

# SEASONALITY OF ECHINODERM PLANKTON IN LOUGH HYNE MARINE NATURE RESERVE

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## ABSTRACT

Zooplankton was sampled almost monthly over a two-year period in and immediately outside Lough Hyne Marine Nature Reserve, Co. Cork, Ireland. In the laboratory, echinoderm larvae were isolated and counted at class level. Mean numbers of all echinoderm larvae and of the separate classes thereof were calculated for the three sites sampled. Echinoderm larvae showed peaks of abundance in spring and summer and were virtually absent in winter. Peaks of abundance at sites in Lough Hyne occurred in July and consisted mainly of asteroid larvae. Peaks of abundance in a coastal site immediately outside Lough Hyne consisted mainly of ophiuroid larvae. Holothuroid larvae were rare, and crinoid larvae were not found. The results of three-factor ANOVA with date, class and site as fixed factors revealed differences between the separate classes and between sites. The environmental parameters of each site—substrata, water exchange, current—and associated echinoderm benthos appeared to influence the echinoderm plankton.

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## INTRODUCTION

Information on the breeding seasons of littoral and benthic invertebrates is often inferred from larval presence in plankton samples (e.g. Marshall 1948; Rees 1954; Pedrotti 1993; Byrne 1995; Lamare 1998; Stanwell-Smith *et al.* 1999). The larvae of echinoids and ophiuroids feature most commonly in literature on echinoderm plankton in Europe (e.g. Chadwick 1914; Marshall 1948; Gotto 1951; Rees 1954; Boyd 1972, 1973; Pedrotti 1993; Williams *et al.* 1993; Byrne 1995; Feldman 1995; Lindley *et al.* 1995; Pedrotti and Fenaux 1996), mainly because their physical structure is more robust than that of the other classes (Hyman 1955).

Most echinoderm species that possess a planktonic larva in temperate waters have recognised breeding seasons. These seasons occur because of the influence of environmental and other exogenous factors on maturation, gametogenic cycles and spawning (Giese and Pearse 1974). Food availability and quality (e.g. Nichols and Barker 1984a; 1984b; Costelloe 1985; Nichols *et al.* 1985), photoperiod (e.g. Scheibling 1981; Pearse and Eernisse 1982; Pearse and Beauchamp 1986; Pearse and Walker 1986; Pearse *et al.* 1986) and temperature change (e.g. Scheibling 1981; Nichols and Barker 1984a; 1984b) have all been recorded as influencing the reproductive cycles of echinoderm species.

Spawning of echinoderms has been linked to various factors including water turbulence (Pedrotti 1993), temperature change (e.g. Minchin 1987; Hamel and Mercier 1995), phytoplankton blooms (e.g. Himmelman 1975; Starr *et al.* 1990; López *et al.* 1998), tidal cycle (e.g. Babcock and Mundy 1992) and pheromones (e.g. Beach *et al.* 1975; Miller 1989). Many echinoderm species have been observed to aggregate before spawning or to spawn synchronously, increasing potential fertilisation success even when individuals are not close to conspecifics (Pearse *et al.* 1988; Minchin 1992; Byrne 1999).

The fauna and ecology of Lough Hyne, a semi-enclosed sea lough in south-west Ireland (Fig. 1), have been extensively researched (see Renouf 1931; Kitching 1987; Myers *et al.* 1991). However, the zooplankton of Lough Hyne has received relatively little attention, with recent work focusing on the hydromedusae (Ballard and Myers 1997; 2000) and copepoda (Holmes 1981, 1985). This study assesses the seasonality of echinoderm larvae in Lough Hyne. Samples were also taken from outside the lough to test for the influence of site location, physical parameters and associated benthos on the echinoderm larval supply.

