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**Observed Sequential Occurrence of Phytoplankton and
Zooplankton in the Dunkellin Estuary, Galway Bay, Ireland.**

P.Byrne¹ and J.H.T. O'Mahony²,
Dept. of Oceanography, University College Galway, Ireland.

Current address: ¹ Environmental Science Unit, Trinity College, Dublin 2, Ireland.

² Fisheries Research Centre, Department of the Marine, Abbotstown, Dublin 15, Ireland.

Summary

The Dunkellin is a small tidally-dominated estuary to the south-east of Galway Bay in western Ireland. The plankton of the estuary was studied for 18 months between December 1984 and July 1986. This paper presents results on the variation in the sequential occurrence of phytoplankton and zooplankton between the inner and outer estuary. Phytoplankton and microzooplankton occurred in high numbers in the spring to autumn months. Highest abundances of phytoplankton and microzooplankton (non-tintinnid ciliates and tintinnid ciliates) were recorded in the inner estuary, whereas mesozooplankton were predominant in the outer reaches.

Introduction

Limited information is available on the seasonal abundance and composition of the plankton of Irish estuaries. Some studies on phytoplankton have been carried out in Killary Harbour (Pybus, in Keegan and Mercer, 1986; Roden *et al.*, 1987), the Shannon Estuary (Jenkinson, 1990) and Galway Bay (Cronin, 1987). Estuarine zooplankton studies also include Killary Harbour (Ryan *et al.*, 1986), the Shannon Estuary (Hensey, 1980) and Galway Bay (Fives, 1967). However, some of these studies were qualitative and few recorded temporal variation in plankton abundance. All studies were specific to

(a)

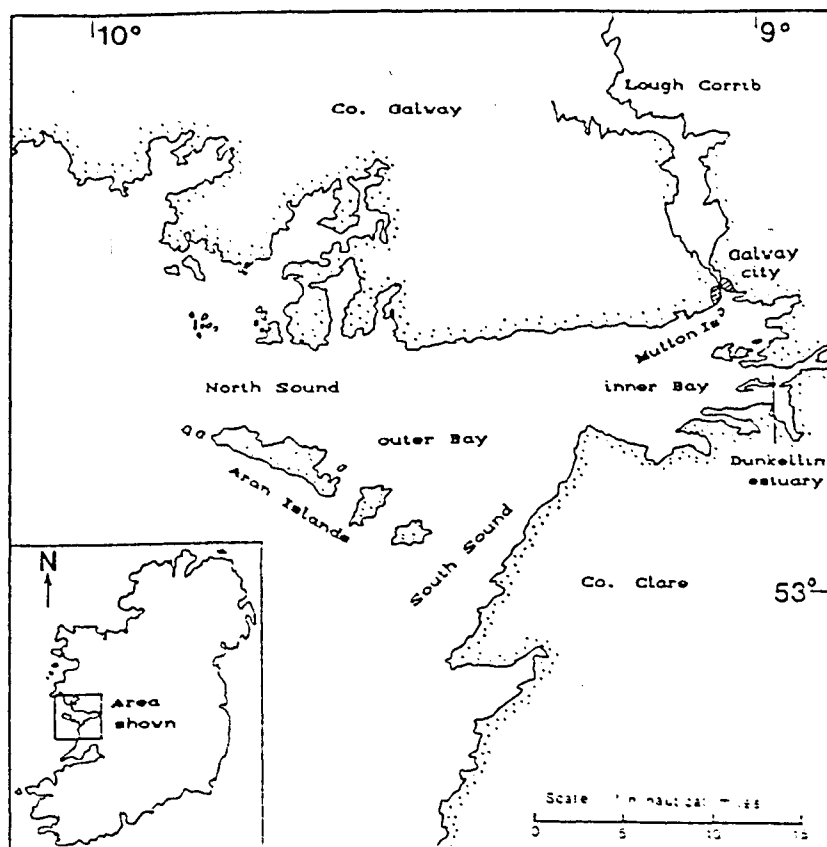
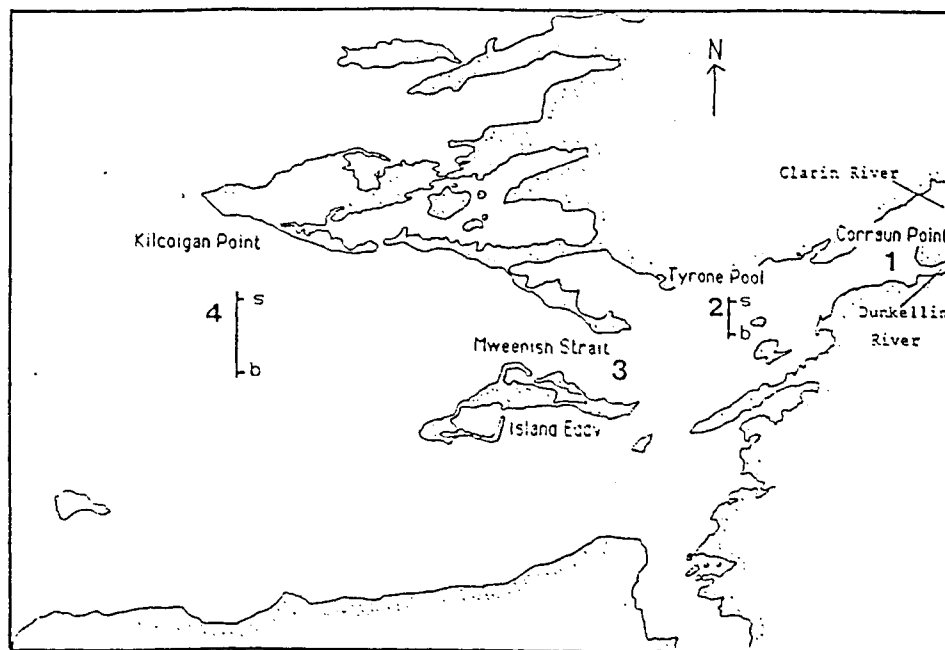


