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Coupling between populations of copepod taxa within an estuarine ecosystem and the adjacent offshore regions

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A B S T R A C T

Population dynamics in open systems are complicated by the interactions of local demography and local environmental forcing with processes occurring at larger scales. A local system such as an estuary or bay may contain a zooplankton population that effectively becomes independent of regional dynamics or the local dynamics may be closely coupled to a broader scale pattern. As an alternative, the details of migration and advection may mean that dynamics in a local system are coupled to other specific areas rather than tracking the overall dynamics at a larger scale. We used a reconstructed time series (1973–1987) for copepod taxa to examine the extent to which zooplankton dynamics in Galway Bay reflect processes in broader areas of the NE Atlantic. Continuous Plankton Recorder (CPR) counts were used to establish time series for nine offshore ecoregions, with the regions themselves defined using underlying patterns of chlorophyll variability. The open nature of Galway Bay was reflected in strong associations between bay zooplankton counts and offshore CPR data in a majority of cases (7/10). For each zooplankton taxon, there were large differences among regions in the degree of association with Galway Bay time series. Akaike weights indicated that one ecoregion tended to be the dominant link for each taxon. This indicates that the zooplankton of the Bay reflect more than the local modification of a regional signal and that different zooplankton in the bay may have separate source regions. The data from Galway Bay also fall within a 'sampling shadow' of the CPR. Later years of the time series showed evidence for changes in phenology, with spring zooplankton peaks generally occurring earlier in the year for smaller species.

1. Introduction

The spatial extent over which population data are collated will affect the processes that are emphasized, a point reflected in the derivations of the Stommel diagram found in biological oceanography and ecology (Stommel, 1963; Vance and Doel, 2010). Basin-scale population dynamics will therefore tend to reflect broad scale climatic processes, while small scale dynamics may reflect particular local factors. Studies of systems such as estuaries and bays often tend to emphasize how the particular features of the system shape local dynamics. For example, how the extent of tidal mixing influences the zooplankton distribution within an estuary (Villate, 1997) or how the details of the zone of maximum turbidity affect zooplankton (Modéran et al., 2010). The primacy of local hydrodynamics and ecology as explanatory variables for estuarine systems means that long term changes are often interpreted in terms of how the local conditions have changed (David et al., 2005). An exception to the locally driven view of estuarine dynamics is that an invasive species may arrive and establish in the system (David et al., 2005).

As estuaries are paradigmatically dependent on the adjoining ecosystems (Elliott and Whitfield, 2011), their internal population dynamics may be more dependent on external population sources than is generally recognised. For example interannual variation in supply from a marine source may influence the interannual variation of zooplankton within an estuary. Broad scale processes such as climate change may therefore affect a system by changing the internal state and dynamics of the system (Najjar et al., 2010) or by affecting an adjoining ecosystem that plays a large role as a source of organisms.

One way in which the role of an external area on an estuarine system can be estimated is to examine the degree of association between the populations in each location. If the population dynamics in the estuary and potential source area are uncorrelated,

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then the different locations are not linked by the movement of significant numbers of individuals or the estuarine system has local features that have sufficient influence on population dynamics so that no correlation occurs between locations. If there is a relationship between the numbers of individuals in the separate areas, then the species has distinct populations responding to similar environmental cues or the two populations are linked by the movement of individuals.

The current study examines Galway Bay, an area in a historical "sampling shadow", to test the hypothesis that local plankton dynamics are independent of patterns seen in larger adjacent areas. The alternative hypothesis is that relationships exist between the multiannual abundances of Galway Bay populations and those in the wider regions. The 'far field' influences may exist through general sampling of all adjacent populations or there may be more specific links to particular source regions. Population dynamics derived from the Continuous Plankton Recorder for a number of previously defined ecoregions were used to examine potential links to particular regions.

The historical data collated in this study for Galway Bay (1972–1987) cover a well-documented period of change within pelagic ecosystems of the N. Atlantic ('regime shift' centred around 1977–1982; Beaugrand, 2004). Given the sparseness of documented responses by Irish coastal zooplankton populations to climatic variability, the Galway Bay data can be used to establish potential similarities with patterns observed elsewhere. Changes in phenology (timing of seasonal maxima) were tested for evidence of change prior and subsequent to Beaugrand's (2004) regime shift.

2. Methods

2.1. Study area

Galway Bay is an open bay situated on the west coast of Ireland. The bay can be characterised as a well-mixed estuary with freshwater inflow from the Corrib River on the north east coast of the bay and an anti-clockwise circulation pattern controlled mainly by inflow rates from the south and outflow to the north. Both salinity and sea surface temperature are influenced by rates of freshwater inflow from the River Corrib and oceanic inflow from the south of the bay (Booth, 1975). Salinity varies between 24 in the inner bay and 34.9 in the outer bay and flow rates from the Corrib change seasonally from winter daily means of $\sim$250 m^3 s^{-1} to summer daily means of $\sim$50 m^3 s^{-1} (Nolan, 2004).

