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Development of an estuarine multi-metric fish index and its application to Irish transitional waters

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ABSTRACT

An estuarine multi-metric fish index (EMFI) was developed and applied to Irish transitional waters. The index comprised a balanced and complimentary set of 14 metrics that represent four fish community attributes: species diversity and composition, species abundance, estuarine utilisation, and trophic composition. Reference conditions and metric scoring thresholds were developed using a combination of historical records, best available data, and expert judgement. The index was applied using representative and robust fish monitoring data collected using a suite of methods designed to cover a range of habitats and conditions. To ensure consistency and comparability, all systems were considered at the whole estuary level. A sensitivity analysis was carried out to assess the response of the EMFI under various scenarios of metric change; five metrics were consistently among the most influential on the EMFI in all scenarios of metric manipulation. The overall EMFI was significantly correlated with environmental condition as measured by two separate indicators of ecological state. Ecological status classes were also established based on the relationship between the EMFI and an index of human pressure. The EMFI provides a robust, sensitive, and integrated measure of the ecological status of fishes in transitional waters and meets the requirements of the EU Water Framework Directive.

1. Introduction

Estuaries are dynamic transitional environments, formed where rivers enter the sea. They are highly variable systems and often experience changes in freshwater flows, tidal currents, sediment transport, salinity, temperature, turbidity, and nutrients, which can vary over tidal cycles or seasonally. These hydrological, physical, and chemical processes, together with biological interactions all serve to produce a variety of habitats in estuaries; these include saltmarsh, reed beds, subtidal and intertidal sea grass beds, and subtidal and intertidal muds and sands (Phil et al., 2002). Estuaries are also highly productive (Odum, 1983; McHugh, 1985) and this, together with the variety of sheltered habitats provided, serve an important nursery function for fishes and invertebrates many of which are of direct or indirect commercial importance to man (Elliott et al., 2007; Franco et al., 2008a).

Their proximity to the coast and sheltered waters has made estuaries popular sites for human development and exploitation. Estuaries are impacted by multiple anthropogenic activities such as fishing and aquaculture, dredging and harbour development, shipping, wetland reclamation and land fill, industrial and commercial development, and residential and recreational development; they are also used for water abstraction as well as industrial discharges and domestic effluents. In addition, estuaries are impacted by activities in the catchments of rivers that feed these systems such as dam construction, flood defence schemes, water abstraction, agricultural runoff and effluent discharges (Aubry and Elliott, 2006; Vasconcelos et al., 2007).

Growing environmental awareness has led to an increase in international, national, and regional programmes for the protection and/or restoration of aquatic systems (Borja et al., 2008). In Europe, the Water Framework Directive (WFD) provides a framework for the protection and restoration of inland surface waters, transitional waters (including estuaries), coastal waters and groundwater (Directive 2000/60/EC). A key objective of the WFD is that Member States must achieve good ecological status in all waters by 2015. According to the WFD, ecological status should be assessed based on several physical and chemical variables, but also includes several biological elements (e.g. phytoplankton, macrophytes, benthic invertebrates). Fish are one of the key biological elements required in the assessment of transitional waters (estuaries) for the WFD. This paper describes the development of a new estuarine

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multi-metric fish index (EMFI) and its application to Irish transitional waters.

2. Materials and methods

2.1. Survey area

The EMFI was developed and applied to transitional waters (estuaries) spanning the entire Irish coastline and included systems within Northern Ireland as well as the Republic of Ireland (Fig. 1).

2.2. Fish surveys

Fish surveys of transitional waters for WFD monitoring purposes commenced in 2005 and since then, transitional waters in both Northern Ireland and in the Republic of Ireland have been sampled at least once during autumn (September–November). A standard multi-method sampling approach designed for the implementation of the WFD was used and this included the use of a 30 m long × 2 m deep seine net (14 mm mesh body with a 5 m long × 6.5 mm central panel), a fleet of double fyke nets (each trap was 0.5 m high, 2.5 m long with a 10 mm mesh cod end and was joined by a 6 m long × 15 mm mesh leader), and a 1.5 m wide × 0.5 m high beam trawl (the body of the net was 3 m long × 10/14 mm mesh with a 1 m long × 5/6.5 mm mesh cod end). Seine netting was conducted in shallow (usually <1.5 m deep) littoral areas, while the fyke nets were set for 24 h in deeper waters. Trawling was typically conducted in mid-channel areas and was towed at a speed of 1–2 knots for approximately 5 min or for a set distance of 100–200 m. The sampling effort (number of samples and deployment of the different gear) varied among estuaries; however, sampling was undertaken to ensure an adequate spatial coverage of each system and that all representative habitats and species were sampled using all gear. In addition, although the sampling effort varied according to estuary size, the proportions of the various sampling gear deployed was fairly consistent. Species accumulation curves indicated that sampling was both sufficient and representative in that no new species were collected during the surveys.

