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Temporal and spatial variability in the recruitment of barnacles and the local dominance of *Elminius modestus* Darwin in SW Ireland

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Abstract

Deployment of processed natural substrata is a common method of investigating early settlement and recruitment processes, but has been under-utilised as a multi-depth method for barnacle study and analysis. Replicate, machined-slate panels (15 cm×15 cm×1 cm) were placed at 0 m (lower portion of the intertidal with ≈2 h emersion per tidal cycle), 6 m and 12 m at two sites of differing flow rate in Lough Hyne, SW Ireland. These panels were replaced serially every 30–60 days for a period of 3 years (2000–2003) to give monthly recruitment rates. Panels were also submersed for 60–120 days (Whirlpool Cliff, two locations) to show seasonal patterns and 370–400 days (Labhra Cliff) to show annual recruitment and survival patterns. The number, percentage cover and identity of all cirripede recruits were recorded. The greatest source of variability was with depth: between the intertidal (with many recruits) and the subtidal zones (few recruits). In general, intertidal recruitment was dominated by the introduced barnacle *Elminius modestus* Darwin. The high degree of water retention in Lough Hyne, combined with the high reproductive potential of *E. modestus*, has led to it becoming a self-perpetuating and locally dominant population. *Balanus crenatus* and *Verruca stroemia* dominated the longer immersed panels, highlighting the importance of post-recruitment processes to the survival of *E. modestus* recruits in the subtidal. Although *E. modestus* were found on subtidal monthly and seasonal panels, none were present on the subtidal annual panels. Temporally, month, season and time of placement were all found to be significant in explaining recruit number variability. Spatially, depth explained most variability of recruit numbers (6 m spatial separation), whilst site (≈200 m spatial separation) only ever being significant in combination with other factors, as was location (≈50 m spatial separation). The work highlights the importance of examining both temporal and spatial scales when investigating recruitment and post-recruitment processes of marine invertebrates, including introduced species.

Keywords: recruitment; panel substrata; *Elminius modestus*; Cirripedia; barnacles; rocky shores; introduced species; invasions

1. Introduction

Few studies have investigated the recruitment of marine invertebrates, including cirripedes on a multi-depth basis simultaneously – normally either intertidal or subtidal recruitment is examined. One previous study showed a competitive variability among species with

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depth (Crisp and Chipperfield, 1948). Given the changing population structures of adult barnacles (in response to invasive species) in the rocky intertidal zone across Europe (Knight-Jones, 1948; Crisp, 1958; Barnes and Barnes, 1961, 1965; Hiscock et al., 1978; Southward, 1991; King et al., 1997) and elsewhere (e.g. Southward et al., 1998; Coles et al., 1999), a detailed study at a local scale, examining both intertidal and subtidal populations, should help to understand recruitment and survival mechanisms better for these species and, more importantly, the effects that an invasive barnacle can have on the current native barnacle populations. As well as being the site of scientific study over many decades, Lough Hyne is a very suitable study site to examine barnacle recruitment patterns at a local scale due to its diverse range of habitats within a small area and the fact that eight species of barnacles have been recorded at the Lough: – *Balanus balanus*, *Balanus crenatus*, *Chthamalus montagui*, *Chthamalus stellatus*, *Elminius modestus*, *Semibalanus balanoides*, *Verruca stroemia* (R.M. O'Riordan, pers. comm.) and *Megatrema anglicum* (J.J. Bell, pers. comm.).

There have been several prominent invasions of marine exotic species to the waters of the southern British Isles over the past 50–60 years, including into Ireland (O'Riordan, 2002). These exotics include the ascidians *Styela clava* (Minchin and Duggan, 1988) and *Perophora japonica* (Nishikawa et al., 2000), the Chinese mitten crab *Eriocheir sinensis* (Ingle and Andrews, 1976; Clark et al., 1998) and the slipper limpet *Crepidula fornicata* (Minchin et al., 1995). The most prominent, and arguably the most successful, invasive species has been the cirripede crustacean *Elminius modestus*. Initially geographically confined (Bishop, 1951), this antipodean cirripede was first thought to have been introduced to European waters via ships and flying boats during World War II (Bishop, 1947). Its first published occurrence in Ireland was nearly 50 years ago (Beard, 1957), although it was probably established in Cork Harbour, Co. Cork before then, but after 1953 (Crisp and Souhward, 1959; O'Riordan, 1996). Its first recorded presence within the area of the Lough itself was not until 30 years later in a survey by Little et al. (1992). Alterations of the barnacle populations (showing general barnacle cover increases) within Lough Hyne occurred between 1955 and 1991.This alteration in barnacle cover was due to increases in *Semibalanus balanoides* cover and *E. modestus* introduction (Little et al., 1992). There are considerable data for adult *E. modestus* populations within Lough Hyne, prompting the present recruitment study. An assessment of local barnacle recruitment, thereby gaining insight into the dominance, or lack thereof, for *E. modestus* at the recruitment stage was, therefore, deemed appropriate.

Analysis of spatial and temporal patterns in nature is essential to gain an understanding of the scales at which important ecological processes are acting (Levin, 1992). Here scales and patterns of cirripede recruitment to machined-slate panels over a three-year period from three depth zones are described. Recruitment for this study is defined as any post-metamorphosis organism, which has settled onto the substrate, and is alive at the time of substrate removal for analysis. This definition assumes a certain level of post-settlement process (including mortality, competition and predation), particularly for the substrata deployed over longer periods. The hypothesis was tested that no scale in either time (season or year) or space (depth or site/locality) dominates the pattern of recruitment. It also hypothesised that no particular barnacle species dominated cirripede recruitment at any scale.

The present study was carried out, over the years 2000 to 2003, exclusively at Lough Hyne Marine Nature Reserve, SW Ireland (51° 31′N, 9° 19′W). Lough Hyne is a small (0.8×0.6 km) sea lough linked to the Atlantic Ocean by a narrow (>20 m wide) channel, known as the 'Rapids' (Fig. 1). The salinity and temperature regimes are similar to those in the adjacent coastal Atlantic. Temperature readings were taken using continuously logged probes from four sites in the lough, at ≈3 m depth. Values rose to a maximum of ≈19.5 °C in September and fell to a minimum of ≈5.5 °C in February. The shallow, and narrow, nature of the 'Rapids' results in asymmetrical timing of inflow and outflow regimes and a reduced tidal range (up to ≈1 m) compared with the Atlantic coastline (up to ≈3.5 m). The general oceanographic and local hydrographic conditions relating to this asymmetrical tidal cycle were described by Kitching (1987). The water flow rate through the 'Rapids' can reach 2–3 ms^{-1} on both incoming and outgoing tides. Complete exchange of water in the lough with 'new' water takes approximately twenty-two tidal cycles (Kitching and Ebling, 1967). As there is bi-directional water exchange along this channel it can be expected that there is also a bi-directional exchange of larvae between the lough and the Atlantic Ocean, but the recruitment success of these larvae may vary. The surface and subsurface water flow speed and directionality have been described in some detail for Lough Hyne (Bassindale et al., 1948, 1957; Bell and Barnes, 2002).

2. Materials and methods

The present study used processed natural substrata (machined-slate panels) to examine recruitment of cirripedes. Most past cirripede studies have used existing (cleared and uncleared) substrata in situ, but this methodology was not practical for the multi-depth