## MATERIALS AND METHODS

Plankton samples were taken from permanent buoys at two locations in Lough Hyne, Western

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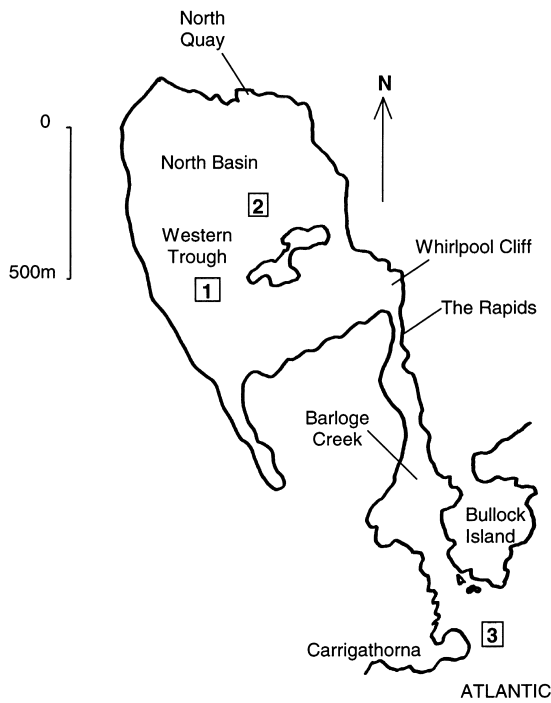


Fig. 1—Map of Lough Hyne showing Sites 1 (Western Trough), 2 (North Basin) and 3 (Barloge Mouth).

Trough (Site 1) and North Basin (Site 2), and from the mouth of Barloge Creek (Site 3) (Fig. 1). These locations were chosen because they are close to each other (Table 1). Samples were taken almost monthly from November 1997 to October 1999 in the Western Trough and at the mouth of Barloge Creek, and from May 1998 to October 1999 in the North Basin. Vertical hauls were taken from 20m depth using a net of 30cm mouth diameter and 100 $\mu$ m mesh. Three replicate samples were taken in each case.

Samples were sieved, rinsed and stored in 4% buffered seawater formalin. In the laboratory, excess formalin was carefully poured off and the samples were diluted with filtered seawater. The samples were then sorted using a Bogorov trough, and any echinoderm larvae were isolated. Larvae were identified using the following sources: Chadwick (1914), Mortensen (1937), Newell and Newell (1977), Smith (1977), Buckley (1980), Todd and Laverack (1991) and Feldman (1995).

Table 1—Description of sampling sites.

| Site              | Depth (m) | Substrata and physical characteristics              |
|-------------------|-----------|---|
| 1. Western Trough | 50        | Soft sediment, low water flow                       |
| 2. North Basin    | 20        | Soft sediment, shallow slope, negligible water flow |
| 3. Barloge Mouth  | 20–24     | Sand, gravel, close to cliffs and exposed shore     |

The filtration rate of the net was not calculated, and hauls were considered to sample an equal volume of water, approximating 1.41m<sup>3</sup>. The mean number and SE of individual classes of echinoderm larvae per m<sup>3</sup> were calculated. Abundances of each class were calculated as  $\log(x + 1)$  individuals per m<sup>3</sup> using the sum of all three replicate samples. These data were graphed but not analysed. Numbers of each class on comparable dates from 1998 and 1999 were compared using ANOVA. The 1998 data were transformed by  $\log(x + 1)$ , and the 1999 data by  $\log(x + 0.1)$ . Multiple comparisons were carried out using Student–Newman–Keuls tests. Interannual differences in abundances of total echinoderm numbers were analysed using  $\log(x + 1)$ -transformed data. The computer package GMAV5 was used for ANOVA analysis.

Echinoid, ophiuroid and asteroid larvae were sorted to developmental stage. The development stages of asteroids are gastrulae, auricularia, early bipinnaria, bipinnaria, bipinnaria–brachiolaria and brachiolaria (Barker and Nichols 1983); of echinoids, early, mid- and late larvae (Pedrotti 1993); and of ophiuroids, early, mid-, late and post-larvae (Pedrotti 1993). Holothuroid larvae were not sorted because of low numbers, and crinoid larvae were not found. The abundances of each developmental stage at each of the three sites were compared.