Where possible, all fishes were identified and counted in the field and returned alive to the water; specimens that could not be identified in the field were placed in labelled plastic bags and kept cool for transport to the laboratory where they were frozen. In the laboratory, fishes were identified by reference to Wheeler (1969), Whitehead et al. (1989) and Maitland and Herdson (2009) and counted. Where large numbers of a particular species were captured, these were batch weighed and the total number of individuals estimated using an average specimen weight based on a sub-sample mass of at least 50 individuals. The total number of species and their numerical abundance was calculated for each system by pooling the catches from all samples.

2.3. Typology and scale of assessment

The WFD requires that transitional waters are assigned to a typology using factors such as ecoregion, salinity, tidal range, depth, current velocity, wave exposure, residence time, water temperature, mixing characteristics, turbidity, substratum composition, and shape. The purpose of assigning transitional waters to a physical type is to enable the establishment of appropriate reference conditions and to make a valid assessment of the ecological status of each system. The UK Technical Advisory Group (UKTAG) on the WFD identified six types of transitional water within the UK and Republic of Ireland based on mixing characteristics, salinity, mean tidal range, wave exposure, depth and substratum. Only two transitional water types were recognised within Northern Ireland and the Republic of Ireland; these are type 2 (TW2) and type 6 (TW6). Type 6 systems are transitional lagoons and are typically isolated from the sea. As these systems are unlikely to serve as a major habitat for estuarine-associated fishes, they were omitted from further analysis (with the exception of the Broadmeadow Water estuary). Although the Broadmeadow Water system has been classified as a transitional lagoon, this is largely due to the construction of railway viaduct in the 1840s, which has restricted tidal flows and resulted in the permanent inundation of what were previously intertidal areas. The system, however, still maintains a permanent connection with the sea and for this reason it is included among the type 2 transitional waters.

Type 2 transitional waters are partially mixed or stratified systems; they are sheltered intertidal, or shallow subtidal estuaries that have a predominantly sand and mud substratum. These systems are strongly mesotidal (mean spring tidal range: 2–4 m) with typically mesohaline (5–18) or polyhaline (18–30) salinities. Several TW2 transitional waters in the Republic of Ireland have been subdivided into separate water bodies, however, to ensure a consistent approach, all systems were considered at the whole estuary or transitional water level; data that were collected for sub-divided transitional waters were pooled to provide a single data set for each estuary. Furthermore, only transitional waters that were fed by a distinct river and catchment were included. In one instance (Foyle and Faughan) the system was sub divided to provide two separate transitional waters, each fed by its own separate river and catchment.

Although only one transitional water type (TW2) was included in Northern Ireland and the Republic of Ireland, a considerable variation exists within these systems, particularly with regards size. A strong relationship between estuary size and taxonomic richness has been observed in estuaries in the United States (Horn and Allen, 1976; Monaco et al., 1992), Australia, (Pease, 1999), South Africa (Harrison and Whitfield, 2006a), South America (Araújo and Azevedo, 2001) and in Europe (Franco et al., 2008b; Nicolas et al., 2010). Based on WFD survey data collected between 2005 and 2008, a relationship between species richness and estuary size was also observed in Irish transitional waters (Fig. 2).

To account for the effect of size, the transitional waters were grouped into one of five size categories according to surface area using data obtained from national geographic information system (GIS) inventories of transitional waters in Northern Ireland and the Republic of Ireland. Since species richness is related to the log of surface area (Fig. 2), the transitional water size classes were based on a $\log_{10}$-scale ($\leq$10 ha; >10 to $\leq$100 ha; >100 ha to $\leq$1000 ha; 1000 to $\leq$10,000 ha; >10,000 ha).

2.4. Index development

2.4.1. Metric selection

The metrics used to construct the EMFI were selected following a global review of measures included in other estuarine fish community indices (e.g. Miller et al., 1988; Deegan et al., 1997; USEPA, 2000; Hughes et al., 2002; Whitfield and Elliott, 2002; Harrison and Whitfield, 2004, 2006b; Jordan et al., 2010; Hallett et al., 2012) as well as European multi-metric indices developed in the context of the WFD (e.g. Borja et al., 2004; Breine et al., 2007, 2010; Coates et al., 2007; Delpech et al., 2010; Cabral et al., 2012). Attention was also given to the ecological relevance of each metric and where possible, both qualitative and quantitative measures were included. Other important considerations were the ease of measurement of each metric as well as its significance in meeting the requirements of the WFD, which should include measures of species composition, abundance, and disturbance-sensitive taxa. A total of 14 metrics were selected that represent four broad fish community attributes: