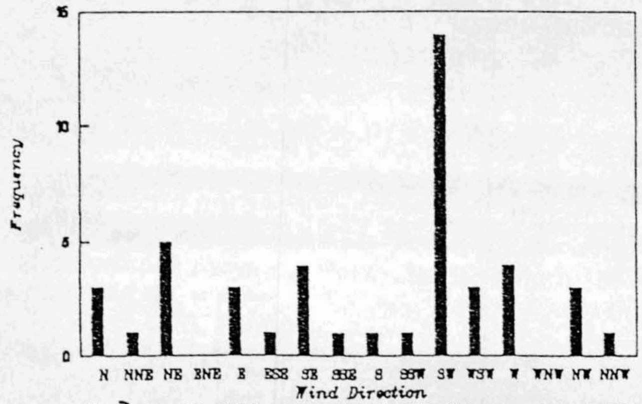

Fig. 3.2b Wind Direction, Dunkellin Estuary, 1984–1986

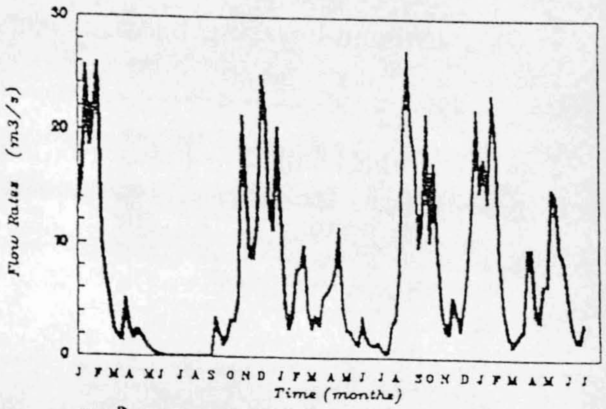

Fig. 3.5. Riverflow Rates, Dunkellin Estuary, 1984–1986

recorded on the sampling dates and in fact were full coverage 8/8 on most days. Combined weekly river flow data show that minimum precipitation occurred during the summer of 1984, and the maximum of 238 mm in August 1985, which was nearly three times the long term mean for that month. Overall there were higher levels of runoff in 1985 than in 1984.

B. Temperature, Salinity & Circulation

Temperature and salinity records are shown in Figure 4. In the Dunkellin Estuary, a salinity gradient exists along the axis of the estuary which varies with both river discharge values and tidally-induced mixing. The water column at station 4 was vertically mixed for most of the year and the highest salinites were recorded there at bottom depths. The other two stations are more stratified and have lowered salinities due to a combination of dilution from river discharge and slack currents at low tide. Values ranged from S3.6 (station 1) to S34.35 (station 4). Water temperatures ranged from 4.1^{o}C - 19.4^{o}C during the survey with winter minima and summer maxima. In contrast to the salinity values, there was very little difference in the temperatures recorded at each station and thermal stratification did not occur. Greater differences were evident, however, between years at the time of the spring increases.

In the Dunkellin Estuary current flow was generally in an east-west direction for the inner part of the estuary, and northwest-southeast for the outer part as is shown in Figure 5. Downstream residual currents were found during periods of high runoff (Bary *et al.* 1986). Flushing rates were high in the inner part of the estuary, with surface water in particular being replaced on each tide, whilst lowered current speeds at the bottom may result in some water being retained or returned there on the flooding tide. This may imply that neritic/coastal species of phytoplankton are recruited from outside the estuary, from Galway Bay rather than endemic brackish species predominating in the inner estuary.

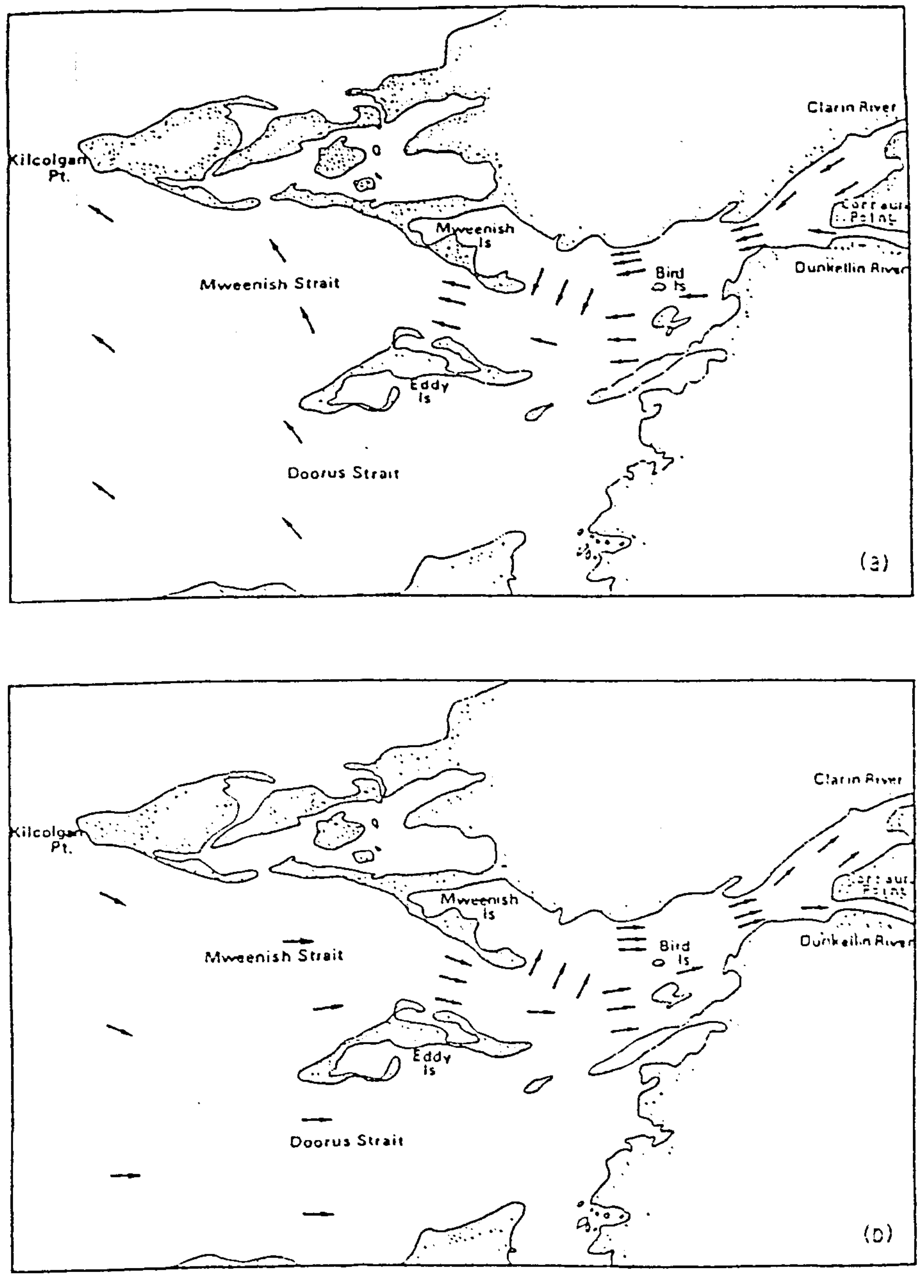

Fig. 5. Generalized circulation pattern (surface, direction only) on (a) an ebbing tide and (b) a flooding tide in the Dunkellin estuary

(after Bary *et al.*, 1986)

D. Nutrient Distributions

Data on nitrates, silicates and phosphates are shown in Figure 6. Overall the nutrient concentrations investigated in the Dunkellin Estuary did not appear to exhibit clearly defined seasonal relationships over the two and a half years of the survey. Occurrences of maximal concentrations were more often associated with the highly variable and anomalous weather conditions than with the seasons. Nutrients did not appear to be limiting in the estuary. Gradients in concentrations were found, with a decrease in concentrations of nitrate and silicate from station 1 to 4, and an increase in phosphate.

E. Particulate Organic Carbon & Chlorophyll a

Data for POC and Chl a for each station are shown in Figure 7. For POC's, considerable fluctuations were recorded at each station, with trends in increases and decreases generally following the same pattern at each station. No clear seasonal trend was apparent over time. POC concentrations were higher in 1986 than either 1984 or 1985. Chlorophyll a concentrations in the Dunkellin Estuary varied between each station and between years during the survey. Maxima varied also both in timing and in magnitude. Station 2 exhibited a more clearly defined seasonal distribution that either stations 1 or 4. Values ranged from not detectable to 14.5 mg/m^3.

F. Phytoplankton

185 taxa were identified from 9 classes of phytoplankton. Percentage class representation is shown in Table 1 and the dominant species are listed in Table 2. Phytoplankton numerical abundance (Figure 8.) ranged from undetectable to 2.9×10^6 cells per litre and were generally highest between April and November. Cell concentrations were generally higher at stations 1 & 2 than at station 4, and were usually lower at subsurface depths. Mean cell numbers per