2.2. Environmental data

Broad scale environmental variables were used as potential covariates for plankton dynamics as there were no long term oceanographic observations available for Galway Bay. Sea surface temperature (SST) data were obtained from the two points of the HadISST1 grid (Rayner et al., 2003) that were most adjacent to Galway Bay (Fig. 1). The NAO winter index (Hurrell, 1995), based on the difference of normalized sea level pressure between the Azores and Iceland, was also used as this has previously been correlated with zooplankton time series (Fromentin and Planque, 1996). Daily flow rates are available from the Irish Environmental Protection Agency (www.epa.ie) for the primary source of riverine input in Galway Bay (Corrib River).

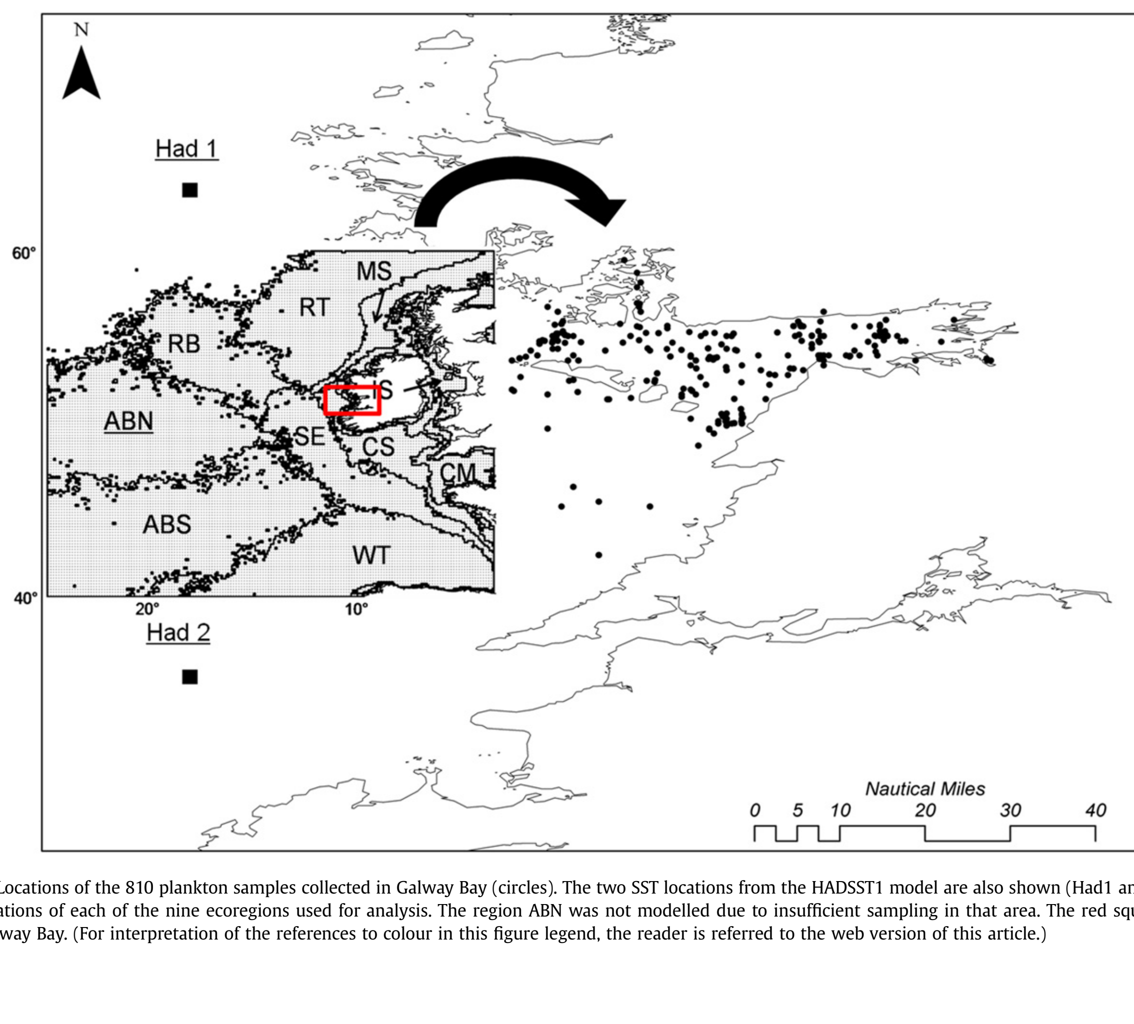

Fig. 1. (Main) Locations of the 810 plankton samples collected in Galway Bay (circles). The two SST locations from the HADSST1 model are also shown (Had1 and Had2, squares). (Inset) the locations of each of the nine ecoregions used for analysis. The region ABN was not modelled due to insufficient sampling in that area. The red square indicates the location of Galway Bay. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)