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The effect of a large-scale irrigation scheme on the fish community structure and integrity of a subtropical river system in South Africa

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ABSTRACT

Large scale irrigation schemes are vitally important for food security in developing countries. This is especially relevant in subtropical countries where there is pressure on their water resources. However, the potential impacts on the fish communities of the rivers associated with these irrigation systems are extensive and potentially devastating. Therefore, the aim of the study was to evaluate the impact of the Vaalharts Irrigation Scheme (VHIS) on the fish community of two rivers (Harts and Vaal rivers) in the subtropical region of South Africa. The fish community was assessed during a three year period from 2007 to 2009 together with environmental and habitat quality parameters. A multivariate approach together with a local biotic index was used to determine the present ecological state and the environmental drivers responsible for the fish community structure. The results indicated that the fish community was in a largely natural state at the start of the VHIS and increasingly became modified due to various environmental parameters being affected by the irrigation scheme. Annual variation in the fish community structures was high while nitrate, zinc and sulphates corresponded with changes in the fish community. The outcome of the study highlighted that a lack of long term monitoring of fish community structures together with environmental and habitat parameters are a major challenge in many developing countries that can potentially affect management of irrigation schemes and the fish communities associated with the aquatic ecosystems.

1. Introduction

Irrigation schemes are a necessity in many countries as they supply the countries with sufficient water to produce food to meet their increasing food demand (Fanadzo, 2012). In South Africa, the Vaalharts Irrigation Scheme (VHIS) is a large irrigation scheme utilising water from the Vaal River via numerous gravity fed canals (Fig. 1). The return flow from the VHIS enters the Harts River (via numerous subsurface and surface drainage canals) (Fig. 1) where after it flows back into the Vaal River. The irrigation scheme is approximately 40 000 ha and supplies a wide range of agriculture products that include maize, wheat, cotton, soft fruit, citrus and some ground nuts. The irrigation scheme's return flow runs into the Harts River and increases the salinity, nutrients (Malherbe et al., 2013), flow velocity (Malherbe et al., 2015) and potentially a variety of pesticides (Malherbe et al., 2013).

Fish communities have been used as a biological indicator since Karr (1981) developed the Index of Biotic Integrity (IBI) to assess environmental degradation. Since then various fish indices have been used around the world and South Africa is no exception with the development of the Fish Assemblage Integrity Index (FAII) (Kleynhans, 1999), the weighted Sensitivity Index of Biotic Integrity (SIBI) (Kotze, 2001), and the Fish Response Assessment Index (FRAI) (Kleynhans, 2007). Fish indices of biological integrity generate a category for the integrity of the fish community based on a matrix of fish community attributes such as habitat, flow and water quality. The use of an index to determine the fish community status can often result in community structure patterns beinglost or overlooked due to the simplification of the data. Therefore, a multivariate statistical approach is used to determine community structure patterns. This has the ability to decrease the complexity of the matrices into a graphical display of the relationships between samples and species. The community structure patterns can be identified and potentially indicate changes in the ecosystem (Clarke and Warwick, 1994; Malherbe et al., 2010).

The aim of this study was to apply selected indicators of fish community structure and integrity and evaluate whether the VHIS

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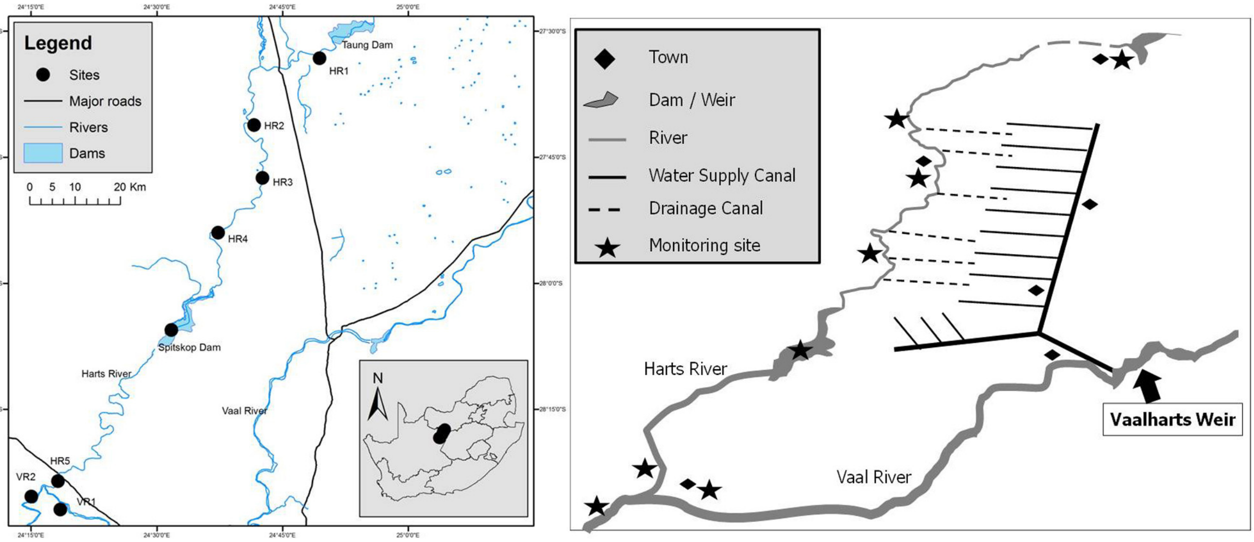

