Government of **Western Australia**
Department of **Water**

Ecosystem health in the Canning River, focusing on the influence of the Kent Street Weir

Assessed December 2009 – September 2011

Looking after all our water needs

Water *Science*
technical series

Report no. WST 50
May 2013

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Cover photograph: Kent Street Weir, 2011.

Disclaimer

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Preface

This study was undertaken to assess the health and condition of the Canning River aquatic ecosystem in the vicinity of the Kent Street Weir (KSW), with a focus on the influence of the KSW. The assessment focused on the finfish and decapod community, although also considered water and sediment quality, phytoplankton and hydrological information.

The purpose of this study was to address knowledge gaps to enhance management of the KSW, in an effort to maximise ecosystem health while protecting the social values supported by the weir.

It is acknowledged the presence of the KSW on the Canning River represents a departure from the natural condition and will elicit a response in ecosystem function. However, the original purpose of the weir (maintenance of fresh water and water level upstream) remains valid today and accordingly its removal is not under review in this study. Further, due to broadscale changes to the Swan-Canning ecosystem since European settlement (e.g. increasing salinity due to opening of the bar at the river mouth, system-wide catchment development and climate change impacts), the weir's removal would not return ecosystem function to its natural state.

Summary

South-west Western Australia is experiencing a drying climate, with winter rainfall significantly lower than the long-term average (BoM 2011a) and resultant reductions in streamflows (DoW 2011). This situation is expected to continue or worsen during the next 30 years (CSIRO 2009). These climatic changes combined with an increased magnitude and frequency of extreme tidal conditions associated with La Niña events (as seen in 2010–11) represent a significant threat to the riverine ecosystem around the Kent Street Weir (KSW) in the Canning River. The study reported here is in response to these conditions: it investigates the health of the KSW pool environment in order to inform management under drying conditions while protecting both the original purpose of the KSW and the additional social and environmental values it supports.

Since 1927, a permanent weir structure has existed in the Canning River near Kent Street. The KSW was constructed to prevent salt water encroaching into fertile agricultural areas. The weir pool created from this structure stretches approximately 5 km upstream. Freshwater abstraction licences exist for irrigation of adjoining lots above the weir.

Historically the KSW has been operated by removing the weir boards when the winter flows are sufficient to prevent estuarine (salt) water moving upstream – for approximately four months each year (depending on river flows). This action restores bioconnectivity and the force of the winter flow is thought to flush the weir pool of some accumulated sediments and turn over stratification. By operating the weir in this fashion, fresh water is impounded upstream during the summer and water levels are maintained.

Due to record low rainfall in winter 2010 the KSW boards were not removed. High tides through 2010–11 resulted in significant saltwater intrusion into the weir pool (overtopping the weir), with water reaching almost marine salinity.

The project reported herein was borne out of the need to understand the current ecology and environmental condition of the Canning River around the KSW (primarily concentrating on the upstream pool environment) and address some of the knowledge gaps relating to the risks of leaving the weir boards in place. This study focused on assessing the fish (finfish and decapod) community, with supporting data on aquatic macroinvertebrates, hydrology, phytoplankton, water quality, and sediment contamination from other studies to provide a more complete understanding of the weir pool environment.

The results of this study suggest the KSW pool environment is degraded, with low relative species richness, low abundance (compared with sites above and below the pool environment), dominance of exotics, and a community comprised largely of salt-tolerant species (fish, phytoplankton and aquatic macroinvertebrates). Routine water quality monitoring shows periods of near anoxic conditions and sediment studies found a number of contaminants exceeding ANZECC and ARMCANZ (2000a) guideline levels in both sediment and water (most notably chlordane, copper, lead, zinc and nutrients). Only minor variability in the data collected was recorded between 2010 and 2011, primary due to temporary changes due to increased salinity above the KSW.

The environmental data analysed in this study suggest that degradation of system health is related to long-term environmental conditions rather than a specific response to the weir boards remaining in place through 2010 and most of 2011. The current ecological state is most likely a function of inputs of contaminants, sediment and organic material from the developed catchment and limited flushing capacity due to the presence of the KSW and reduced streamflow (damming in the upper catchment and reduced rainfall). Associated effects include stratification and subsequent deoxygenation – particularly in bottom water – and reduced capacity to remove tidal-derived salt.

Degradation of the weir pool environment is expected to worsen under predicted climate conditions. This may result in increasing impacts to system ecology and is likely to have ramifications for social values (e.g. impacts to aesthetic quality and recreational use relating to increased phytoplankton blooms, contaminant build-up and fish kills).

Extensive intervention has already occurred in the management of the weir pool including removal of the invasive aquatic plant *Hydrocotyl ranunculoides*, treatment with Phoslock™ to reduce sediment released phosphorus and the establishment of two oxygenation plants to provide oxygenated water to over 2 km of the Canning River upstream of Kent Street weir.

In addition to social values associated with aesthetics, abstraction and recreation, the Canning River contains over 30 species of finfish, decapods and tortoise and almost 30 species of aquatic macroinvertebrates. In the freshwater environment above KSW, four freshwater finfish endemic to south-west Western Australia, four native estuarine finfish (two of which are endemic) and two endemic freshwater crayfish species are present. The river therefore remains important in terms of its fish assemblage. Accordingly, there is a strong case to protect and improve river ecology.

A preliminary risk analysis has been conducted for several potential management scenarios to address the impacts identified above and threats to ecosystem health into the future: these are discussed and recommendations provided.

It is clear that action is required to prevent further degradation of system health; however, the solution is complex with all options having advantages and disadvantages related to the range of values present. Whether the KSW is redesigned, removed or moved, or the area is left as an in-situ treatment zone for water quality, or otherwise, needs to be determined through a detailed risk analysis. This includes a decision around the importance for improving fish passage (which was a specific driver of the study reported herein). This study demonstrated that the KSW prevents movement of some fish species at certain times; restricting habitat availability and resulting in some mortality where individuals become trapped by the weir (e.g. freshwater species trapped below the weir). However, current evidence does not support a significant risk to survivability of any species. There are also a number of risks associated with improving fish passage (particularly with construction of a fishway), which further complicates the decision and further demonstrates the need for a holistic assessment of the interplay between threats, risks and values present in the Canning River around KSW.