The gross amount of zooplankton in the different sites was measured as the volume of settled plankton in each sample. A note was made of samples containing high levels of phytoplankton, which would bias measurement. Samples containing visible debris were not measured. Large individual zooplankters such as ctenophores were removed before measurement. Differences between sites were tested using ANOVA on  $\log(x + 1)$ -transformed data.

Observation of any spawning echinoderms during the sampling period was recorded.

## RESULTS

Echinoderm larvae were absent from all three sites in samples taken in December 1998 and January and October 1999, and reached a maximum of 156m<sup>-3</sup> in July 1998 at Site 3 (Fig. 2). Signifi-

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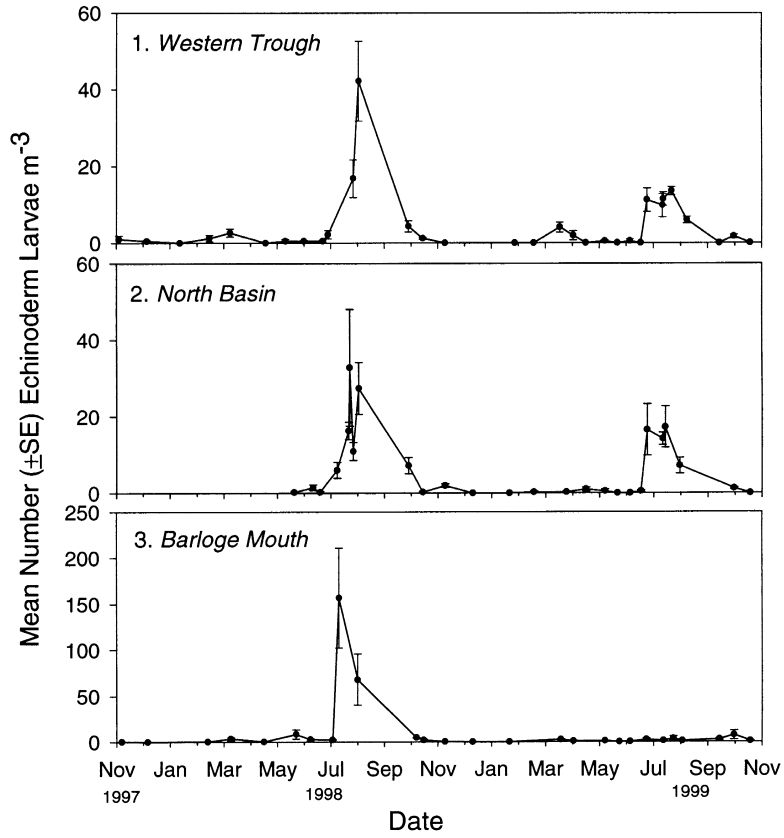


Fig. 2—Seasonality of total echinoderm plankton at three sites, shown as mean number  $\pm$  SE of individuals per  $m^3$ . Note the different scales used.