Fig. 1 Dunkellin Estuary, showing (a) location and (b) sampling stations (s=surface, b=bottom).

(b)



either phytoplankton or zooplankton and none of them included the microzooplankton.

Estuarine plankton varies in both species composition and abundance, and the diversity of the endemic component depends mainly on the reproductive rate and the flushing time of the estuary (Perkins, 1974). The plankton, therefore, reflect the inherent variability of a specific estuary. To determine the extent of such variability in an Irish estuary, we compare and examine the composition, distribution and abundance of phytoplankton, microzooplankton and mesozooplankton from two positions within the Dunkellin estuary over an 18-month period.

Study Area

The Dunkellin Estuary ($53^{\circ} 36' \text{ N}$, $8^{\circ} 54' \text{ W}$) (Fig. 1) lies at the south-eastern end of Galway Bay, and covers an area of approximately 19 km^2 . The Clarin and Dunkellin rivers are the main freshwater sources and have a catchment area of approximately 500 km^2 . The average combined monthly discharge of the rivers during the study period was $8.0 \text{ m}^3/\text{s}$ (minimum = $2.2 \text{ m}^3/\text{s}$, maximum = $18.4 \text{ m}^3/\text{s}$). The depth of the estuary varies from less than 1 m at the river mouths, with a variety of shallow and deeper channels along its length, to a depth of approximately 10 m at the seaward end.

The longitudinal axis of the Dunkellin Estuary runs east-west, and the current flow on ebb and flood tides is generally parallel to this. Maximum current speeds occur at the surface and increase down stream. Current speeds are highest along the central axis of the estuary. Tides are diurnal with a mean spring and neap tide range of 4.7 m and 1.9 m respectively. The dominant process is tidal mixing. The estuary has a large tidal compartment and a small residual volume (Byrne, 1990).