1 Introduction

The Kent Street Weir (KSW) is in place to maintain water level and freshwater upstream. Its management includes annual removal of weir boards when freshwater flows are sufficient to counter tidal (salt water) intrusion above the weir: this is to increase flushing of the system and provide for bioconnectivity.

The study reported here was originally designed to assess the general ecological health of the Canning River in respect to the influence of the KSW. A major impetus for the study was the likelihood of the weir boards not being removed, given the declining stream flows of recent years. Due to low freshwater flows in 2010, following a record low winter rainfall (BoM 2011a), the weir boards were not removed and substantial intrusion of saltwater above the KSW also occurred. The study thus became a direct assessment of the response of the Canning River ecosystem to weir boards remaining in place.

The ecosystem health of the Canning River in the vicinity of the KSW was assessed in relation to fish and macroinvertebrates, water quality, sediment quality, phytoplankton and hydrology – primarily in relation to the weir's influence. The assessment focused on elucidating any direct response to the weir boards remaining in place.

The study was designed to inform management of the Canning River under a scenario where the original purpose of the KSW was maintained (sustaining water level and freshwater conditions upstream of the weir). Expectations of healthy ecosystem function, in which to assess current condition, were set accordingly. This included assessment of the system's ability to provide ecosystem services and maintain values.

1.1 Kent Street Weir

The KSW is situated on the Canning River within the Canning River Regional Park and separates the Canning Estuary from the Canning River (see Figure 1 to Figure 3).

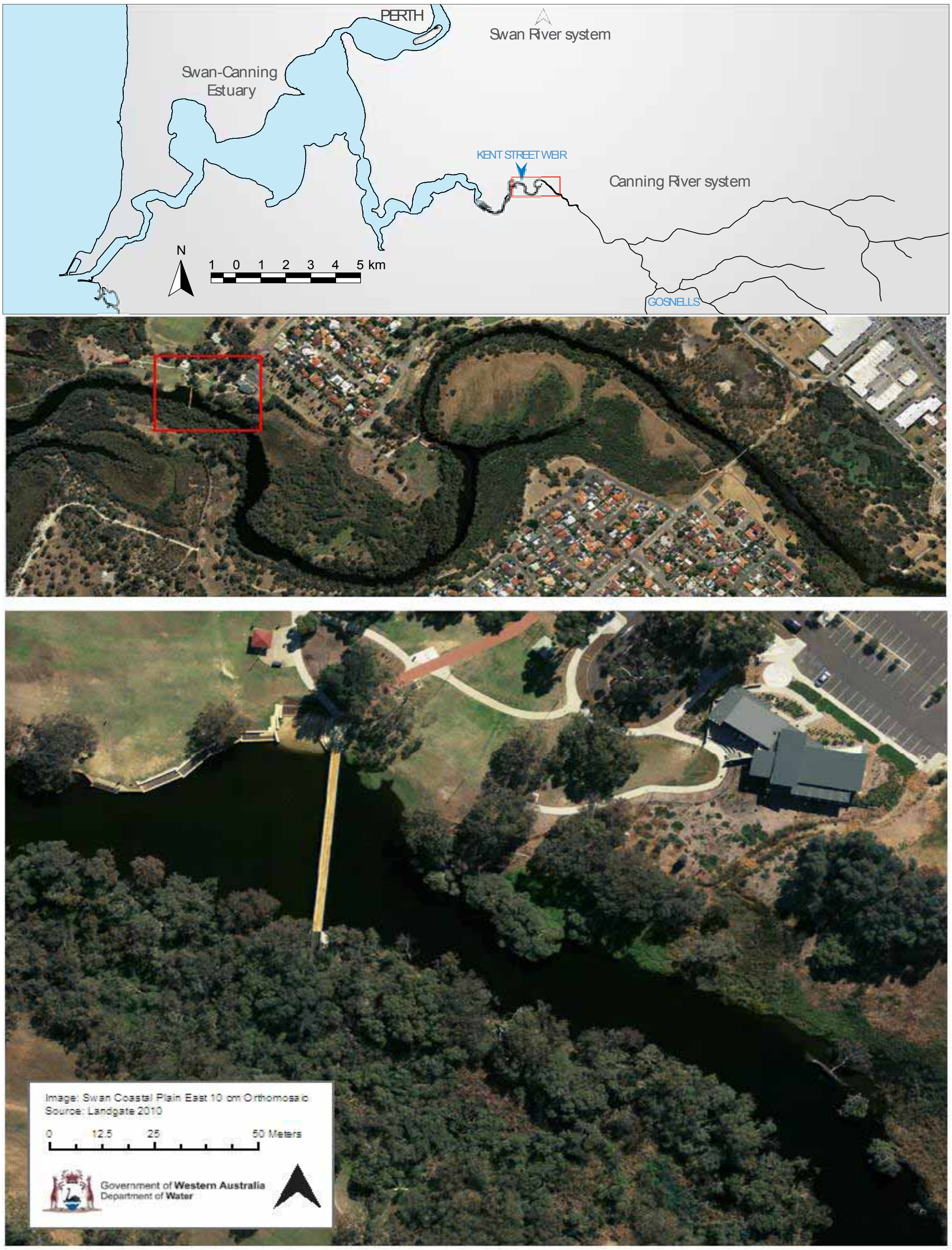


Figure 1 Location of the Kent Street Weir on the Canning River, south-west Western Australia.

Figure 2   Kent Street Weir from the left bank facing upstream (winter 2010).