Fig. 1. (A) Map indicating regional location of the study area (inset) and the various sampling sites from the relative reference site (HR1) to the sampling sites on the Harts (HR2–HR5) and Vaal (VR1–VR2) Rivers. (B) Vaalharts Irrigation Scheme graphical depiction of scheme structure.

has affected this community structure. The fish community indicators used included the use of multivariate statistical analyses and a biotic index, the Fish Response Assessment Index (FRAI) (Kleynhans, 2007), which makes use of biotic community metrics to assess present ecological state.

2. Materials and methods

2.1. Sampling site habitat

Sampling sites comprised of seven sites on the Harts River (HR). Site HR1 was situated upstream of the VHIS and was chosen as a relative reference site for the VHIS. Habitat at site HR1 was composed of deep pools around bridge pylons, deep pool upstream of the bridge, rocky riffle section downstream (fast shallow habitat) with numerous smaller backwater areas. Marginal vegetation was present in the pool as well as in the riffle sections. Sites HR2–HR4 were situated along the length of the VHIS (Fig. 1) and the final site HR5 was situated downstream of the VHIS and the Spitskop Dam. Habitat at site HR2 to HR4 was comprised of slow deep sections upstream with marginal vegetation in the form of reeds while the downstream habitat was made up of fast shallow and slow deep habitats interspersed with marginal vegetation and overhanging trees. Additional habitat at site HR3 and HR4 included algal growth (mainly filamentous algae) in especially the deep water sections. Fish sampling surveys were also completed in the Spitskop Dam situated between sites HR4 and HR5. Site HR5 was located on a water monitoring weir with the upstream habitat thus mainly slow deep habitat while the downstream area were comprised of fast shallow habitat that flowed into slow deep areas with little marginal vegetation present. Filamentous algae were also dominant within the weir creating additional habitat.

2.2. Fish sampling

The fish community in the Lower Harts River were sampled during one low flow season (July 2007) and two high flow seasons (January 2008 and February 2009). Sampling was carried out during all three surveys at five localities on the Lower Harts River (HR1–HR5) (Fig. 1).

Various sampling techniques were used to evaluate the fish community as recommended by river monitoring programmes in South Africa (DWAF, 1999; Kleynhans, 2007). All the caught fish were identified using the taxonomic keys in Skelton (2001). Fish were measured, counted and the data captured for analysis. Sampling of fast and shallow habitats was carried out using the electrofishing technique (Barbour et al., 1999). The 2007 and 2008 electrofishing surveys were carried out using a standard 220 V (2.5Kw) AC 50 Hz portable generator while the 2009 survey was carried out using a 12 V battery-operated SAMUS electrofishing apparatus (SAMUS 725 M Electrofisher, SAMUS Special Electronics, Poland). The battery operated electrofisher was used during the 2009 survey due to the added mobility but sampling times within each habitat was still the same as in the previous surveys. A medium (30 m; 22 mm mesh size) bagged seine net was used at sites with pools and slower flowing water. A gill net with various mesh sizes ranging from 28 mm to 100 mm were deployed for a set number of hours at Spitskop Dam and the two Vaal River sites. Electrofishing at these sites was ineffective due to the water depth. Medium sized (50 cm × 10m; 22 mm mesh size) fyke nets were used to sample fish at all the sites for a minimum of two hours per site during the 2007 and 2008 sampling surveys. The catch per unit effort was extremely low at most sites due to the depth.

2.3. Water and sediment analysis

Water and sediment samples were collected to use as explanatory variables for the fish community structure analysis. The detailed water quality results can be found in Malherbe et al. (2013) and the sediment results have been published in Malherbe et al. (2015). Water and sediment samples were collected during each survey at each site for nutrient, ions, metal and pesticide analysis. Nutrient analysis was completed using a Merck Pharo 100 Spectroquant (Merck KGaA, Germany) and relevant test kits. Ions and metal concentrations were determined using an Ethos Microwave Digester with analysis on an Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS). Pesticide analyses were completed in the sediment samples with analyses for synthetic pyrethroids, organochlorine and related pesticides using a GC-ECD method while organophosphorous pesticides were analysed using a GC-FPD/NPD.