Materials and methods

Between December 1984 and July 1986, sampling was carried out at four stations (Fig. 1) on twenty nine cruises. Sampling took place monthly, and bi-weekly during the spring. At all stations a Secchi disc was lowered to extinction to determine water transparency. Water temperature and salinity profiles were obtained at 1 m intervals from

surface to bottom, using a temperature and salinity bridge (Electronic Switchgear, type MC5). Water samples were taken at surface, mid and bottom depths with 9-litre Van Dorn samplers (Van Dorn, 1956) for nutrients (see O'Mahony, 1992), plant pigments (chlorophyll *a*) and phytoplankton/microzooplankton samples. Chlorophyll *a* samples were filtered onto Whatman GF/F filters and frozen until returned to the laboratory and analysed using the methods of Strickland and Parsons (1972). Quantitative phytoplankton/microzooplankton samples (in duplicate) were stored in 30ml Sterilin bottles and preserved in Lugol's Iodine (Thronsdon, 1978). In the laboratory phytoplankton samples were gently shaken 100 times to redistribute the plankton evenly throughout the bottle. Samples were then 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, 1979). Results are given in cells per litre (cells l⁻¹). The major components of the microzooplankton were grouped and recorded as non-tintinnid ciliates and tintinnid ciliates. Micrometazoans (planktonic larvae) are included in the mesozooplankton.

Mesozooplankton were sampled quantitatively using 12.5 cm diameter, open-closing Clarke-Bumpus plankton samplers (Clarke and Bumpus, 1940), fitted with monofilament nylon nets of mesh aperture 0.16mm. Horizontal hauls were taken simultaneously 1m from the surface (s) and 1m from the bottom (b) at station 2 (Tyrone Pool) and station 4 (Kilcolgan Point), and at 0.5-1m depth at station 1 (Corraun Point). Tows were made at a speed of approximately 2 knots for 10 minutes. The volume of water filtered on each tow was calculated from the revolutions registered by the flowmeter on each sampler. This varied from 5 m³ to 13 m³ (\bar{x} = 8.5 m³). Samples were preserved in 4% buffered formalin in seawater. In the laboratory large or scarce organisms were counted directly from the total sample. Subsampling for more numerous organisms followed a standardised procedure using a Stempel pipette (Frolander, 1968). Animals were sorted and identified, and the number per m³ was calculated for each species or group.

Results

Results for all parameters are only given here for the inner estuary (station 1) and the outer estuary (station 4b).

Hydrographic features

Seasonal changes in temperature and salinity at stations 1 and 4 are shown in Figure 2, to illustrate the general hydrographic features of the estuary. Salinity varied between S 4.5 and S 34.5. A horizontal salinity gradient was apparent along the axis of the estuary, with lowest salinities recorded at the surface at station 1 and highest salinities at the bottom at station 4. Salinities at station 1 varied between S 4.5 to S 32.3 at the surface but were usually greater than S 28 at the bottom. Salinities at station 4 fluctuated between S 22.9 and S 33.76 at the surface and indicate that this station is least under the influence of river discharge. Bottom salinities at station 4 were less variable, ranging from S 32 to S 34.5. Water temperatures varied between 4.2 °C in January 1985 and 18.5 °C in July 1986. Temperature gradients were never greater than 0.5 °C to 1.0 °C over the whole length of the estuary from station 1 to station 4. No thermoclines were evident during the study period.

Phytoplankton

The seasonal distribution of total phytoplankton numerical abundance at stations 1 and 4b are presented in Figure 3(a). Maximum abundances were recorded between March and November, with concentrations in the summer months, May to August, exceeding those of the spring or autumn. Lowest concentrations were observed between December and February. Cell concentrations were generally an order of magnitude greater in the inner estuary (station 1) than in the outer estuary (station 4b).