The physical features of the KSW are described below, adapted from Section 2.1.2 of GHD (2009) and updated information from the Swan River Trust. The weir structure is 52 m long and consists of a concrete sill as the base with concrete bullnose piers at 3.0 m centres and sheet pile cut-off walls. The piers protrude above the sill to a height of 1.5 m and support a metal bridge that spans the Canning River. The piers have slots for placement and removal of stop boards. According to the original design drawings, the concrete sill is approximately 2.4 m above the riverbed (RL -0.45 m AHD). With all stop boards in place, the weir height reaches approximately 3.4 m above the riverbed to RL 1.07 m AHD.

Original drawings are available from the Department of Transport.

Purpose and history

It is expected the historic water regime of the Canning River above the KSW, before anthropogenic influence, would have been predominantly fresh and perennial. Salinity levels rose with the opening of the river mouth at Fremantle in 1896 (Brearley 2005), with increased frequency of saline to brackish water intrusion into established agricultural districts immediately above the weir's current location. Saltwater conditions in the Canning River around KSW would have been exacerbated due to reduced streamflows after dams were constructed on the Canning River (pipehead erected in 1924, Canning Dam completed in 1940) and the largest tributaries (Southern-Wungong River and Munday and Churchman brooks). Without the KSW the perennial nature of the Canning River would be at risk given reduced flows from damming and the recent decline in rainfall (BoM 2011a).

The KSW's purpose was to prevent saltwater penetration into the lower reaches of the Canning River during periods of low river flow to maintain fresh water for market gardeners and agriculturalists upstream of the weir (reducing the estuary's tidal range). This included the maintenance of water levels.

Stages in construction

The following information was compiled from information held by the Heritage Council of Western Australia's Register of Heritage Places (HCWA 1997) and an assessment of the weir by GHD (2009), which examined whether its original design function could be maintained.

1911 Artificial modification of the Canning River began with a 'sand bag weir' installed annually by local residents.

1927 A weir made from steel piling with removable timber boards was installed.

1937 The Canning River dried out due to construction of the Canning Dam. As a result, the previous structure was replaced with a higher weir in 1940, including replacing steel piling with concrete.

1960s General upgrades

1989 Existing bridge structure was added and work carried out to the roads and recreational park area nearby

2005 Reconstruction of the left abutment. Existing wooden weir boards were replaced with concrete boards in January 2005 – repairing a hole that had developed.

The original purpose of the KSW remains, being formally supported by existing licences for surface water extraction (three licences in the weir pool with a combined allowance of 6000 kL/year and a further 12 licences through to Gosnells totalling 88 070 kL/year). Further, the Canning River supports a high diversity of values that have become established over almost 100 years and in many cases are intrinsically linked to the KSW (see below).

Associated values

The KSW supports a range of social, economic and environmental values. These values are an important consideration for this study because they provide an ecological management benchmark in so much as a certain degree of ecosystem functionality is required to maintain them.

Values are largely associated with the permanent fresh water and water levels created by the KSW, and include:

- historic value (as discussed above) – this incorporates almost 100 years of a structure at this site
- freshwater source for extraction by licence holders and riparian users (irrigation and stock water supply) – includes requirement for high water quality
- aesthetic value – HCWA (1997) reports a statement of community value: 'appearance of a full and connected river with healthy water quality and supporting fish, bird and tortoise populations and a riparian zone of native vegetation'
- economic value associated with tourist and resident attraction to the aesthetic quality of the riverine landscape

- fishing (recreation and food) – the primary angling species in the area is black bream (*Acanthopagrus butcheri)*
- recreation – swimming (Slee 1973; HCWA 1997), canoeing/kayaking, walking and picnicking
- access over water via the bridge – connecting park with bush (see HCWA 1997)
- associated environmental education centre and site for adult and school groups.

Many of these values are contingent on a healthy functioning ecosystem and largely depend on the artificially maintained permanent fresh water and raised and stable water levels upstream of the KSW.

Water levels in the KSW pool are also maintained by releases of water from the Integrated Water Supply Scheme at six distribution points into the upper Canning River (in operation since the 1950s).

Given the long history of fresh water and stable water levels above the KSW, it is likely the system has adapted to some degree. This adaptation is supported by an altered riparian vegetation community, as reported by GHD (2009 – see sections 2.1.4 and 3.1). It should be noted however that the system is not ecologically stable; having undergone a significant change over the past 40 years from a system dominated by invasive free-floating and emergent macrophytes, to one dominated by phytoplankton and, most recently, to native submerged aquatic vegetation.

The current dominance of submerged native macrophytes is suggested to be due to intervention techniques, namely oxygenation and application of Phoslock™ (Malcolm Robb pers comm.), see review in section 1.2.

Weir management

The KSW has traditionally been operated by weir boards being removed when winter flows are sufficient to prevent saline estuarine water moving upstream.

By operating the weir in this way, fresh water and water levels upstream of the KSW have historically been maintained, while removal of the boards during high winter flows has allowed for flushing, flood relief and restoration of bioconnectivity. Weir boards are typically removed in spring and replaced in early summer – equating to approximately four months a year without boards. Note: due to a permanent concrete footing, bed level is not continuous from upstream to downstream when boards are removed.

The continued ability to manage the KSW in this way has become uncertain due to changing environmental conditions – primarily reduced streamflow (DoW 2011; IOCI 2005) – threatening the ability to remove boards without risking saltwater penetration (due to insufficient flushing capability). Further reduction in streamflow is predicted under even conservative climate modelling scenarios (CSIRO 2009).

Ongoing management of the weir is also at risk due to deterioration of the concrete structure and that manual board removal and replacement cannot be done to contemporary occupational health and safety standards.

Not removing the boards has the potential to significantly affect ecosystem health due to impeded flushing because, coupled with a small degree of 'leakage' and overtopping tidal events, this will result in lingering stratification of the upstream environment (saline water underlying fresh water), associated thermocline, potential for anoxic conditions in the hypolimnion, and build-up of catchment sediment and organic material in the weir pool (including smothering of habitat by sediment and potential accumulation of contaminants bound to sediment). Further, not removing the weir boards effects fish migration.

