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# Fish-based indicators of estuarine condition that do not require reference data

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ABSTRACT

The species composition of fish communities in 15 microtidal estuaries in south-western Australia, ranging from permanently-open to normally-closed, is shown to be related to the geomorphological and hydrological regimes and not to environmental condition. This study then explored the effectiveness of using qualitative taxonomic distinctness and ABC curves for fish data as indicators of the environmental condition in nearshore, shallow waters of these estuaries and, in the case of taxonomic distinctness, also of their offshore, deeper waters. Neither of these indices require spatial or temporal reference data, which may be either prohibitively expensive and time-consuming to collect or unavailable. Taxonomic distinctness, in both nearshore and offshore waters, varied consistently among estuaries in relation to their recorded environmental status, and is thus a good indicator of overall estuarine condition. ABC analyses, however, did not prove a good measure of the environmental condition of the estuaries, because their results largely reflect differences in accessibility of the estuary to marine estuarine-opportunist species and especially those that grow to a larger size. It is concluded that taxonomic distinctness indices provide a rapid and cost-effective method for assessing the environmental condition of estuaries, particularly those with limited spatial or temporal reference data.



## 1. Introduction

The attributes of a range of biological elements, including fish, have been used widely to assess the ecological condition, or 'health', of estuaries and other aquatic environments (Roset et al., 2007; Birk et al., 2012; Pérez-Domínguez et al., 2012; Borja et al., 2016). At the multispecies level, species-dependent multivariate analyses of abundance data have been shown to be very sensitive for detecting differences in fish community composition in space and over time (Dawson-Shepherd et al., 1992; Valesini et al., 2014; Veale et al., 2014; Potter et al., 2016). In general, however, these methods are used simply to detect differences in composition and offer no value judgement on environmental quality. Although a few possible approaches to the measurement of community stress employing multivariate methods have been suggested (Warwick and Clarke, 1993a), the use of phylum-level meta-analysis and breakdown of seriation patterns are inappropriate for fish as the members of this taxon are all located in a single phylum and are motile rather than sedentary. Furthermore, multivariate dispersion has only been employed for the resident fish species on coral reefs (Warwick and Clarke, 1993b). Instead, species-independent methods that are rather less sensitive, such as diversity indices e.g. Shannon-Weiner (Strong, 2016), have been used as fish-based indices of environmental condition.

A wide variety of these indices have used fish data to assess the ecological quality of estuaries and other transitional waters, either singly or in combination as multimetric indices (e.g. Bortone et al., 2005; Marques et al., 2009; Birk et al., 2012; Pérez-Domínguez et al., 2012). Such indices have employed, inter alia, data on the diversity and abundance of species, the numbers and proportions of trophic, life-history and/or habitat-use guilds, and morphological, physiological or immunological condition (Delpech et al., 2010; Richardson et al., 2011; Hallett et al., 2012). They are typically based on a variant of the reference condition approach (Bailey et al., 2004; Hawkins et al., 2010), whereby pristine, least impacted or best available reference sites, hindcasting, predictive modelling or best professional judgment are used to establish the reference points against which ecological condition can be quantified (Stoddard

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et al., 2006; Borja et al., 2012).

The use of reference conditions has a number of limitations. 1) a pristine state may not represent an appropriate reference point against which potentially impacted sites or systems can be evaluated because it is an unrealistic target for management, since the vast majority of estuaries have been subjected to anthropogenic influences (ICES, 2002; Kopf et al., 2015). 2) Environmental conditions in estuaries are highly dynamic, can change dramatically and unpredictably at different times of the year, and vary among their regions (Elliott and Quintino, 2007). Multimetric indices typically account for the last issue through setting spatially and temporally-adjusted reference conditions (Teixeira et al., 2008; Hallett et al., 2012). However, this requires the collection of extensive data sets that incorporate samples from across the extent of the estuary at multiple time points (Muxika et al., 2007; Borja et al., 2012), and which are thus relatively expensive and time-consuming to compile. The two indices used in the current study, i.e. taxonomic distinctness and Abundance Biomass Comparison (ABC) curves, adopt different approaches by setting reference conditions that do not require extensive spatial or temporal data for establishing a baseline (Warwick and Somerfield, 2015). Furthermore, the best metrics or indicators of ecological degradation are those that are not, or are only minimally, affected by natural variability, but are sensitive to anthropogenic disturbance (Kurtz et al., 2001; Rice, 2003; Pérez-Domínguez et al., 2012), properties that have been claimed to apply to the above two indices (Warwick and Clarke, 1998; Warwick, 2008; Tweedley et al., 2015).