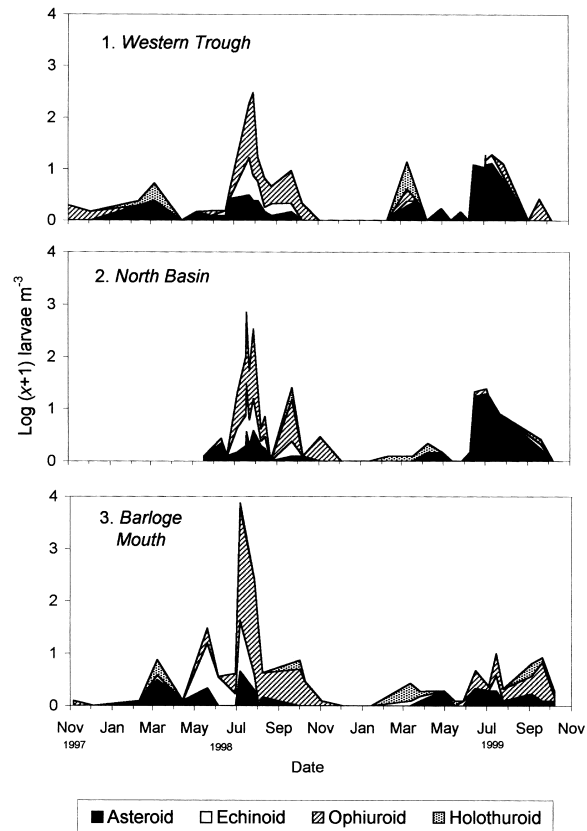


Fig. 3—Seasonality and class composition of echinoderm plankton at three sites.

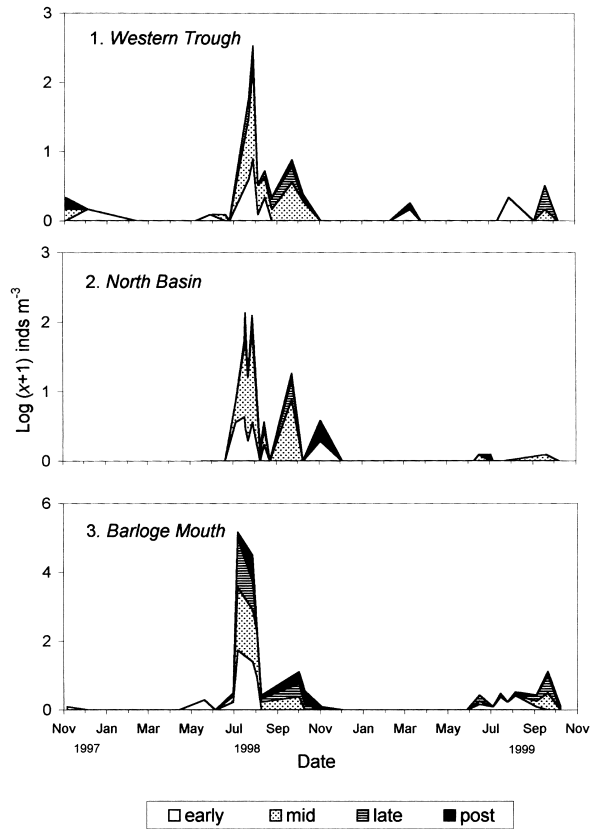


Fig. 4—Stages of ophiuroid larvae at Sites 1–3. Note the different scales used.

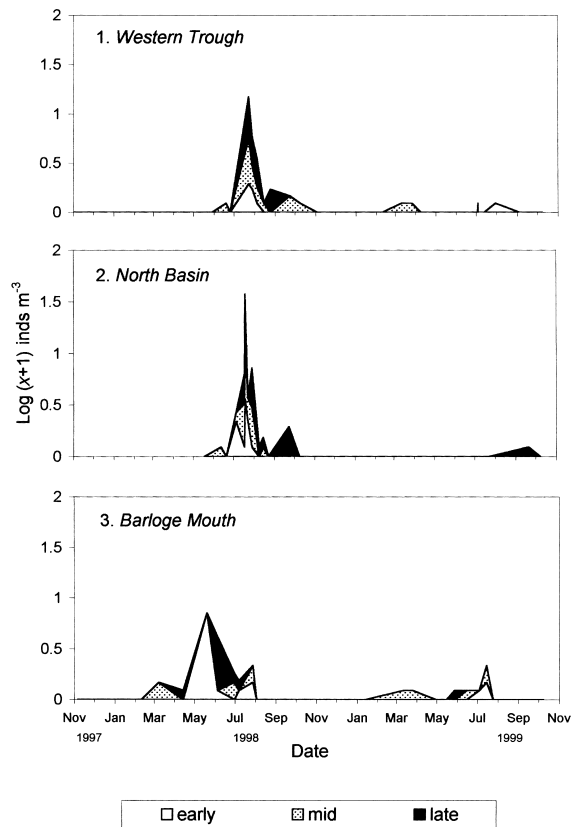


Fig. 5—Stages of echinoid larvae at Sites 1–3.