As stated in the introduction, the likelihood of the weir boards remaining in place under a reduced streamflow scenario was realised in 2010 after the driest winter on record (since records began in 1900, BOM 2011a), with weir boards not being removed until winter 2011 (see history of weir board management in Appendix C).

1.2 A history of intervention

The weir pool is an environment significantly altered from its natural state and has required considerable management intervention especially in response to high nutrient and organic loading from the mixed urban, industrial and agricultural land-uses through the Canning River catchment. Concern about industrial contamination has led to a number of water and sediment studies. A brief summary of both the studies and intervention is essential to consideration of the risk analysis presented in this report.

From 1970 to 1990, a succession of introduced aquatic plants threatened ecosystem and recreational values of the weir pool as sections of the channel were completely choked with free-floating and emergent aquatic plants. Outbreaks of *Salvinia molesta* (a floating fern introduced from South America) were common and by the early 1990's *Hydrocotyl ranunculoides* (a common aquarium plant) dominated much of the area. In the summer of 1992-3, *H. ranunculoides* was largely removed using physical means and herbicide applications. In the following summer, a severe toxic blue-green algal bloom caused the river upstream of the weir to be closed for several months. This algal bloom was comprised of species of the toxic blue-green (or cyanobacteria) genera Anabaena, Anabaenopsis and Microcystis.

This shift from macrophyte dominance to toxic algal blooms in the Canning, as well as algal blooms and fish deaths in the Swan River, focused community attention on the deteriorating health of the system. In 1994, the State government commenced the Swan Canning Cleanup Program (SCCP) to investigate the causes of these water quality problems and develop intervention technologies.

One of these technologies was the phosphorus binding clay Phoslock™ developed as acollaboration between the CSIRO, Water and Rivers Commission (now Department of Water) and the Swan River Trust (SRT) which was applied experimentally between 1999 and 2003 demonstrating reduction in phosphorus release from sediment and reduction in dissolved phosphorus concentrations in water during application.

The other technology trialled in the KSW pool during this period included artificial oxygenation (during the summers of 2002-03, 2003-04 and 2004-05) which led to the construction of two oxygenation plants which deliver oxygen to approximately 2 km of the weir pool between KSW and Nicholson Road Bridge. Water quality data used in this report for the period of 2009 to 2011 will include the effects of both oxygenation and Phoslock™ application especially during the extended saline intrusion of 2010.

Since these interventions have been applied the weir pool has shifted from an algal dominated system to one dominated by the submerged native aquatic plant *Potomageton* and the floating fern *Azolla.* Thirteen species of macrophytes are present in the freshwater areas of the Canning River. Notably, a study assessing the potential for macrophyte reestablishment (Novak and Chambers 2005) showed that macrophyte biomass was higher in areas previously treated with Phoslock™.

Water quality in the Canning River has been monitored weekly by the Water and Rivers Commission/Department of Water and the Swan River Trust since 1995. Substantial additional water quality data has also been collected during trials of Phoslock™, oxygenation and other intervention strategies.

Water flows through the Canning River have also been managed through releases from the Canning Dam since the 1950s. This includes augmentation from scheme water to offset loss from damming in the upper catchment, abstraction and now reduced rainfall. The releases are designed to supplement low rainfall periods during the dry summer months, and are used to maintain water for both human use (licensed abstraction) and environmental needs. Water is currently released from six points in the Canning River above the KSW based on minimum flow triggers outlined in the lower Canning River water allocation plan (DoW 2010). The importance of these flows in maintaining environmental values has been supported by a targeted assessment by Norton et al 2010.

Community and government concern over the safety of the existing weir structure has led to engineering studies which have made a case to remediate the weir to allay these safety concerns. The opportunity exists during any such remediation works to modify the weir to improve flushing of the weir pool and to provide fish passage. The studies discussed in this report are timely in relation to developing a weir replacement strategy.

1.3 Objectives of this study

The initial objective of this study was to assess the general health of the Canning River as influenced by the KSW – primarily what aquatic fauna were present and how the community may be influenced by changes in water quality, hydrology, phytoplankton and bioconnectivity.

This objective evolved into a direct assessment of system health under a scenario where weir boards were not removed – following a decision to leave the boards in place due to insufficient freshwater flows in winter 2010 (to prevent salt water intruding past the weir).

The study comprised several components investigating:

- general environmental attributes and ecological function of the Canning River from KSW through to Gosnells, focusing on biotic indicators
- water quality conditions generally and due to the weir boards not being removed (flushing)
- the effect of saltwater intrusion on water quality above the KSW

- whether sediment contaminants accumulate behind the KSW
- the extent of sediment contamination in the weir pool (KSW to Hester Park)
- fish barrier effects of the KSW.

A secondary objective was to comment on possible mitigation strategies (for stressors identified in this study) to conserve the social/economic values supported by the KSW while optimising protection of general ecological health – incorporating a predictive element considering climate change scenarios. This has been addressed in the form of a risk assessment (Appendix J).

1.4 Stakeholders

Primary stakeholders are the Department of Water, Swan River Trust (SRT), City of Canning, South East Regional Centre for Urban Landcare (SERCUL), Department of Fisheries (DoF) and the local community. The weir is situated on Crown vested land owned by the Department of Water, operated by the SRT and located within the City of Canning (owners of the footbridge over the weir) (GHD 2009).

The Department of Water manages the state's water resources; SRT manages the Swan-Canning Riverpark for environmental, social and economic values; and SERCUL focuses on protecting land and water resources in Perth's south-east region, where the KSW is located.

The objectives of all stakeholders include protecting the ecosystem processes (form and function) required to maintain ecosystem health and associated services (including the supporting values identified in Section 1.1), understanding that the weir's original purpose (maintaining fresh water and water level above the KSW) is not under review.

This project was conducted with funding from the Department of Water, SRT and SERCUL.