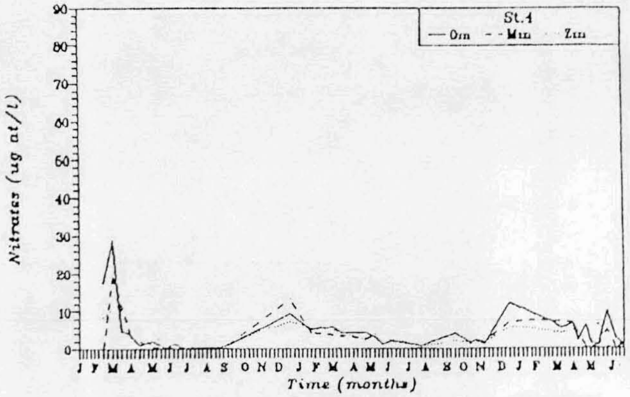

Fig. 6a Nitrates, St. 4, Dunkellin Estuary 1984–1986

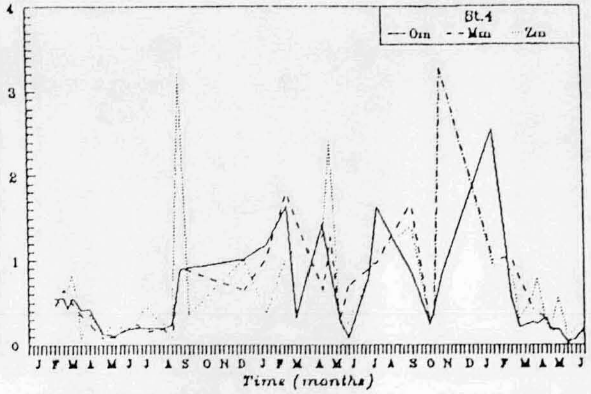

Fig. 6d PO4-P, St. 4, Dunkellin Estuary 1984–1986

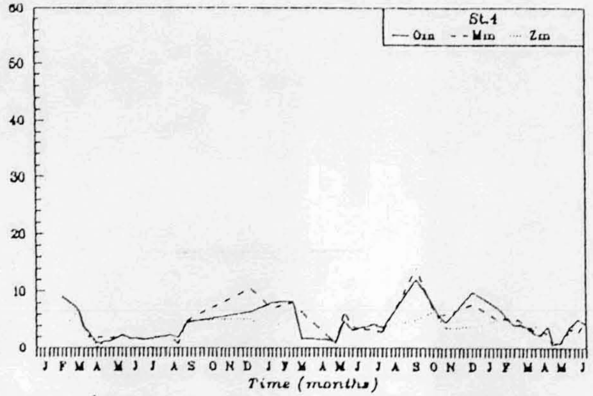

Fig. 6g Silicates, St.4, Dunkellin Estuary 1984–1986

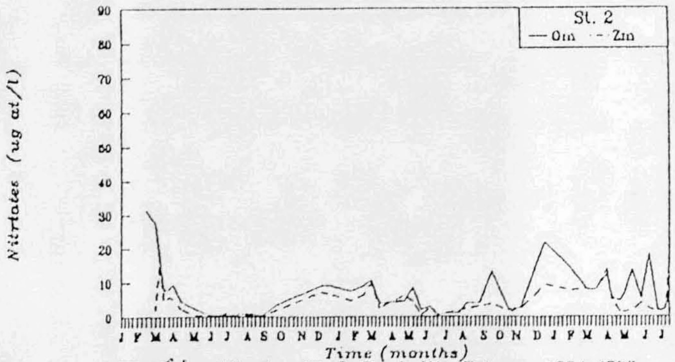

Fig. 6b Nitrates, St. 2, Dunkellin Estuary 1984–1986

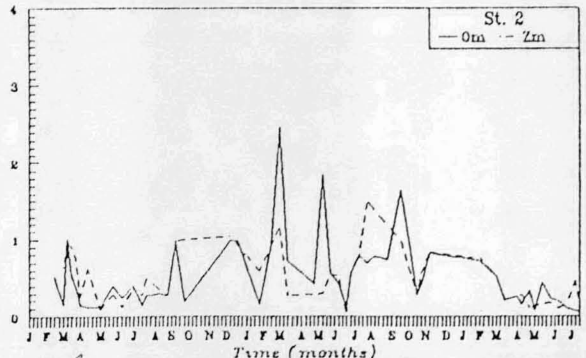

Fig. 6e Phosphates, St. 2 Dunkellin Estuary 1984–1986

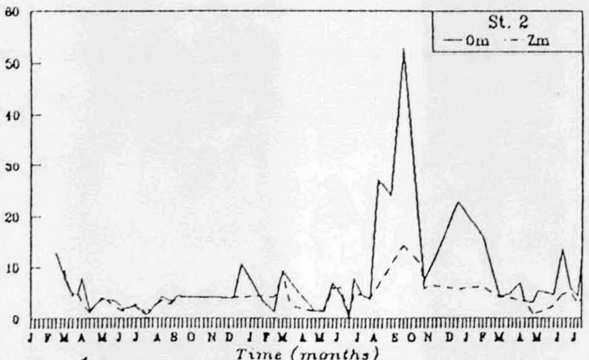

Fig. 6h Silicates, St. 2, Dunkellin Estuary, 1984–1986

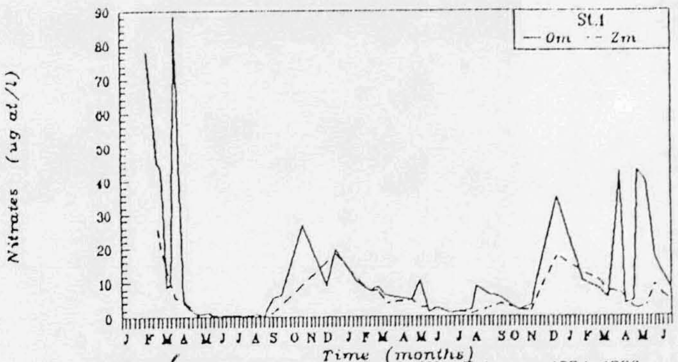

Fig. 6c Nitrates, St. 1, Dunkellin Estuary, 1984–1986

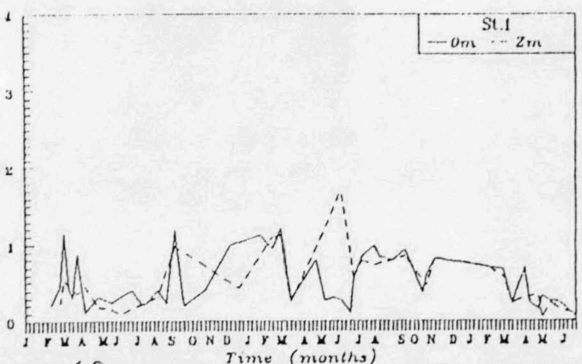

Fig. 6f Phosphates, St. 1, Dunkellin Estuary, 1984–1986

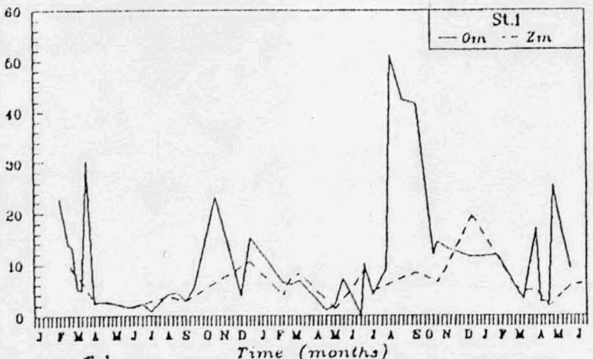

Fig. 6i Silicates, St. 1, Dunkellin Estuary, 1984–1986

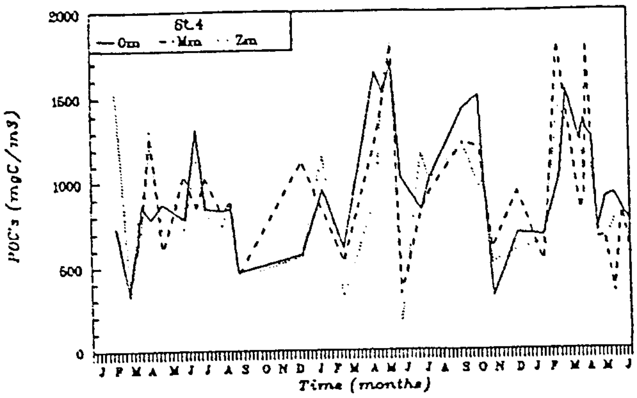