cantly higher numbers of echinoderm larvae were recorded in 1998 than in 1999 (ANOVA: Site 1: d.f. = 12,  $F = 2.55$ ,  $P < 0.01$ ; Site 2: d.f. = 6,  $F = 12.37$ ,  $P < 0.001$ ; Site 3: d.f. = 10,  $F = 12.35$ ,  $P < 0.001$ ), with peaks of abundance in July 1998 at all three sites, and in July 1999 at Sites 1 and 2. The 1999 peak of abundance at Site 3 was both delayed (occurring in late September) and reduced. The peak of echinoderm larvae observed at all sites in 1998 consisted mainly of ophioplutei, whereas asteroid larvae were dominant at Sites 1 and 2 in 1999 (Fig. 3).

The results of three-factor ANOVA revealed a significant class-site-date interaction in both 1998 (d.f. = 30,  $F = 2.45$ ,  $P < 0.001$ ) and 1999 (d.f. = 48,  $F = 4.69$ ,  $P < 0.001$ ). In both years asteroid larvae were found at higher abundances at Sites 1 and 2 than at Site 3 (results expanded from statistical analysis). Echinoid larvae were more common in 1998 than in 1999 and more common at Site 3 than at the other two sites. Ophiuroid larvae were found mainly at Sites 1 and 3 in both 1998 and 1999. Holothuroid larvae were not included in analysis of 1998 data because they were not recorded from dates used in the ANOVA. However, in 1999 they were found in higher numbers at Site 3 than at Sites 1 or 2 (Fig. 3).

Ophioplutei were generally more abundant in 1998 than in 1999 at all three sites (Fig. 4). During winter 1997–8 they were present but rare at Sites 1 and 3. During July and early August 1998 they were present in all developmental stages at Site 3, but from mid-August early-stage ophioplutei were absent and post-larvae were more abundant. This transition of abundance of developmental stages was also evident at this site in 1999 (Fig. 4).

At all three sites greater numbers of echinoplutei were found in 1998 than in 1999 (Fig. 5). Echinoplutei were found mainly from May to September, although low numbers were also found in Sites 1 and 3 in March 1999. The samples from Site 3 revealed many early-stage echinoplutei in May–June 1998 and a large number of late-stage echinoplutei in June–July, but there was no such transition over time at Sites 1 and 2 (Fig. 5). Many of the late-stage larvae found at Site 3 were those of spatangoid echinoids. *Paracentrotus lividus* (Lamarck) was observed spawning in July 1999 at the North Quay and on the south shore of Lough Hyne.

Asteroid larvae were more abundant at Sites 1 and 2 in 1999 than in 1998 (Fig. 6). A transition of abundance of developmental stages was evident at all sites, although late stages of development were rare. Asteroid larvae were present until October at all sites and were absent during winter 1998–9. The lecithotrophic larvae of *Henricia oculata* (Pennant) and the giant bipinnaria of *Luidia ciliaris* (Philippi) were not found, and hence the asteroid

larvae found can be presumed to be those of *Asterias rubens* L. and *Marthasterias glacialis* (L.). *Marthasterias glacialis* was observed to spawn in July of both 1998 and 1999 at the inland end of the Rapids and near the North Quay. *Asterias rubens* was not observed spawning during the sampling period.

Holothuroid larvae were the least numerous echinoderm class found in plankton samples (Fig. 3). They were found at Site 1 only in spring (January–April 1998 and February–April 1999), whereas at Site 3 two peaks evident, one in spring and one in autumn (September–October) of each year. The holothuroids found were a mixture of doliolaria (Mortensen 1937) and heavily convoluted auricularia typical of synaptids (Chadwick 1914). The larvae of crinoids were not found.