2 Scope and general approach

Health of the Canning River system was assessed between December 2009 and September 2011, with emphasis on understanding the influence of the KSW.

A multiple lines of evidence approach was taken given the expected spatial and temporal complexity, while the indicator suite was chosen to characterise the system and elucidate the likely impacts typically associated with weirs.

The study's primary focus was assessing aquatic fauna (finfish and decapods, and to a lesser extent aquatic macroinvertebrates, as end-point indicators of ecosystem health), with phytoplankton, hydrology and water quality data collected largely for interpretation.

A targeted assessment of contaminants in both water and sediment within the KSW pool environment was added to the program in the final year, in response to results from 2009-10.

Data were assessed based on expectations of ecosystem health derived specifically for the Canning River system, given the unique conditions of the system (see Section 2.1).

2.1 Reference condition: establishing a management benchmark

Assessing ecosystem health requires a benchmark or reference against which observations can be compared. This 'reference condition' can be set at the ecological state before anthropogenic impact (pristine) or at a state with a certain degree of impact or change from historically natural conditions. The latter is a more pragmatic approach given that the health of most river systems in south-west Western Australia has been affected by anthropogenic changes and that some of these changes are outside of localised control (e.g. climate change). This type of reference also provides scope to exclude certain environmental perturbations that are not open to change within the study under investigation; for example, determining optimal health in catchments dammed for water supply (where factors such as water level are permanently altered from the natural state). This does not imply that returning systems to a pristine state is undesirable, only that it is often impractical. A further limitation of using a pristine benchmark is that the ability to accurately define the pristine state is typically constrained by a lack of empirical data.

Expectations of healthy ecosystem form and function are difficult to derive for the Canning River system due to a number of factors that have permanently altered the natural state. These factors include opening of the Swan River mouth (resulting in increased salinity of the greater Swan-Canning system – Brearley 2005), large-scale modifications due to catchment development, the presence of the KSW (effects include reduced flushing and it being a barrier to fish migration) and climate change. As such, a pragmatic approach to defining reference condition was required for the assessment herein.

Reference condition for the Canning River system was derived from a general understanding of species requirements. This was based on biota expected to exist in the system given findings from other studies in the Canning River system (post-weir installation), however few studies have been conducted within the specific study area between the KSW and Gosnells.

Expectations of biotic assemblages were set considering that management of the KSW is designed around maintaining a permanent freshwater system upstream, with allowance for estuarine species to enter the area during periods of weir board removal (coinciding with high freshwater streamflow, typically around winter/spring). The aquatic environment below the KSW is maintained as an estuarine system where conditions change from near-marine salinities through to fresh water between summer and winter respectively. It should also be recognised that the KSW pool represents a relatively deep freshwater pool environment and there is a paucity of data available for similar systems on the Swan Coastal Plain, particularly at the freshwater/saltwater interface. As such, any expectations derived are indicative only.

In the absence of relevant baseline data, a theoretical reference condition was compiled for each ecological health indicator used in this assessment by considering data from other studies within the Canning River, data from other river systems of similar form and function, expert knowledge of biological requirements, and guidelines for aquatic ecosystem protection. Reference conditions for each indicator are referred to within the associated methods.

3 Aquatic fauna: 2009–11

3.1 Methods

Site selection

The study area was the lower section of the Canning River from the pool immediately downstream of the KSW (site KENDS) through to Gosnells (site GOS, upstream extent) (Figure 3). This encompasses approximately 12 km of the Canning River and constitutes the area most likely influenced by water quality changes associated with weir management. The study area includes a weir pool of approximately 5 km above the KSW (see depth profile in Figure 4).

Six sites were chosen to assess biotic assemblages within the study area. Sites were selected to capture conditions in the wider, deeper section directly above and below the KSW, with four additional sites providing a gradient extending upstream to Gosnells (Figure 3) (site coordinates are provided in Appendix B). Note: site GOS occurs above the known limits of saltwater intrusion and was unlikely to change in response to weir management or hydrology during the study period (representing a freshwater reference site). All sites were situated on the Swan Coastal Plain.