Fig. 7a POCs, St. 4, Dunkellin Estuary, 1984-1986

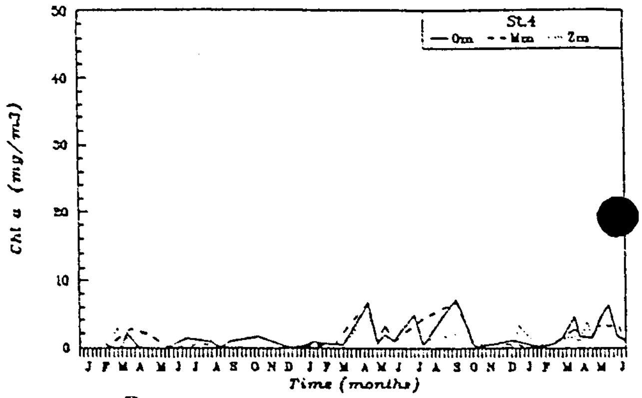

Fig. 7d Chl a, St. 4, Dunkellin Estuary 1984-1986

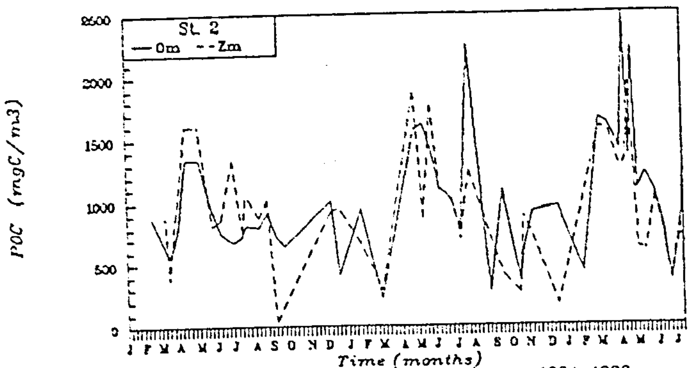

Fig. 7b POCs, St. 2, Dunkellin Estuary, 1984-1986

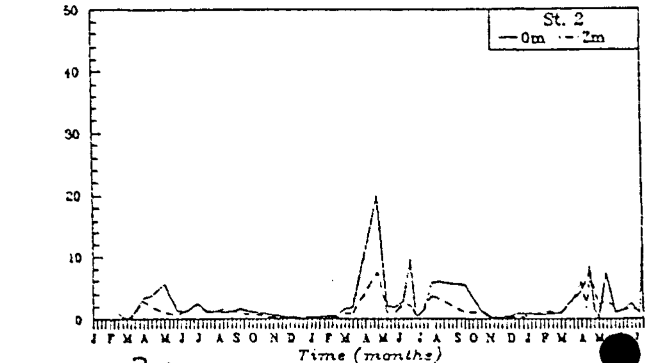

Fig. 7e Chl a, St. 2, Dunkellin Estuary, 1984-1986

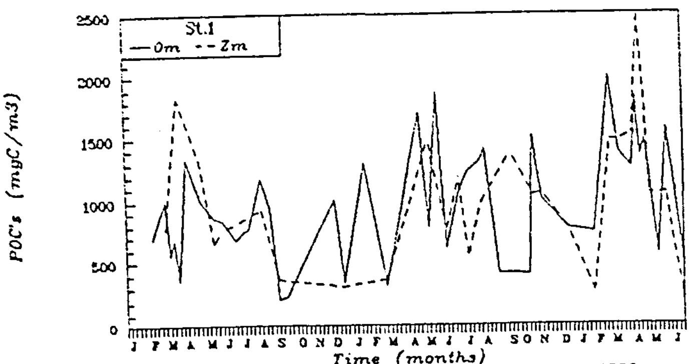

Fig. 7c POCs, St. 1, Dunkellin Estuary, 1984-1986

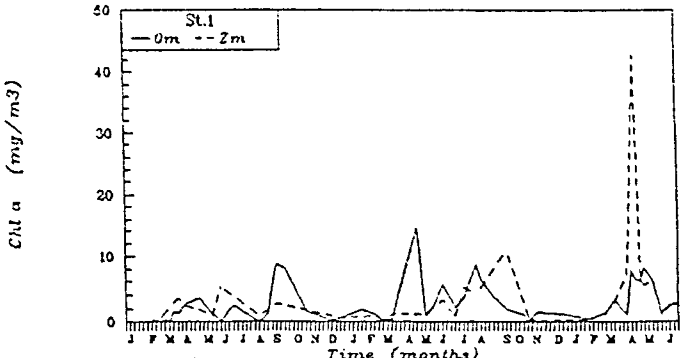

Fig. 7f Chl a, St. 1, Dunkellin Estuary, 1984-1986

Table 1 Percentage Class Representation - Dunkellin Estuary

CLASS	NO. OF SPECIES	% CONTRIBUTION
Bacillarophyceae	80	43.2
Chlorophyceae	4	2.1
Chrysophyceae	4	2.1
Craspedophyceae	1	0.5
Cryptophyceae*	4	2.1
Dinophyceae	86	46.4
Euglenophyceae	1	0.5
Prasinophyceae	2	2.1
Pyrmnesiophyceae	3	1.6
	185	100

* includes *Mesodinium rubrum*, unid. microflagellates, and Sp. F.

