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Seasonal variability of turbidity, salinity, temperature and suspended chlorophyll in a strongly tidal sub-estuary: The Lynher Marine Conservation Zone

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ABSTRACT

The Lynher Estuary in Southwest England is a small, strongly tidal sub-estuary of the Tamar Estuary. It is a Site of Special Scientific Interest (SSSI), a Marine Conservation Zone (MCZ), a part of the Plymouth Sound and Estuaries Special Area of Conservation (SAC) and a Special Protection Area (SPA). Management of the Lynher SSSI and MCZ stipulates that good water quality and sediment quality should be maintained; as such, a good understanding of its responses to influences such as climate change and changes in agricultural practices within its catchment area is required. Observations of salinity, temperature, suspended particulate matter (SPM) concentrations, estuarine turbidity maximum (ETM) behaviour, and chlorophyll-*a* are presented for the Lynher over a 1-y period. The dataset provides important baseline information with which to identify future changes and guide management of the SSSI and MCZ as well as adding to our knowledge of estuarine systems. Salt intrusion is largely controlled by tides and runoff. A persistent ETM occurs that is closely associated with the freshwater-saltwater interface at high water (HW) and with a minimum in dissolved oxygen concentrations. HW depth-averaged ETM magnitudes are relatively low, less than 60 mg l^{-1} and typically 30 mg l^{-1} over the observation period. Larger tides and stronger flood-tide wind speeds lead to a stronger ETM. Tidal river HW SPM concentrations are intrinsically small (8 ± 8 mg l^{-1} during the observation period). Surface chlorophyll-*a* concentrations are low during winter (when they often peak near the ETM) and are much higher during spring and summer.

1. Introduction

The Lynher Estuary in Southwest England (Fig. 1a, b, c) is a sub-estuary of the Plymouth Sound and Estuaries Special Area of Conservation (SAC) that covers an area of approximately 64 km^2 (JNCC, 2017). This SAC is representative of ría estuaries in the southwest of England. The Lynher is confluent with, and a sub-estuary of, the Tamar Estuary (Fig. 1b and c) and is partially within the Tamar Estuary Marine Conservation Zone (MCZ) regions (JNCC, 2017). These MCZs are located in two spatially separate areas and cover an area of approximately 15 km^2 that includes the upper reaches of the Tamar and Lynher Estuaries, which are the only areas in the southwest of England where there is good evidence for use by the mobile FOCI (Feature of Conservation Importance) *Osmerus eperlanus* (smelt).

The Lynher Estuary was notified as a Site of Special Scientific Interest (SSSI) in 1987 (Natural England, 2018a). The reasons for its notification highlighted the extensive saltmarsh and highly productive mudflats that provide important feeding and roosting grounds for large populations of wintering wildfowl and waders as well as its relatively unimpeded freshwater inputs from the Rivers Tiddy and Lynher, which generate a gradient of salinity along which transitional marsh communities have developed (Natural England, 2018a). Management of the SSSI stipulates that 'good water quality and sediment quality should be maintained and that the sediment budget within the system should not be restricted by anthropogenic influences' (Natural England, 2018b). Some condition-status monitoring has taken place for the Lynher that has facilitated an assessment of the present favourable condition of its littoral sediment habitats and identified species and biotopes that are representative or notable within the estuary (Ecospan, 2015). Nevertheless, the extent and status of its saltmarshes, mudflats and littoral sediment habitats are ultimately dependent on the estuary's salinity gradients and its fine-sediment transport, which are sensitive to

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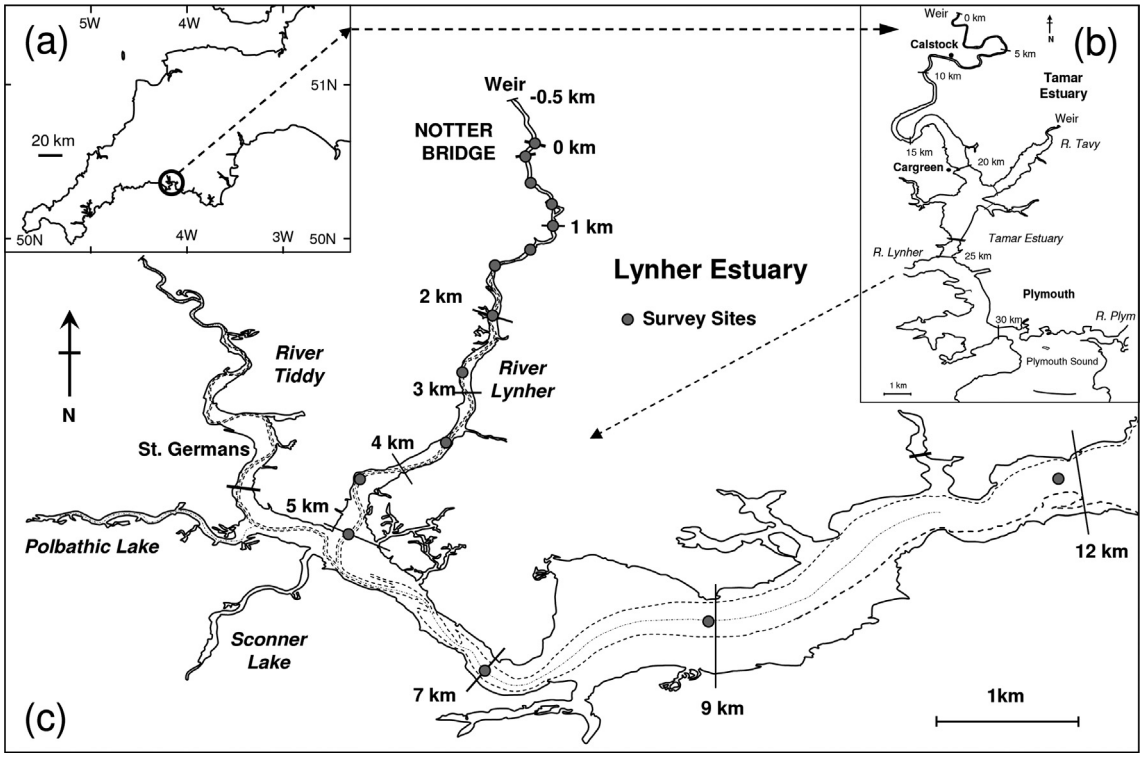