Diatoms, dinoflagellates and microflagellates were almost equally important components of the phytoplankton. All three groups generally showed highest abundance in the months between March and November (Fig. 3(a),(b),(c)). Lower concentrations of all groups were observed at station 4b than station 1. Microflagellates were only evident at station 4b during May 1985 and between March and June

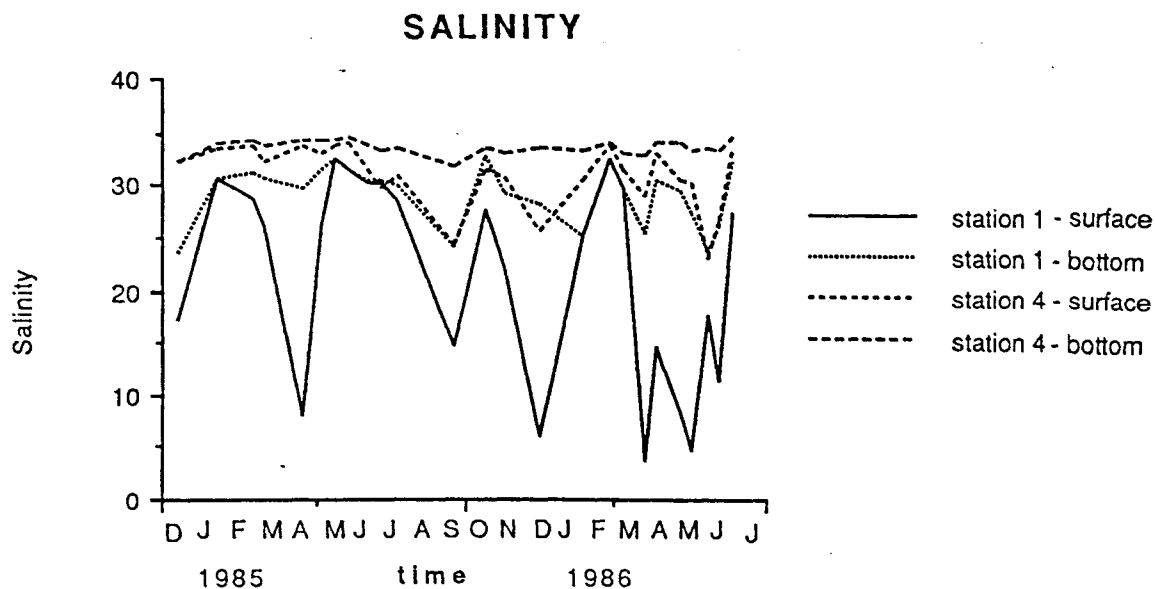


Fig. 2(a) Temporal distribution of salinity at stations 1 and 4.

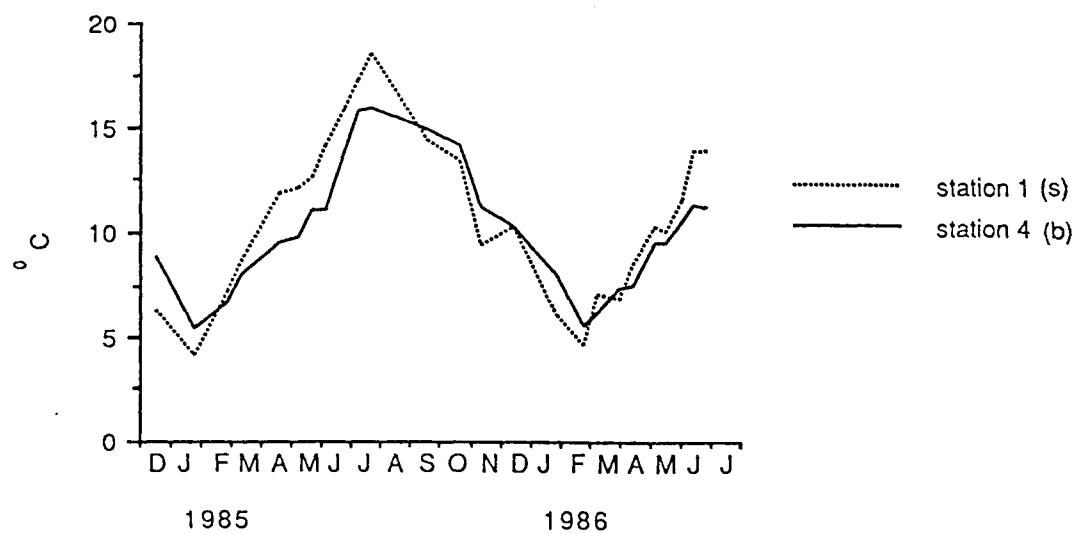


Fig. 2(b) Temporal distribution of water temperature at station 1 (surface) and station 4 (bottom).