Table 2. Dominant Phytoplankton, Dunkellin Estuary, 1984-1986

DIATOMS

BACILLAROPHYCEAE (26)

Ceratulina pelagica
Chaetoceros spp. (small)
Chaetoceros spp. (large)
C. curvisetus
C. decipiens
C. simplex
C. socialis

Leptocylindrus danicus
L. minimus
Nitzschia spp.
N. closterium
N. delicatissima
N. seriata
Unidentified pennate diatoms

Rhizosolenia delicatula
R. hebatata f. semispina
R. ?pungens

Skeletonema costatum
Thalassionema nitzschoides
Thalassiosira spp.
Thal sp. AB
Thal. sp. C
T. gravida/rotula
T. rotula/gravida
T. nordenskioldii
T. polychorda

DINOFLAGELLATES

DINOPHYCEAE (11)

Ceratium lineatum
Dinophysis acuminata
Glenodinium foliaceum
Gonyaulax polyedra
G. spinifera
Gymnodinium simplex
G. splendens
Heterocapsa triquetra
Prorocentrum micans
Scrippsiella trochoidea
Unidentified dinoflagellates

MICROFLAGELLATES (8)

CHRYSOPHYCEAE (1)

Apedinella spinifera (W)

CRYPTOPHYCEAE (2)

Mesodinium rubrum
Rhodomonas ? minuta (Z)

EUGLENOPHYCEAE (1)

Eutreptia marina

PRASINOPHYCEAE (1)

Pyramimonas sp. (Y)

PYRMNESIOPHYCEAE (HAPTOPHYCEAE) (1)

Chrysochromulina sp. (V)

Unidentified microflagellates
Species F.

Table 3. Mean Phytoplankton Cell Concentrations, Dunkellin Estuary (cells/litre)

Station No.	1	2	4
Depth			
Surface	199,507	164,610	73,354
Mid	-	-	42,057
Bottom	190,480	69,581	28,551