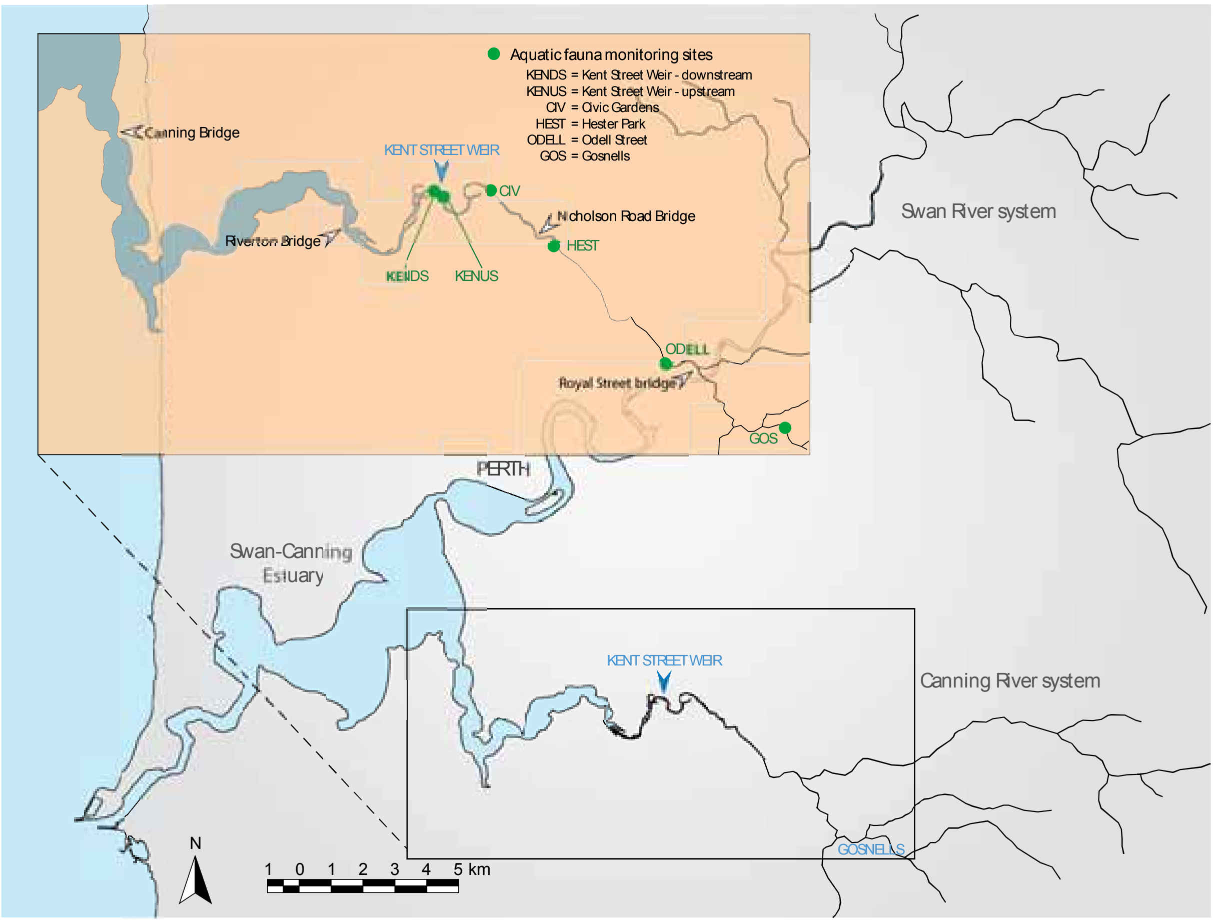


Figure 3   Location of aquatic fauna monitoring sites.

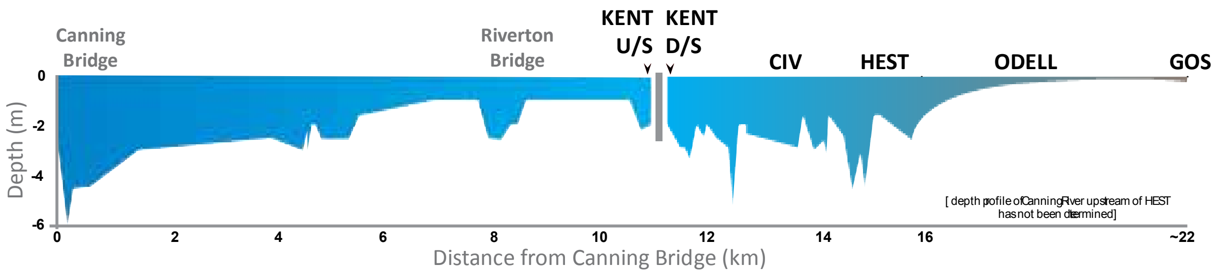


Figure 4   Distance from the weir and approximate channel depth at Canning River sampling sites.

Indicator selection

Fish (finfish and decapods) and aquatic macroinvertebrate assemblages were chosen as indicators.

Assessment of fish community composition was included in this study given the range of information (multiple scales) that can be expressed by data. Information can be gained relating to broad ecosystem functionality through to specific and localised environmental perturbations. Associated data also provide a direct measure of several social values, such as recreational fishing value.

Fish are important ecological health indicators as they are:

- relatively long lived (representing changes occurring over extended temporal periods)
- widely distributed (ability for comparison among systems within species range)
- mobile (reflecting changes that may occur further upstream or downstream of a study site, including the influence of fish barriers)
- easily identified and sampled
- sensitive and responsive to many specific changes in water quality, habitat or other components of the ecosystem (e.g. Karr 1981; Plafkin et al. 1989; USEPA 1990; Rosenberg & Resh 1993; Lonzarich 1994; Harris 1995; Karr 1999; White & Storer 2012a,b)
- typically at the top of the aquatic food chain, forage at all levels of the trophic structure and accordingly represent an integrated view of the watershed environment. This equates to a potential to display effects occurring through the entire trophic structure and show the cumulative impacts of chemical, physical, and biological stressors and an integration of food and habitat quality)
- information is easy to relate to the broader community.

As outlined above, fish can be an important diagnostic tool with knowledge of general behaviour, ecological requirements and specific tolerances of fish having the potential to inform on both acute and chronic effects to system health (for instance, absence of species can be linked to poor water quality condition and size distribution within a population may indicate reproductive success over previous years).

Aquatic macroinvertebrate communities also provide valuable information on ecological function. Macroinvertebrates, compared with fish, can provide more sensitive information regarding site-specific conditions (Rosemberg & Resh 1993; Harris 1995) as their comparatively reduced mobility and associated smaller ranges result in species dynamics being more reflective of localised conditions. In particular, macroinvertebrates are targeted for assessment as they are sensitive to environmental disturbance, with even small changes to the physical or chemical environment altering community composition and structure through the loss, addition or replacement of taxa. Macroinvertebrate community dynamics have been shown to reflect a number of anthropogenic activities including changes in water chemistry (Metzeling 1993), sedimentation (Doeg & Milledge 1991), land use (Kay et al. 2001), flow regime (Wood & Petts 1994), salinity (Kay et al. 2001), heavy metal contamination (Grumiaux et al. 1998) and riparian vegetation loss (Quinn et al. 1992).

Reference condition for finfish and decapods

As previously introduced, the Swan-Canning system has changed significantly in both form and function from its natural state (see Section 2.1). Accordingly, comparing biological data collected in this study to an inferred pre-European ecology is both unrealistic and impractical. Further, the continued presence of the KSW presents a significant and ongoing alteration of system ecology and, at least in terms of the weir's original purpose (maintenance of water level and fresh water upstream), will continue to influence system function into the foreseeable future. As such, data in this study were assessed in respect to reasonable expectations of biota under these new conditions, with a primary objective to maintain ecosystem services (and associated processes).