1986, whereas they were recorded at station 1 on almost all sampling occasions.

A series of peaks in diatom abundance occurred throughout the growing period. These peaks were often dominated by several different species. *Chaetocerus* spp. and *Thalassiosira* spp. were often dominant early in the year. The small pennate diatom *Leptocylindricus minimus* was observed in high numbers in June 1985. Other diatoms of importance were *Rizosolenia delicatula*, *Ceratium pelagica*, *T. grvida*, *T. polychorda*, *Nitzschia closterium* and *N. deliatisima*.

Dinoflagellates showed a variation in dominant species from year to year and station to station. Abundant species included *Heterocapsa triquetra*, *Gyrodinium spinifera*, *G. foliacium*, *Scrippsiella trochoidea*, *Glenodinium foliaceum*, *Dinophysis acuminata*, *Ceratium lineatum*, *Prorocentrum micans*, *Gmnodinium splendens* and *Gonyaulax polyhedra*.

Microflagellates were dominated in the spring by the Euglenophyte *Eutreptia marina*, *Rhodomonas? minuta* and *Apedinella spinifera*. Other important species observed later on in the year included *Pyramimonas* sp. and *Chrysochromulina* sp.

Chlorophyll a

Chlorophyll *a* concentrations are frequently used to estimate phytoplankton standing crop (Lehman, 1981). Chlorophyll concentrations in the Dunkellin Estuary (Fig. 3(e)) varied from less than 0.1 mg/m³ in the winter, to a peak of 14.5 mg/m³ in April 1985. Highest levels were recorded between April and September. Concentrations were frequently higher at station 1 than at station 4b.

Microzooplankton

The seasonal distribution of total microzooplankton abundance at stations 1 and 4b is shown in Figure 4(a). The seasonal trend in cell concentrations appeared to follow that of phytoplankton abundance. The highest cell concentrations were observed from February to June 1985, November 1985 and May and June 1986. at station 1. Lower cell concentrations were recorded in the outer estuary at station 4b. At

