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# Testing the efficacy of an estuarine eutrophic condition index: Does it account for shifts in flow conditions?

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ABSTRACT

Eutrophication of estuaries via anthropogenic nutrient enrichment is an issue being addressed extensively on a global scale, however it remains a topic that garners further attention due to its complexity. The aim of this study was to test the efficacy of a recently proposed eutrophic condition index in five permanently open estuaries, subsequent to flow variations. Further, in order to elucidate their potential role in augmenting eutrophic conditions, the influence of vegetated habitats on associated microalgal communities was investigated. The study took place in the summer of 2014 and 2015. On each sampling occasion, all of the proposed 'state' indicators (nutrients, oxygen and microalgal communities) were assessed and supplemented with a heuristic 'pressure' component (flow conditions). Overall, the proposed index was shown to be sensitive to environmental perturbations providing shifts in classification ratings illustrating the dilution (Swartkops Estuary) or augmenting (Kromme, Gamtoos, and Kariega estuaries) effect of freshwater pulse events. Additionally, the sensitivity of selected epiphyte and microphytobenthos (MPB) parameters to water quality variations was verified, thus supporting their inclusion as indicators in the proposed index. Regarding the role of microhabitats in promoting microalgal growth, it was found that MPB biomass was higher (5–290%) and benthic diatom diversity generally lower (5–50%) in vegetated compared to unvegetated habitats – an important consideration when applying the index. The habitat complexity and stabilisation provided by estuarine macrophytes (*Phragmites australis* and *Zostera capensis*) supported notable autotroph colonisation. This highlights their importance in structuring trophic pathways, whilst also potentially providing a corridor for the intensification of eutrophic symptoms in estuaries. Overall, this study provides an important step towards the verification of a proposed assessment methodology which may serve to provide a baseline from which the eutrophic status of estuaries can be monitored – particularly in countries where such assessment frameworks are lacking.


## 1. Introduction

Eutrophication of estuaries is a longstanding global issue, and as such remains a key research focus area due to the potentially severe socio-economic consequences of continued ecosystem degradation. An important consideration regarding the assessment of eutrophication is to realise that it is a process rather than a state, requiring – by definition – "*undesirable disturbances*" to occur as a result of anthropogenic inputs (OSPAR, 2003). In order to assess the eutrophic condition of a system, selection of relevant indicators is required as it is not possible, nor logistically or economically feasible, to assess every component (Devlin et al., 2011). As such, some of the known consequences of nutrient enrichment include: increased macro- and microalgal biomass, oxygen depletion (hypoxia/anoxia), shifts in community composition, harmful or toxic algal blooms, red tide events, elevated epiphytic growth, loss of submerged macrophytes and fish kills (Bricker et al., 2003; Devlin et al., 2011; Lemley et al., 2016).

Numerous studies aimed at documenting such occurrences have been undertaken, particularly in Europe and the United States, to determine and understand the extent and magnitude of eutrophication, as well as to standardise assessment methodologies thereof (Bricker et al., 2003; Devlin et al., 2011; Garmendia et al., 2012; McLaughlin et al., 2014). These assessment methodologies serve as the basis for operative monitoring programmes and establishment

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of ecological objectives (McLaughlin et al., 2014), which can in turn be utilised to track the response of estuarine systems to changes in anthropogenic pressures over time. A study by Ní Longphuirt et al. (2015) demonstrated the value of long-term monitoring in an Irish estuary, where marked improvements in the overall eutrophic condition were shown to occur concomitantly with improvements in catchment management practices.

In South Africa, the National Water Act (No. 36 of 1998) provides the legal framework aimed at protecting water resources through implementation of the Resource Directed Measures (RDM) process. Unfortunately, the RDM method is not formulated with eutrophication being explicitly incorporated as a prerequisite component. As such, a review by Lemley et al. (2016) highlighted the need for an asserted effort in terms of eutrophication research in South African estuaries. Lemley et al. (2015) propose a eutrophic condition index that incorporates multiple 'state' indicators of the two elements central to the definition of eutrophication (i.e. nutrients and primary producer responses), as well as a heuristic 'pressure' component (e.g. flow conditions, nutrient loading, and ecohydrodynamics). However, as stated by O'Boyle et al. (2015), the selection of effective indicators needs to be founded on a sound understanding of the interactions between pressures and environmental factors and the subsequent response of biological receptors. In the study by Lemley et al. (2015), this is a premise that was highlighted as an aspect that required further investigation to verify the responsiveness of the proposed index to episodic events and temporal variations. As such, the primary aim of this study was to evaluate the efficacy of the proposed eutrophic condition index relative to freshwater inflow conditions. In addition, the responsiveness of the selected 'state' indicators to changing water quality and quantity were assessed.