Only a few studies have previously been conducted on the Canning River between the KSW and Gosnells (study area for this trial). Table 1 provides a list of relevant studies and species collected for the study area above KSW. These data provide reference for conditions found in this study, however as the system is not managed with an expectation of natural form and function, these data are only indicative.

Table 1 Fish collected in previous studies within the main channel of the Canning River downstream of Gosnells

Species	Location and relevant methods	Reference
Western minnow, western pygmy perch, freshwater cobbler, nightfish, Swan River goby, western hardyhead, marron, gilgie, mosquitofish, one-spot livebearer, spangled perch, yabbie	GOS site (site from this study) Monthly sampling, Nov 2009–Apr 2010 (1 of 4 sites assessed on the Canning River between Gosnells and Roleystone)	Norton, Storer & Galvin 2010
Swan River goby, western hardyhead, mosquitofish (KSW) Sea mullet (Gosnells)	Two sites on Canning River; KSW and Gosnells Specific locations and sampling times undefined, see Figure 1 in reference	Unpublished data referred to in Morgan, Beatty & McAlleer 2007
Swan River goby, gilgie, oval spider crab, carp and mosquitofish	Four sites: KSW to Nicholson Road (small fish traps only)	Storey & Rippingale 2000
Western minnow, western pygmy perch, Swan River goby, western hardyhead, gilgie	Two sites: one near GOS and one near HEST (15 sites assessed in study: 8 on Canning River, remainder on Southern River and Wungong River tributaries)	Storey 1998

Drawing on these studies, the following native species are expected within upper portion of the study area for this trial: western minnow, western pygmy perch, freshwater cobbler, nightfish, Swan River goby, south-western goby, western hardyhead, gilgie, oval spider crab and smooth marron. Of these only the Swan River goby, western hardyhead, oval spider crab and gilgie are expected towards the downstream end of study area (above the KSW). Note: the Swan River goby and western hardyhead are known to inhabit and move between the estuary and freshwater stream, oval spider crab are generally found in salt water and gilgie are highly salt tolerant, previously found at over 40 ppt (salinity) in the Preston River and commonly found in systems over 10 ppt throughout south-west Western Australia (data from Storer et al. 2011a,b).

No endangered, threatened or vulnerable fish were expected (as listed on the Department of Environment and Conservation Threatened or Priority Fauna database or through the *Environmental Protection and Biodiversity Conservation Act 1999*, International Union for Conservation of Nature 1994/2001 or Threatened Species Scientific Committee).

Although few studies have examined aquatic biota within the Canning River from the KSW through to Gosnells, many have examined species assemblages upstream (including associated tributaries) and provide a general idea of distribution within the river's catchment. The following species have been recorded: four native freshwater finfish (western minnow, western pygmy perch, nightfish, freshwater cobbler); three species known to migrate between freshwater and estuarine environments (Swan River goby, south-west goby, western hardyhead); four freshwater crayfish (gilgie, marron, koonac, the exotic yabbie); and five exotic finfish (mosquitofish, one-spot livebearer, goldfish, rainbow trout, brown trout). Studies reviewed were ARL 1988a,b,c; Beatty et al. 2003, 2005a,b, 2006; DoW unpublished data 2007–10; Norton et al. 2010; Hewitt 1992; Maddern 2003; Morgan & Beatty 2006; Morgan & Sarre 1995; Morgan et al. 2004, 2007; Morrison 1988; Pusey et al. 1989; Sarti 1994; Storey 1998; Storey et al. 2000; Tay 2005; WRM 2006; and unpublished Department of Fisheries and Western Australian Museum records. Methods used in these studies encompassed fyke netting, trapping and electrofishing.

Museum data also include a single record of the pouched lamprey in the upper Canning River. Given the migration pattern of this species and a general accepted home range outside of the Canning River system, this species is not expected to be commonly found.

A reference-baseline for fish in the environment below the KSW has not been provided as an assessment of estuarine communities below the weir was not a specific objective of this study. Estuarine species recorded entering the area above the weir is discussed separately. Data are available for review through the DoF website (DoF 2012).

Fish Health Index

Data from this study were also assessed using the Fish Health Index (FHI) developed by Department of Water (Storer et al. 2011b). The FHI is calculated from observations compared against expectations for both richness and abundance (native and exotic species), and incorporating species catchability. Given that the system is managed as a freshwater body it was expected that the entire complement of native freshwater species previously found in the permanent freshwater areas of the system were expected at all study sites at some stage throughout an annual cycle (refer to the species list in Table 1). The applicability of this reference condition under the current environment setting is discussed.

The FHI provides a score between 0 and 1 (1 being least modified from reference) calculated using the weightings described in Table 2.

The **O/E metric** (observed/expected) only scores species commonly 'expected' at any one site; that is, species that if present have a high chance of being caught. Rare or seasonal species are not incorporated in either observations or expectations.

The **two O/P metrics** (observed/predicted) compare the native species predicted to have occurred in a subcatchment against the native species caught at the site. All species are included in the reference and observation lists, including both rare and seasonal species. Rare and seasonal species are assessed separately in the O/P metric to account for different expectations and these are:

- **O/P_r** – rare: species that naturally exist in low abundance within their distribution range, or do not readily enter traps, hence their probability of capture is reduced. Further, when they are captured it is typically in low numbers.
- **O/P_s** – seasonal: species with a high probability of no capture due to factors such as seasonal migration. When caught these species are typically in large numbers.

Table 2 Components and scoring protocol for the Fish Health Index.