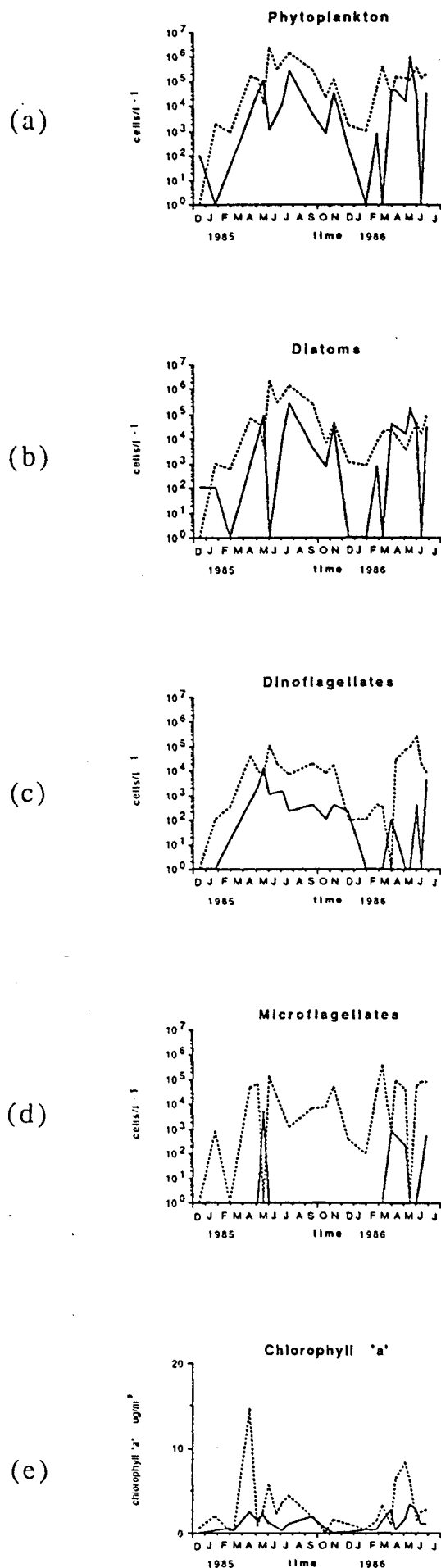


Fig. 3 Abundance of (a) Total Phytoplankton cells, (b) Diatoms, (c) Dinoflagellates, (d) Microflagellates and (e) Chlorophyll *a* concentrations ($\mu\text{g}/\text{l}$) at station 1 (-----) and station 4b (—).

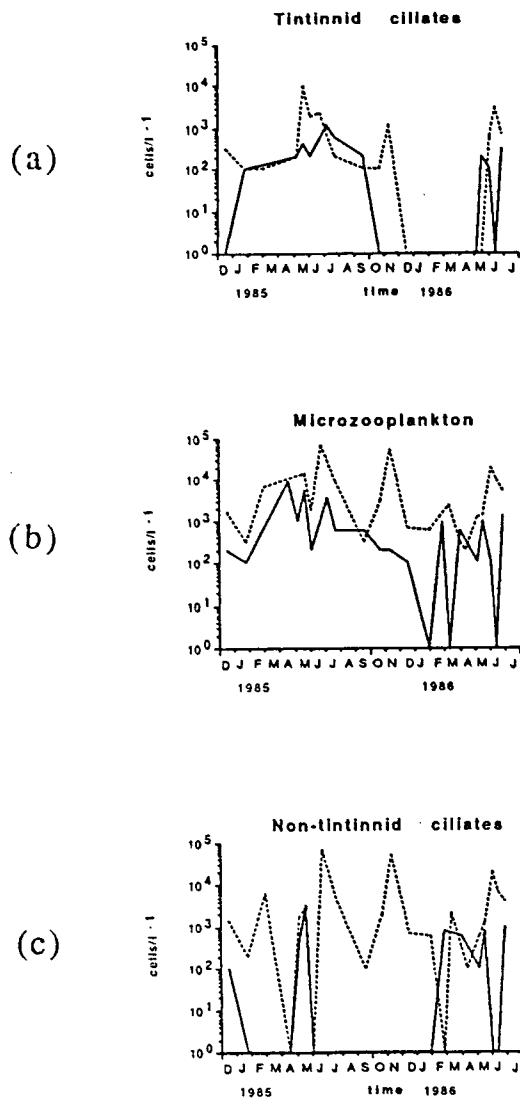


Fig. 4 Abundance of (a) Total microzooplankton, (b) Non-tintinnid ciliates and (c) Tintinnid ciliates at station 1 (-----) and station 4b (——).

station 1, non-tintinnid ciliates (Fig. 4(b)) showed several peaks in abundance throughout the sampling period. Numbers were less frequently observed in the outer estuary at depth (station 4b) and in 1985 were only recorded once, in May. Tintinnid ciliates (Fig. 4(c)) were less abundant than non-tintinnid ciliates. Distinct seasonal peaks in abundance were observed in May and June of both years and in November 1985. Tintinnid ciliates were not recorded at either station 1 or 4b in the months between December 1985 and May 1986.

The most common non-tintinnid ciliates were *Strombidium* sp. and *Mesodinium rubrum*. The dominant tintinnid ciliates were *Helicostomella subulata*, *Tintinnopsis* spp., *T. urnula* and *Savella* spp.

Mesozooplankton

The seasonal abundance of total mesozooplankton is presented in Fig. 5(a). The mesozooplankton was most abundant from January to July 1985 and from February to June 1986. The holoplankton, dominated by copepods (Fig. 5(b)), and the meroplankton (Fig. 5(c)), the two components of the mesozooplankton, have slightly different times of maximum abundance (Fig. 6). During early spring (February/March) the meroplankton dominated the plankton and mainly consisted of cirripede and polychaete larvae. This pulse receded rapidly in April, as a result of the settlement of larvae of benthic organisms and the increase in the holoplankton population. A small midsummer peak of meroplankton occurred in July, 1985, but declined thereafter and remained low during the winter months. Of the total mesozooplankton the meroplankton comprised 45% and the holoplankton 55%. The copepod population showed highest abundance during May of both years, with a small autumn peak in October/November. The high numbers of copepods recorded in the winter were dominated by the cyclopoid copepod, *Oithona nana*, a species not previously recorded in Galway Bay.