A secondary aim of this investigation was to elucidate the influence of macrophyte habitats on their associated microalgal communities. Aquatic macrophytes are a critical component of estuarine ecosystems, playing a pivotal role in shaping ecological processes, directly or indirectly. Some of the ecosystem services they provide include: nutrient cycling (release or uptake), organic carbon deposition (detrital food web and sequestration), habitat stabilisation (reduced erosion), habitat complexity/heterogeneity (nursery areas), and oxygen production (Grimaldo et al., 2009; Thomaz and da Cunha, 2010). These habitats are pertinent to such assessments in that higher forms of plant life – key to the definition of eutrophication – are potentially critical in terms of augmenting eutrophic symptoms in estuaries through the provision of increased habitat complexity and stabilisation, thus increasing the likelihood of autotroph colonisation.

## 2. Materials and methods

### 2.1. Study area

Five permanently open estuaries (POE), situated along the warm temperate south-eastern coastline of South Africa, were assessed over two summers in 2014 and 2015. The estuaries sampled were, from west to east, the Kromme, Gamtoos, Swartkops, Sundays and Kariega (Fig. 1). These systems were selected based on estuarine type (i.e. permanently open mouth conditions), as well as the similarities and dissimilarities that exist among them. The selected estuaries provide examples of systems subject to extensive water abstraction (Kromme and Kariega), agricultural inputs (Gamtoos and Sundays), and urbanisation (Swartkops). This inter-system variability allows for a robust evaluation of the eutrophic condition index proposed by Lemley et al. (2015). The characteristics and pressures associated with each of the estuaries are summarised in Table 1.

### 2.2. Sampling design

The estuaries studied provide important ecosystem services such as a nursery habitat for fish and recreational sites for residents and holidaymakers. The value of these services is amplified during summer as it is the larval and juvenile fish recruitment period, as well as the holiday season (increased fishing and recreational use). As such, the summer season was the focus of this study. Initially, sampling was undertaken in November and December 2014 to determine the eutrophic condition of the estuaries during this critical phase. The occurrence of flood events in the spring of 2015 (~September) prompted replication of the sampling design in November 2015, thus enabling a comparison of the condition of these estuaries pre- and post-flood events.

### 2.3. Flow variability

Long-term river flow data (https://www.dwa.gov.za/hydrology/hymain.aspx) was obtained for selected gauging stations from the Department of Water and Sanitation (DWS). In order to determine the timing and volume of river flow influencing each estuary, river stations were selected based on closest proximity to the upstream estuarine boundary (5 m lateral contour). In the case of Gamtoos, flow was determined through the combination of multiple stations that each act as a source of water for the estuary. The flow records for each system varied in terms of monitoring period (Table 3), ranging from 21 to 46 years of data. A suite of percentiles were applied to the flow data in order to quantify low (<25th percentile), 'normal' (25th–75th percentile), and high (>75th percentile) flow periods in each system (Helsel and Hirsch, 2002). Furthermore, the average monthly flow rate – 30 days before each sampling date – for 2014 and 2015 was determined for each estuary in order to contextualise flow regimes. Quantification of flow variability provides the primary heuristic 'pressure' component in this study.

### 2.4. Water column parameters

For the pelagic component, all of the estuaries were sampled at five sites along their length (i.e. from mouth to river reaches) (Fig. 1). This is an important aspect to be incorporated in eutrophic assessment studies due to the intrinsically high spatial heterogeneity of these systems.

#### 2.4.1. Physico-chemical characteristics

Physico-chemical parameters were recorded at each site using an YSI 650 MPS multiprobe deployed at 0.5 m depth intervals from the surface to the bottom of the water column. The following parameters were measured: dissolved oxygen (mg $l^{-1}$), pH, salinity, and temperature (°C).

#### 2.4.2. Inorganic nutrients

Water samples were collected in the surface (0.5 m intervals up to 1 m) and bottom waters at each site along the length of the estuaries. The samples were gravity-filtered through glass-fibre filters (Whatman© GF/C), and subsequently filtered through hydrophilic polyvinylidene difluoride (PVDF) 0.47 μm pore-size syringe filters. The filtrates were stored in the dark and frozen until analyses could commence (i.e. within a week after sampling). Once in the laboratory, the water samples were analysed for soluble reactive phosphorus ($PO_4^{3-}$) and ammonium ($NH_4^+$) using standard spectrophotometric methods as described by Parsons et al. (1984). Total oxidised nitrogen ($NO_3^-$ and $NO_2^-$) was analysed using the reduced copper cadmium method as described by Bate and Heelas (1975). Inorganic nutrients were categorised as dissolved inorganic nitro-