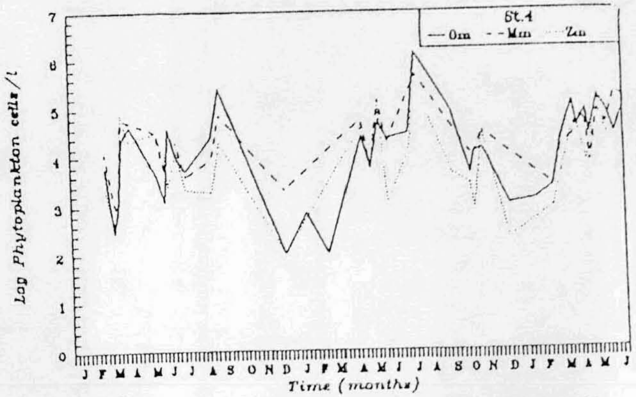

Fig. 8a Phytoplankton Abundance, St. 4, 1984-1986

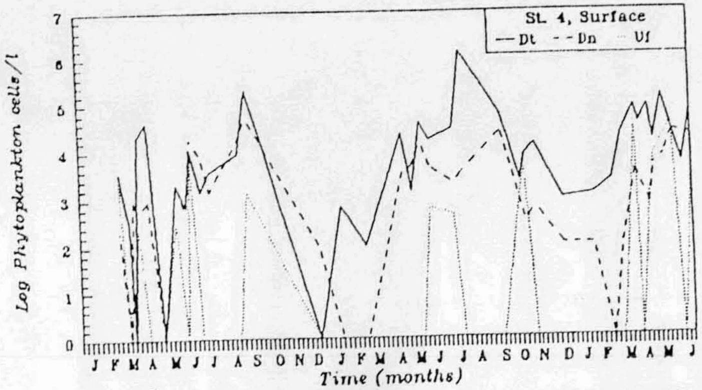

Fig. 9a Phytoplankton Group Abundance St.4, '84-'86

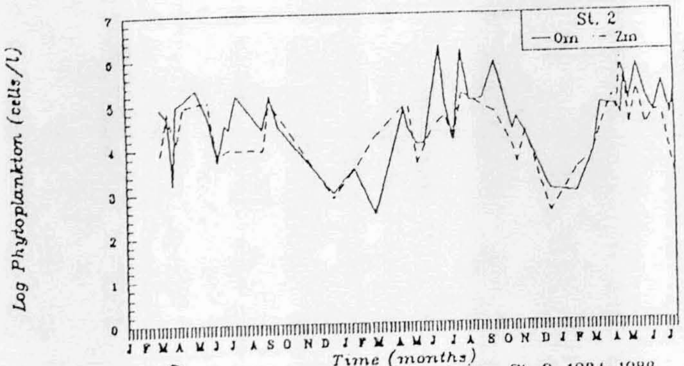

Fig. 8 b Phytoplankton Abundance, St. 2, 1984-1986

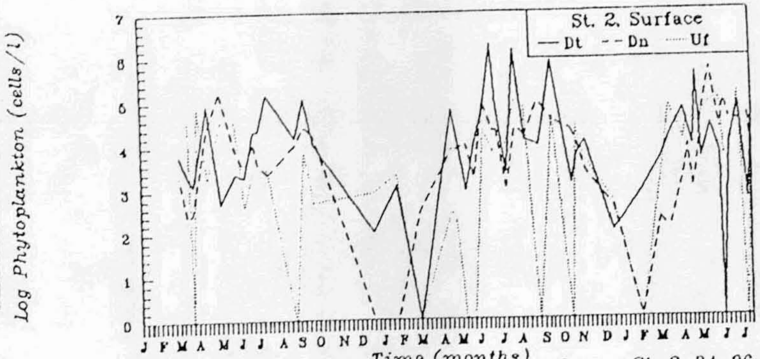

Fig. 9b Phytoplankton Group Abundance, St. 2, 84-86

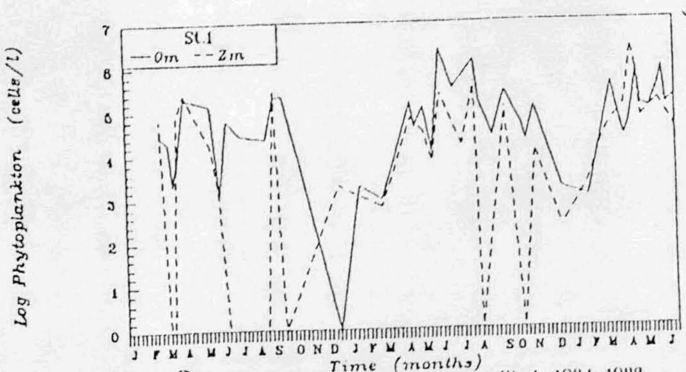

Fig. 8c Phytoplankton Abundance, St. 1, 1984-1986

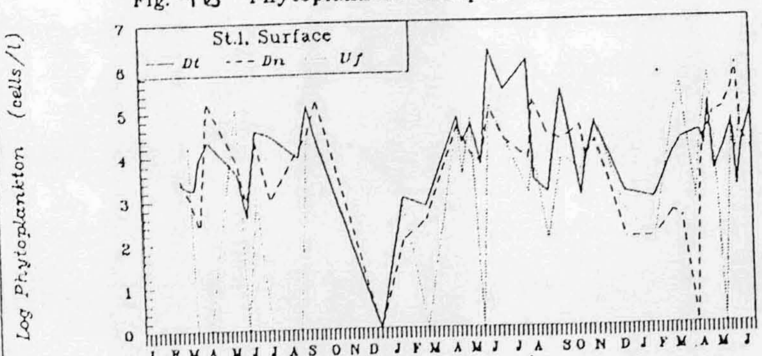

Fig. 9c Phytoplankton Group Abundance, St.1, 1984-1986

station are shown in Table 3. The classical bimodal pattern in phytoplankton standing crop (using numerical abundance), was not observed in the Dunkellin Estuary ; levels fluctuated continually during the productive months, and the highest spring concentration was usually exceeded by concentrations in June, July and September. This does not imply that these were periods of greatest biomass, as blooms of some very small species such as *Nitzschia delicatissima* and *Leptocylindrus minimus* occurred. The group dominance (in terms of numerical abundance), also varied between sampling dates as is illustrated in Figure 9.

General Characteristics of the Annual cycle of Phytoplankton in the Dunkellin Estuary 1984-1986.

Winter (December - mid February)

A very sparse flora was generally found between **December** and the end of **February**, when low water temperatures (<8^{o}C) and light intensity were found. Assemblages present at this time were characterized by low species diversity and low cell abundance (<10,000 cells/litre). This winter flora began to be replaced in late February/early March at stations 1 & 2, by microflagellates, notably *Eutreptia marina* and *Rhodomonas spp.*

Spring (End February-end May)

The spring increase in cell concentrations began in the last week of February of the years sampled, though not necessarily at all stations together, or at the same station each year. These months were characterized by an overall increase in species diversity and total cell concentrations, as well as temperatures and chlorophyll a. During this survey the spring peak usually occurred in April. In **March**, species diversity increased when water temperatures rose above 10^{o} C, with microflagellates and diatoms such as *Thalassiosira spp.* appearing at stations 1 & 2 and small *Chaetoceros spp., Thalassiosira spp.*, microflagellates and the dinoflagellate *Scrippsiella trochoide*a at station 4. The *Scrippsiella* was interestingly concentrated at mid depths only.

By **April,** both species diversity and cell concentrations had greatly increased at stations 1 & 2, and less so at station 4. Mixed populations of microflagellates, dinoflagellates and diatoms were found at stations 1 & 2, whereas station 4 was dominated by diatoms. At station 1 the dominant flora was composed of *Eutreptia marina, Rhodomonas sp., Heterocapsa triquetra*, a small *Gymnodinium sp., Thalassiosira spp., T. polychorda,* small *Chaetoceros spp., Skeletonema costatum* and *Nitzschia spp.* At station 2, the flora was similar, except that *E. marina* and *Gymnodinium sp.* were replaced by large *Chaetoceros spp.*, and more species of *Thalassiosira.* At Station 4, the water contained mixed diatoms such as small *Chaetoceros spp., Thalassiosira spp., Thalassiosira ?levanderi, T. gravida, T. polychorda S. costatum* and *Rhodomonas sp.*

In **May**, species diversity decreased in comparison to April. The diatom *Rhizosolenia delicatula* appeared in the plankton at all stations, together with the dinoflagellate *Glenodinium foliaceum* at station 1 and *S. trochoidea* at station 2. At station 4, *S. trochoidea* dominated in the surface waters, with mixed diatoms and microflagellates at subsurface depths.