The dominant mesozooplankton were typical of neritic waters and numbers of specimens decreased from the higher salinity water of the outer estuary to the lower salinity water of the inner estuary. Dominant copepod species recorded were *O. nana*, *O. helgolandica*, *Acartia clausi*,

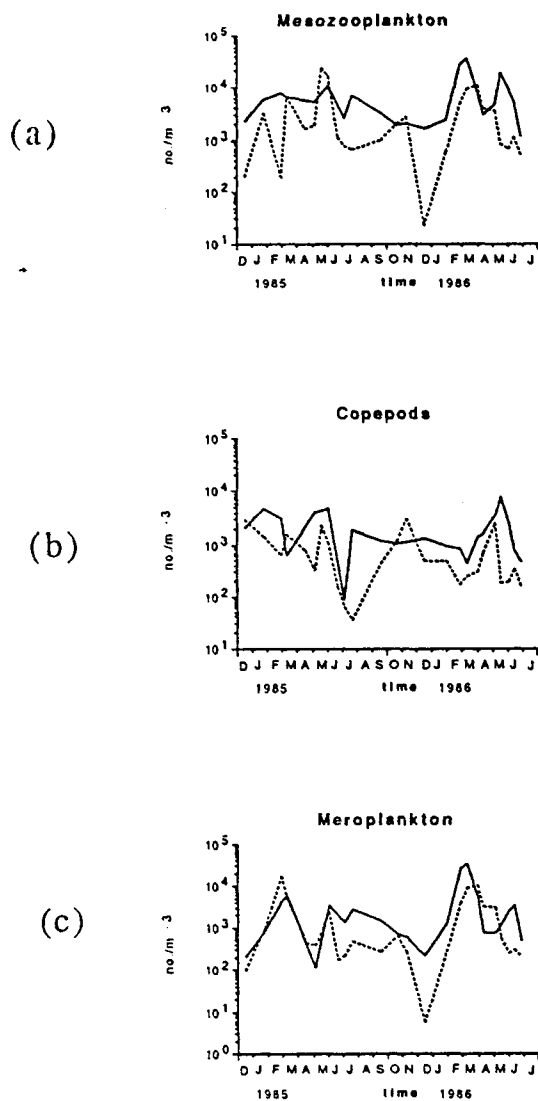


Fig. 5 Abundance of (a) Total mesozooplankton (b) Copepods and (c) Meroplankton at station 1 (-----) and station 4b (—).

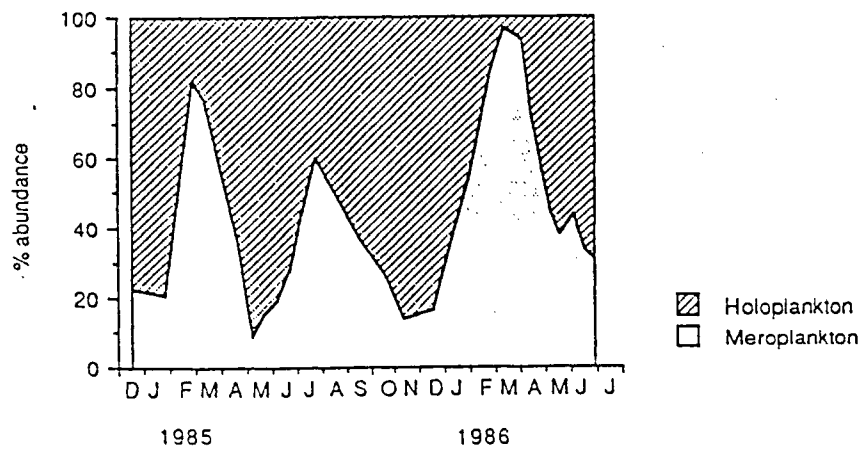


Fig. 6 Mean percentage abundance of holoplankton and meroplankton, averaged from stations 1, 2, and 4 on each cruise during the sampling period.