The zooplankton showed a seasonal pattern of increased gross volume during spring and summer (Fig. 7). The volumes at Sites 1 and 3 differed significantly (ANOVA: d.f. = 24,  $F = 9.72$ ,  $P < 0.001$ ), with the volume greater at Site 3 than at Site 1 on only three of the 25 dates, two of which coincided with phytoplankton blooms in Barloge Mouth.

## DISCUSSION

Zooplankton samples from two consecutive years revealed large differences in both the total numbers and the composition of the echinoderm plankton. This finding corresponds with many other studies of echinoderm plankton (Chadwick 1914; Boyd 1973; Minchin 1992; Byrne 1995; Feldman 1995; Lamare 1998).

This study investigated the influence of seasonality and location of sampling site on numbers and composition of echinoderm plankton. Regarding sampling site, differences were apparent in both the magnitude and the composition of the echinoderm plankton. The mechanism of water exchange in Lough Hyne (Minchin 1992; Johnson *et al.* 1995) may increase retention of larvae after production within the lough or after entering with the tide. The increased abundance of asteroid larvae found in Lough Hyne compared with Barloge Mouth, and in the North Basin of Lough Hyne compared with Whirlpool Cliff (Fig. 1) (Greenwood *et al.*, in press), suggests that Lough Hyne may act as a source of larvae, in a similar way to Boca del Infierno, Vancouver Island (Sewell and Watson 1993).

The sampling sites within Lough Hyne were chosen to reflect depth differences and to investigate possible retention within the North Basin. However, within the lough itself the only apparent difference was slightly increased numbers and later stages of asteroid larvae in the North Basin com-

pared with the Western Trough. This may be due to the high density of adult *M. glacialis* near the North Quay (Greenwood *et al.* 1999), which was observed to spawn during the sampling period, or to the proximity of the North Basin sampling site to areas of potential settlement (Buckley 1980).

The composition of the echinoderm plankton may reflect the different populations of adult echinoderms in the given sampling site. For example, dense beds of ophiuroids are not present in Lough Hyne (A. Greenwood, pers. obs.), whereas they are found in coastal areas experiencing higher levels of tidal streams (Keegan *et al.* 1985). Boyd (1973) found ophioplutei to be the most common type of echinoderm larvae in Strangford Lough. Ophioplutei and echinoplutei were found to occur at significantly higher levels outside Lough Hyne than within it. Indeed, only asteroid larvae occurred at higher levels in the plankton within Lough Hyne, reflecting the higher densities of adult asteroids at certain sites inside the lough than outside (Greenwood *et al.* 1999).

Based on known adult breeding seasons, the low numbers of echinoplutei found in March may have been those of *Echinus esculentus* L. (Chadwick 1914; Nichols *et al.* 1985), whereas those found later in the year (May–September) were more likely those of *Paracentrotus lividus* (Byrne 1990; Minchin 1992). Within Lough Hyne the site of highest density of *Echinus* is near the site of tidal exchange with the open sea, perhaps leading to low numbers in the plankton inside the lough. *Paracentrotus* is locally abundant only in certain sites in Lough Hyne (Barnes *et al.* 1999). Although this species was observed to spawn during the sampling period, the reproductively active population of *P. lividus* in Lough Hyne was estimated to be only approximately 2100 individuals in 1995 (Barnes *et al.* 1999). With fertilisation success highly dependent on proximity of conspecifics (Pennington 1985) and given high larval mortality rates in the plankton (Morgan 1995), it is perhaps not surprising that echinoplutei densities were low. Spatangoplutei were only rarely found in samples taken from within Lough Hyne. The spatangoid *Echinocardium cordatum* (Pennant) is rare in Lough Hyne (Thrush 1991), whereas it is abundant in sandy areas outside the lough (A. Greenwood, pers. obs.).

Of the species of ophiuroid present within Lough Hyne and possessing a planktonic larva, all are reported to be summer breeders (Bowmer 1982; Hendler 1991). A number of the later stages collected were identified as those of *Ophiothrix fragilis* (Abildgaard), a species abundant both within and outside Lough Hyne (Renouf 1931). The ophioplutei found in the Western Trough in winter may also have been of that species (*sensu* Hendler 1991). That there was some transition of

abundance of developmental stages of ophioplutei suggests that there may be some synchrony of spawning (Pedrotti 1993).