Fig. 1. Maps showing: (a), the location of the Lynher Estuary in Southwest England, UK; (b), the location of the Lynher Estuary in relation to the Tamar Estuary; and (c), the Lynher Estuary showing distances from Notter Bridge and station positions.

dynamic physical processes within the estuary and catchment that vary with agricultural use and with altered freshwater inputs and rising sea levels due to climate change. A baseline dataset on physical variables and an interpretation and quantitative understanding of its physical behaviour therefore provide important information with which to guide future management of the SSSI and MCZ.

Accordingly, we describe results from fieldwork in this small, strongly tidal estuary that over a year illustrate seasonal and spring-neap variations in the mouth-to-head longitudinal distributions of salinity and suspended particulate matter (SPM) concentrations and the estuarine turbidity maximum (ETM), which are important drivers of saltmarsh and mudflat spatial extent and composition, as well as temperature and concentrations of suspended chlorophyll-*a*. Chlorophyll-*a* is an important variable to include here because the Lynher has a tendency towards eutrophication and is considered moderately vulnerable to nutrient enrichment (Parr and Wheeler, 1996). Excess nutrient inputs are thought to be mainly due to diffuse agricultural pollution and, to a lesser extent, from sewage infrastructure (Ecospan, 2015). In view of a potential oxygen demand in the estuary, some discussion is also given of dissolved oxygen concentrations (DO).

Although the ETM is usually studied as a physical phenomenon, it can have a profound influence on the ecology of an estuary (e.g. Garnier et al., 2010; Savoye et al., 2012; Keller et al., 2014), and whereas some work has been published on ETM behaviour in small estuaries (e.g. Jago et al., 2006; Uncles and Stephens, 2010), much of the research relates to larger estuaries (e.g. Rao et al., 2011; Sommerfield and Wong, 2011; Ralston et al., 2012; Jiang et al., 2013; Yu et al., 2014; Jalón-Rojas et al., 2016; Kitheka et al., 2016; Toublanc et al., 2016). Despite the SSSI designation of the Lynher, very little information on its physical regime has been published and previous studies have focussed on its biology (Joint, 1978; Warwick and Price, 1979; Bayne et al., 1987) or its contaminants (Bland et al., 1982; Austen and McEvoy, 1997). A review of some biological, chemical and ecological studies of the Plymouth Sound and Estuaries SAC and SPA (including the Lynher Estuary) is given by Langston et al. (2003).

This article is intended to contribute both to our understanding of the Lynher Estuary as a guide to its future management and to add to our knowledge of salt intrusion, ETM processes, seasonal variability and its consequences for chlorophyll-*a* in small estuaries using measurements from this little-studied SSSI. The issues addressed here that are significant to the Lynher as a Marine Protected Area include: (1), salinity intrusion and its dependence on environmental forcing factors (determining the salinity gradients along which transitional marsh communities have developed); (2), suspended sediment concentrations and sediment transport in the tidal river and estuary, including the ETM (contributing to and interacting with the extensive saltmarsh and highly productive mudflats and subject to the requirement that the sediment budget within the system should not be restricted by anthropogenic influences); (3), chlorophyll-*a* concentrations and the measurement of dissolved oxygen levels (in the knowledge that good water quality and sediment quality should be maintained). Particularly important aims include: examination of the sensitivity of salinity intrusion and ETM location and magnitude to tidal range and freshwater inflow from the catchment; the presence or otherwise of unusually elevated chlorophyll-*a* levels as an indicator of excessive or normal nutrient levels; and the existence or absence of dissolved oxygen 'sags' as an indicator of potential water quality issues.

2. The Lynher Estuary

The Lynher Estuary is approximately 13 km long from its mouth in the lower Tamar Estuary (x = 12.5 km, Fig. 1b and c) to its tidal limit at the weir (x = −0.5 km, Fig. 1c), where x is the centre-line (i.e. midway between adjacent estuary banks/shores) distance along the estuary. The distance origin (at x = 0 km) is chosen to be Notter Bridge (Fig. 1c) because the great majority of surveys started at this station and only two started farther up-estuary (x = −0.23 and −0.25 km) during the HW stands of very large spring-tide, low-runoff surveys. The Lynher is a shallow estuary, typically less than 5-m deep at high water (HW). In the lower estuary it has extensive intertidal mudbanks and saltmarsh areas,