A. discaudata and *Centropages hamatus*. *Eurytemora affinis*, a true-estuarine copepod, was recorded in low numbers in the inner estuary.

Discussion

The seasonal distribution of phytoplankton in the Dunkellin Estuary was unimodal in appearance and closely followed the seasonal temperature profile and levels of incident radiation. Nutrients did not appear to be limited within the estuary (O'Mahony, 1992), with continual sources from river input. The highest phytoplankton concentrations were recorded in the warmer/lighter periods of the year from April to September. Similar distributions have been documented in the Kiel Bight, Germany (von Bodungen, 1975) and in Narragansett Bay, U.S.A. (Hulsizer, 1976).

Microzooplankton distributions closely followed the phytoplankton pattern. Their small size and inherently fast metabolic and growth rates (Sorkin, 1981; Porter *et al.*, 1985) permit a rapid response to incipient phytoplankton growth rate. Non-tintinnid ciliates were more abundant than tintinnid ciliates, which could be related to their ability to utilise a wider variety of food sources, like bacteria and nanodetritus (Revelante & Gilmartin, 1987) during winter periods of low food concentrations.

The mesozooplankton were most abundant in the early spring and summer. The meroplankton dominated the zooplankton in February/March, the larval release coinciding with the increase in phytoplankton as available food. Copepod production occurred slightly later, with maximum abundances in May. The spring phytoplankton increase probably serves as a trigger for zooplankton reproduction (Williams & Lindly, 1980; Krause & Trahms, 1982). The latter found that the time lag between peaks of occurrence of diatoms and copepod eggs was only three days, and that between diatoms and the release of benthic larvae was five days, thus accounting for the time lag between the two peaks; as copepods may take several weeks to develop from egg to adult.

The rapid decline of mesozooplankton in the summer months of June and July may have been caused by predation by the ctenophores *Pleurobrachia pileus* and the carnivorous scyphomedusae, *Aurelia*

auritia and *Chrysaora hysocella*, which were visually observed in the water column. Yip's (1980) study of ctenophores in Galway Bay demonstrated the important effect of *Pleurobrachia pileus* on controlling the population dynamics of copepods in the Bay. The reduction of the copepod population may also allow for an increase in phytoplankton concentration, due to a relaxation of grazing pressure by copepods.

The plankton within the Dunkellin estuary showed variable horizontal distributions. Higher concentrations of phytoplankton and microzooplankton were observed in the inner estuary, at station 1, than in the outer estuary at station 4b. Mesozooplankton had a reverse distribution, with higher concentrations in the outer estuary. The presence of the true-estuarine calanoid copepod *Eurytemora affinis* in the inner estuary indicates a residence time for the water of several weeks, or at least the length of the life cycle of the copepod. This indicates a more stable water mass, which, with higher nutrient levels and slightly higher temperatures than the outer estuary, would enable phytoplankton populations to reach high concentrations without being flushed out of the estuary. The mesozooplankton, which are almost all of neritic or coastal origin, are brought in with the tidal currents. Their lower concentrations in the inner estuary would, therefore, have a reduced impact upon the phytoplankton population. Microzooplankton, as 'microfiltering' organisms, probably replace the majority of mesozooplankton as the consumers of particulate matter within the inner estuary. Their high metabolic rate and a rapid recycling of organic material probably accounts for the continual high concentrations of phytoplankton in the summer months, despite grazing pressure.

The lower concentrations of both phytoplankton and microzooplankton and the higher abundance of mesozooplankton at station 4b, indicates that processes of more indicative of coastal/marine conditions are probably taking place there.

The Dunkellin estuary exhibits a range of conditions, from true-estuarine to marine. This study demonstrates the variation in plankton abundance over a short horizontal scale and emphasises the potential

importance of the microzooplankton in the energy flux of the estuarine food web.

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