Because asteroid larvae at Lough Hyne tend to be found more at depths of 6m and less (Greenwood *et al.*, in press), larvae that leave Lough Hyne with the tide would be rapidly dispersed by surface currents and swell. There was evidence of both a spring (March) and summer (June–July) spawning. The first peak may be that of *A. rubens*, which is reported to spawn in spring, with larvae present in March–June (Barker and Nichols 1983). The second period of asteroid larval abundance corresponds with the reported breeding season of *M. glacialis* (Buckley 1980; Nichols and Barker 1984b) and with observations of spawning (Minchin 1987; A. Greenwood pers. obs.). Tattersall and Sheppard (1951) state that Lough Hyne is ‘not the natural home of *Luidia*’ and that larvae enter the lough only under the right combination of wind and current. It should also be noted that juvenile *L. ciliaris* was not observed during detailed survey dives in Lough Hyne (Greenwood 2000), and hence it appears that the reproductive output of *L. ciliaris* in Lough Hyne is low. The low numbers of late-stage asteroid larvae may reflect mortality in the plankton (Morgan 1995) or be due to late-stage larvae selecting settlement sites in shallow areas (Buckley 1980).

Pedrotti (1993) found holothurian larvae to be absent in summer and rare throughout the rest of the year. The spring peak of holothurian larvae found in this study may be due to local spawning of *Aslia lefevrei* (Barrois), which was reported to breed from February to April in Galway Bay (Costelloe 1985) and which occurs at high densities on the cliffs of Bullock Island and Carrigathorna (A. Greenwood, pers. obs.). Adult crinoids are absent from Lough Hyne but are abundant at cliff sites immediately outside Barloge Creek. This may be due either to larval supply not entering the lough through the Rapids or to a lack of suitable settlement sites. However, because larval crinoids, which are short-lived and lecithotrophic (Mortensen 1921), were not found in this study, no conclusion can be reached on the causes of their adult distribution.

The low densities of echinoderm larvae found in this study compared with, for example, Ryan *et al.* (1986) in Killary Harbour and Byrne (1995) in the Dunkellin Estuary, Galway Bay, may be due to a number of factors. The two earlier studies involved shallow tows; because echinoderm larvae tend to be found more in surface than in deeper waters (Pedrotti 1993; Sewell and Watson 1993; Medeiros-Bergen *et al.* 1995; Stanwell-Smith *et al.* 1999; Greenwood *et al.*, in press) a sampling protocol of this type would presumably collect more echinoderm larvae. Patchiness of larvae may mean

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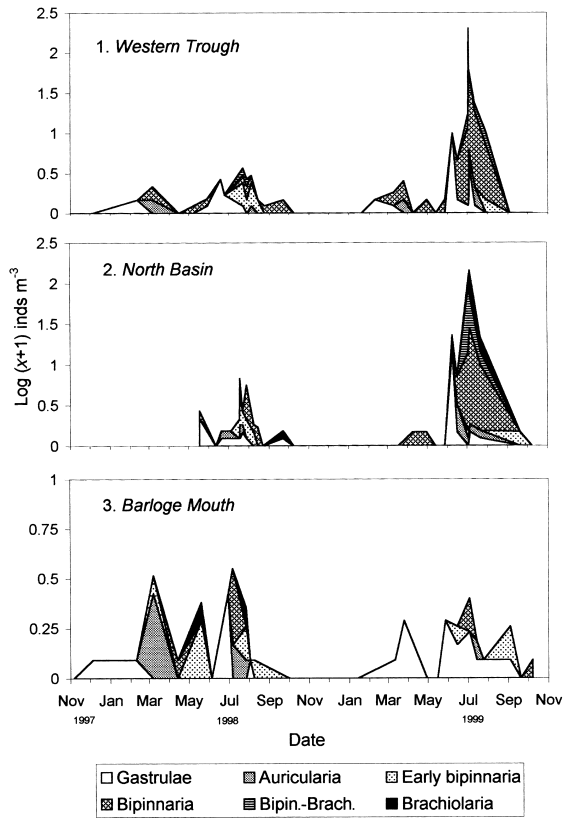


Fig. 6—Stage of asteroid larvae at Sites 1–3. Note the different scales used.

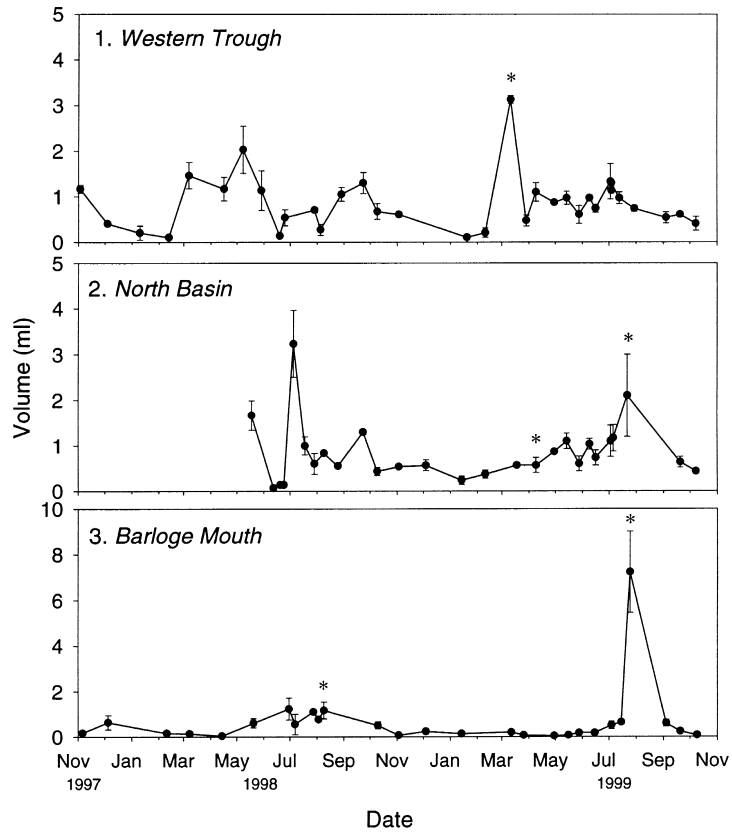


Fig. 7—The mean gross volume of zooplankton in samples from Sites 1–3, shown as mean  $\pm$  SE; \* = sample containing visible phytoplankton. Note the different scales used.

that 'swarms' of larvae are missed by vertical hauls (Omori and Hamner 1982). Echinoderm larvae are thought to act as passive, neutrally buoyant particles (Banse 1986), under mainly hydrographic influences, and so, again, a small mouth diameter of net and limited haul time may mean that patches of larvae are missed. There is no evidence that echinoderm larvae are capable of net avoidance (Clutter and Anraku 1968) or vertical migration (Banse 1986). It is also possible that there were low levels of spawning during the time of sampling because of factors such as temperature, turbulence and phytoplankton blooms.

Overall, the gross amount of zooplankton followed a similar trend to that of the echinoderm plankton, with increased levels in spring and summer and increased levels at sites within Lough Hyne compared with immediately outside.

In conclusion, the echinoderm plankton showed seasonal variation, with increased numbers found in summer. This finding correlates well with the agreed breeding seasons of temperate echinoderms. There appeared to be some larval retention within Lough Hyne, demonstrating that even species with planktonic larvae and the capability of dispersal may settle close to parent populations, possibly resulting in genetic differentiation (Lamare 1998). Genetic testing of adults (Hunt 1993) and larvae (Medeiros-Bergen *et al.* 1995) would aid the study of dispersal of these species.

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