Taxonomic distinctness measures have been used to assess the ecological status of many groups of terrestrial, freshwater and marine organisms, including fish in freshwater (Bhat and Magurran, 2006) and marine environments (Rogers et al., 1999a; Stobart et al., 2009; Campbell et al., 2010; Shan et al., 2010; Tolimieri and Anderson, 2010; Zintzen et al., 2011; Barjau-González et al., 2016), but hitherto not for estuarine fish assemblages. The ABC method has mostly been used for benthic macroinvertebrates, and less well explored with other biota. It has been used successfully, however, to indicate environmental impacts on fish assemblages in freshwater (Coeck et al., 1993; Penczak and Kruk, 1999; Pinto et al., 2006; Piperac et al., 2015), estuarine (Ecoutin et al., 2010; Viana et al., 2012) and marine environments (Rogers et al., 1999b; Blanchard et al., 2004; Jouffre and Inejih, 2005; Yemane et al., 2005).

Along the microtidal coast of south-western Australia, some estuaries remain permanently-open, whereas others become either intermittently-open, seasonally-open or normally-closed through the formation of a sand bar at their mouths, which prevents exchange of water with the ocean (Chuwen et al., 2009a; Potter et al., 2010; Tweedley et al., 2016a). The condition of the estuaries in south-western Australia has been shown to vary markedly through using indices, including taxonomic distinctness, that employ data for their benthic macroinvertebrate faunas (Wildsmith et al., 2009, 2011; Tweedley et al., 2012, 2014a; 2016b). There have been no comparable studies using fish as indicators of estuarine health and, since fish are mobile as opposed to sedentary and often represent species spawned at sea, there is no a priori reason why the indices should necessarily follow the same trend.

The aims of this paper are twofold. First, to use multivariate methods to compare the composition of fish species in a range of estuaries along the south-western Australian coast to determine whether the ichthyofaunas of these estuaries group according to estuary type, i.e. permanently-open, intermittently-open, seasonally-open and normally-closed, and/or with the purported environmental condition of these estuaries, i.e. near-pristine through to extensively modified. Second, to investigate whether taxonomic distinctness and ABC curves are effective indicators of the extent of degradation among a range of estuaries.

## 2. Materials and methods

### 2.1. Data sources

Abundance values were obtained from published sources for each fish species recorded in nearshore, shallow and offshore, deeper waters at sites throughout 15 estuaries along ~1200 km of the south-western Australian coast (Table 1; Fig. 1). Biomass data for nearshore waters were also available for each of these systems except the Hardy and Walpole-Nornalup estuaries. These data had been collected seasonally from numerous sites throughout each system over two years. Nearshore waters were sampled during daylight hours using a 21.5 m seine net, which comprised two 10 m-long wings (6 m of 9 mm mesh and 4 m of 3 mm mesh) and a 1.5 m-long bunt (3 mm mesh), swept an area of 116 $m^2$ and fished to a maximum depth of 1.5 m. Offshore waters were sampled at night using a 160 m–long, sunken gill-net, which consisted of eight panels that were 20 m long and 2 m high, each with a different mesh size, ranging from 38 to 127 mm (Table 1).

Assessment of the environmental condition of these 15 estuaries was taken from The Australian Catchment, River and Estuary Assessment (Commonwealth of Australia, 2002), which classified Australian estuaries according to the degree to which they had been modified from the pristine state, based on a number of criteria relating to the condition of the catchment, estuarine use and ecology (Table 2). The four categories are: near-pristine (NP), largely unmodified (LU), modified (M) and extensively modified (EM).

### 2.2. Statistical analyses

As some of the fish species found in estuaries around the world enter those systems incidentally and for short periods of time, they are regarded as marine stragglers and are thus neither facultative nor obligate users of the estuary (Potter et al., 2015a,b). While the species in this guild can make a substantial contribution to the total number of species in an estuary, each is typically present only in low numbers. Across the 15 estuaries, marine stragglers accounted for 75 (57%) of the 131 species recorded in nearshore waters and 55 (58%) of the 95 species in offshore waters. The total number of species in the regional species pool was 172, of which 107 (62%) were marine stragglers. This guild only comprises 0.3% of the total number of individuals in the permanently-open Peel-Harvey Estuary on the lower west coast of Australia for example (Potter et al., 2016), and less than 0.1% in the seasonally-open to normally-closed Broke, Irwin, Wilson and Wellstead systems on the south coast (Hoeksema et al., 2009, Fig. 1). Marine stragglers are therefore not considered to contribute meaningfully to any representation of the condition of estuaries, particularly as they also spawn at sea. For the purposes of this study, the data for species in the marine straggler guild have therefore been omitted from all analyse4s.

#### 2.2.1. Community composition

Each species in both nearshore and offshore waters of the 15 estuaries, except marine stragglers, was recorded as present or absent to provide a direct comparison with the taxonomic distinctness analyses described below, which also use presence/absence data. Fourth-root transformed species composition and presence/absence data for fish species in nearshore and offshore waters were used to construct separate Bray-Curtis similarity matrices. Each of these was then subjected to non-metric Multi-dimensional Scaling (nMDS; Clarke, 1993) ordination to provide a visual indication of the differences in ichthyofaunal composition