Summer (June-August)

In **June**, species diversity again increases, particularly at station 1. The diatom *Cerataulina pelagica* appeared at stations 1 & 2, and the dinoflagellate *Ceratium lineatum* at station 4. The diatom *Leptocylindrus minimus* also appeared in very high numbers at stations 1 & 2. The number of *Chaetoceros spp.* present also increased, with species such as *C. curvisetus* and *C. sociale* at station 1, with *Rhizosolenia hebatata.* At station 4, *R. delicatula* was present at all depths.. During this month red tide blooms of *Glenodinium foliaceum* occurred. In July, the diatom *Thalassionema nitzschoides* forms an important component of the phytoplankton assemblages at all stations, with small *Chaetoceros spp., Scrippsiella* and microflagellates also important at station 2, and *C. lineatum* at station 4. Species diversity decreases during this month. In 1985 there was a localized bloom of the dinoflagellate *Gonyaulax spinifera* near station 1.

August was one of the few months of the year where sampling was disrupted or cancelled due to bad weather. Phytoplankton composition generally shifted from a mixed diatom/dinoflagellate assemblage to a predominantly dinoflagellate one at stations 1 and 4, with a mixed assemblage at station 2. Species diversity decreased at all stations and depths, except at station 1, where increases occurred. The predominant dinoflagellates were *Prorocentrum micans* and *Glenodinium foliaceum* at station 1, *P. micans* at station 4 and mixed small *Chaetoceros spp., Eutreptia marina, G. foliaceum* and mixed microflagellates at station 2.

Autumn (September - November)

By **September** species diversity generally increased again with assemblages of mixed diatoms, dinoflagellates and microflagellates. The diatom *Leptocylindrus danicus* and the dinoflagellate *Gymnodinium splendens* occurred during this month at station 1, with *R. hebetata, L. minimus, C. curvisetus* and *Skeletonema costatum.* In **October** and **November** sampling disruption occurred frequently due to bad weather. Species diversity generally decreased. In October, the dinoflagellate *Prorocentrum micans* was dominant at stations 1 & 2, with microflagellates at station 1. A very sparse flora was present at station 4. During November, (samples only from 1985), microflagellates dominated at station 1, *Thalassiosira rotula* at station 2 and *Thalassiosira rotula/gravida* at subsurface depths at station 4.

Discussion

185 species of phytoplankton were recorded during this survey from 9 algal groups. This is a relatively rich flora when compared to other Irish estuaries, due in part the relatively long duration of this study. Species were principally neritic and temperate (north & south) in origin. Both dinoflagellates and microflagellates were important components of the flora as well as diatoms. Highest phytoplankton concentrations were found in the warmer/lighter periods of the year from April to September. The classical bimodal peaks in both cell abundance and chlorophyll a concentrations, so much a feature of many temperate estuaries and coastal waters, were not found in the Dunkellin Estuary; instead frequent high concentrations were found throughout the growing season. This has also been documented by other researchers, including Riaux & Douville (1980), in the Penze Estuary, France; by Hulsizer (1976) in Narragansett Bay U.S.A., von Bodungen (1975) in the Kiel Bight, Germany.

Seasonal successions/sequences in phytoplankton often occur in areas that are characterized by having seasonal temperature and nutrients, and the timing of their community dominance is usually an indication of their environmental preferences (Smayda 1980). In the Dunkellin Estuary, where microflagellates were as important a component of the phytoplankton assemblages as diatoms and dinoflagellates, succession seemed to occur within these groups over the annual cycle. However, this was succession not obvious between groups, as these underwent continual rapid changes in dominance, as well as reversals to previous assemblages, during the growing period.

A feature of the two and a half year study of the Dunkellin Estuary, and documented throughout much of the meteorological, physical and chemical data collected, is the variability that occurred between years. This was also reflected in the phytoplankton data. Additionally, the annual maximum of chlorophyll a concentrations did not necessarily occur during the spring peak, but in the months of September (1984) and June (1985). his has also been found to be the case in Narragansett Bay, U.S.A. (Smayda 1983).

Due to the relatively short duration of this research (in comparison to over 30 years data from Narragansett Bay in eastern U.S.A.), it is difficult to speculate whether the variations encountered in the Dunkellin Estuary during the study are the norm, part of a longer term cycle, or unusual. They indicate that caution should be observed in interpreting data from one annual cycle alone, where interannual variations are masked and that longer term studies are more desirable. Results from this study indicate that the Dunkellin Estuary is a complex ecosystem.

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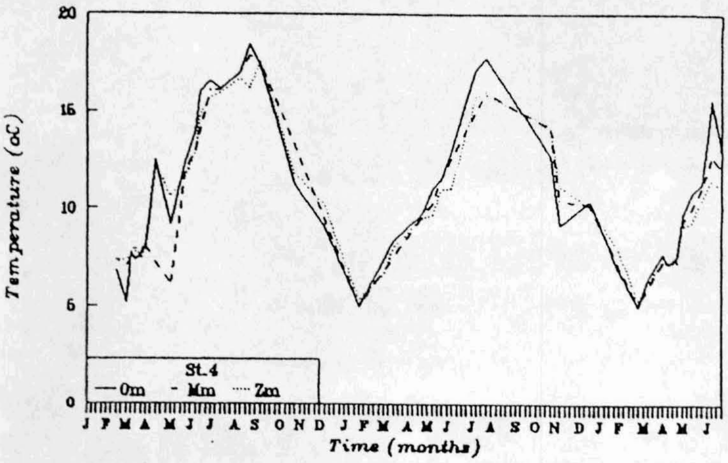

Fig. 4 Temperature, St. 4, Dunkellin Est. 1984–1986

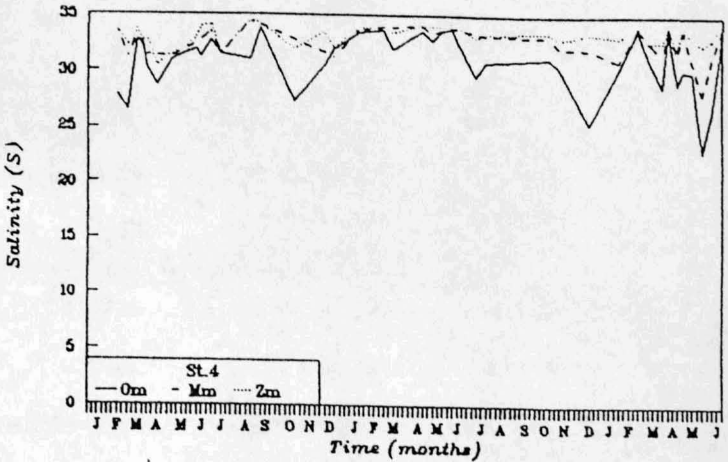

Fig. 4 Salinity, St. 4, Dunkellin Estuary, 1984–1986

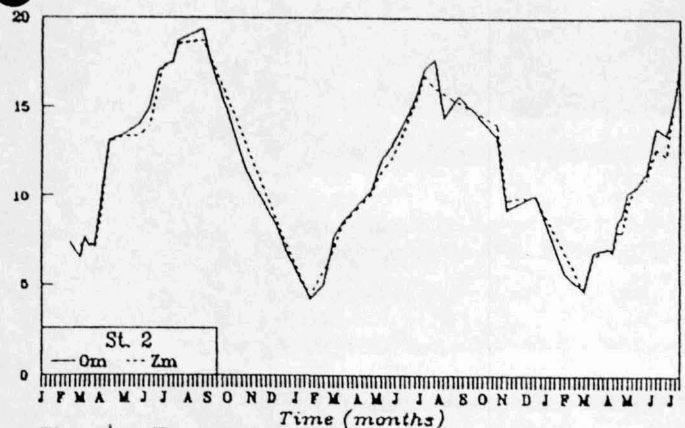

Fig. 4 Temperature, St. 2, Dunkellin Estuary, 1984–1986

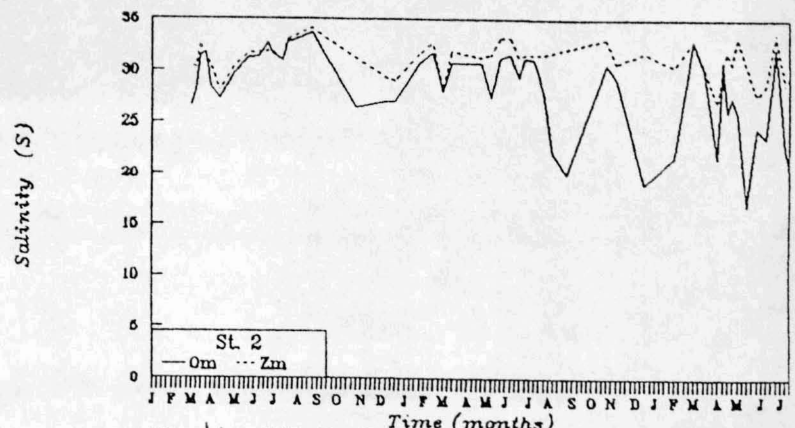

Fig. 4 Salinity, St. 2, Dunkellin Estuary, 1984–1986

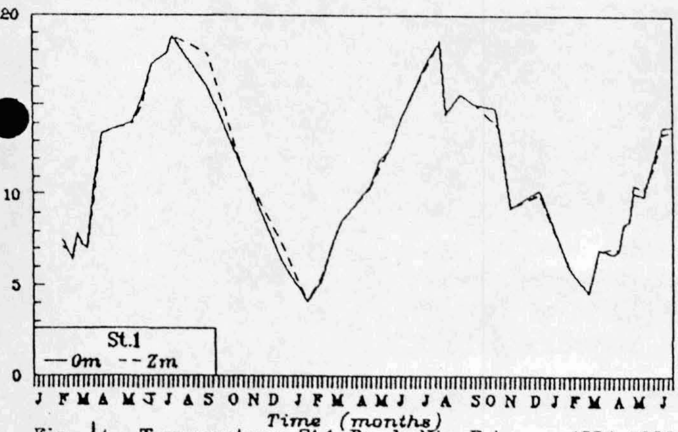

Fig. 4 Temperature, St.1, Dunkellin Estuary, 1984–1986

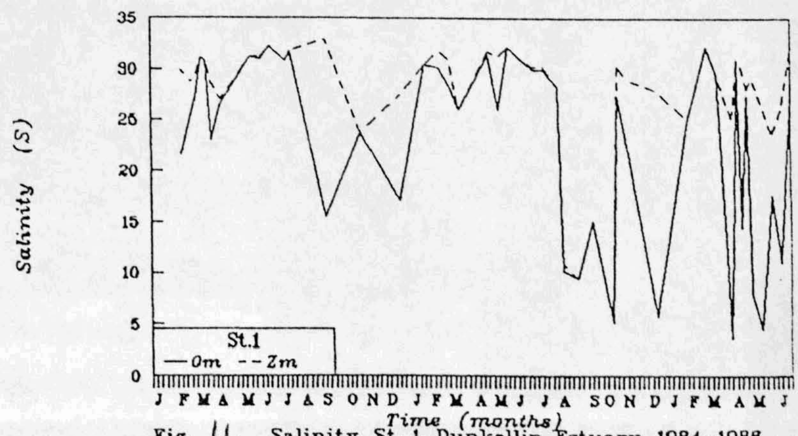

Fig. 4 Salinity, St. 1, Dunkellin Estuary, 1984–1986