Component	Metric	Definition	Weighting
Expectedness **species richness relative to reference condition**	Observed to expected ratio (O/E)	Compares the native species expected to occur in a site based on reference condition and the actual species collected. The total number of native species predicted to occur in the subcatchment does not include species assigned as either rare or seasonal.	0.25
	Observed to predicted ratio: **rare** (O/P_r)	Compares the native species predicted to have occurred based on reference condition in a subcatchment against the native species actually caught at the site. This metric includes the **rare species**.	0.17
	Observed to predicted ratio: **seasonal** (O/P_s)	A comparison of the native species predicted to have occurred based on reference condition in a subcatchment against the native species actually caught at the site. This metric includes the **seasonal species**.	0.08
Nativeness **proportion of abundance and species richness that are native**	Proportion native abundance	Proportion of individuals that are native species.	0.25
	Proportion native species	Proportion of species that are native species.	0.25

Expert rule: where exotic fish are present in the absence of natives the site is automatically assigned a score of 0.05. Where no fish are present the site is assigned a score of 0 (as no fish is deemed less healthy than exotic fish only).

Rare and seasonal taxa occurring in systems in south-west Western Australia are listed in Table 3. Both *Lepidogalaxias salamandroides* (salamanderfish) and *Galaxiella nigrostriata* (black-stripe minnow) were not included in the FHI as they are predominantly found in ephemeral pools, which the FHI protocol has not been designed for (sensitivity and power analysis not carried out). The burrowing crayfish (Engaewa) were also not included as they are not typically found in surface waters.

Table 3 Rare and seasonal species

Seasonal species		Rare species
Tandanus bostocki (freshwater cobbler)	*Cherax preissii* (koonac)	*Nannatherina balstoni* (Balstons pygmy perch)
Geotria australis (pouched lamprey)	*Cherax crassimanus* (restricted gilgie)	*Galaxiella munda* (mud minnow)

The FHI provides an overall measure of system health based on fish composition, factoring in the elements discussed above. The FHI's inclusion allows direct comparison with the FHI scores of more than 100 sites across south-west Western Australia. The FHI only includes species of fish residing in freshwater systems (non-freshwater species are not accounted for except the estuarine species Swan River goby, south-western goby and western hardyhead, which are commonly found within freshwater systems within their distribution). A detailed explanation of the FHI is provided in Storer et al. 2011b.

Fish sampling

Fish were sampled using fyke nets, as per the protocols outlined in Storer et al. 2011b. Two dual-wing fyke nets were deployed at each site – one facing upstream and one facing downstream (downstream of the other) and capturing species moving downstream and upstream respectively. The KENDS and KENUS sites only assessed fish travelling upstream and downstream respectively (given the KSW's presence prevented the alternative migration in most periods). Two fyke nets were used to sample upstream migration at the KENDS site given the larger width of the river[1].

Rectangular mouthed fyke nets were used: mouth 1 m wide and 0.75 m high, mesh 2 mm, tail 3 m long, and each wing 4 m long and 0.55 m high. Ball floats were provided in the tail of each fyke to provide space for any trapped air-breathing species (particularly designed for tortoises, ducks and water rats). Mesh screens were placed on the mouth of the fyke nets to restrict tortoise catches and in turn reduce predation of the other species captured (after many tortoises were collected in the initial sampling periods)[2].

Nets were retrieved 24 hours after deployment and the following information was collected: species, abundance, direction of movement (upstream or downstream), size-class (see categories in Appendix D), visual reproductive condition (including presence of berried or gravid females, nuptial colours, reddened vents, altered appearance of urogenital papillae) and any conspicuous signs of declining fish condition (presence of ectoparasites, disease, physical injury or behavioural symptoms of stress, such as moribund or lethargic individuals).

[1] Given the variability in stream width and depth through the Canning River the proportion of the stream channel covered by fyke nets varied: 100% of the channel width was assessed at the GOS site, ~90% at KSW sites (using stop nets) and ~ 50% at ODELL, CIV and HEST. Nets were fixed to the bank and bottom of river bed at all sites. Given the length of the assessment period it is unlikely the variability in per cent coverage had an effect on total richness over the trial period.

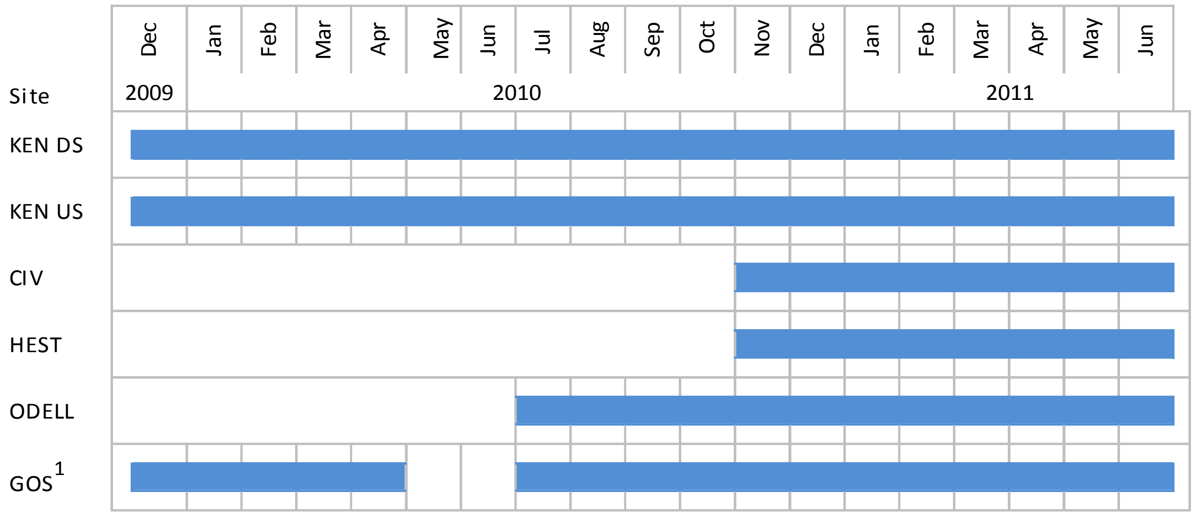
[2] Screens were only employed at sites KENUS (from February 2010), CIV and HEST (from January 2011) and at ODELL (between March and June 2011) in response to the high abundance of tortoises.

Note: all native species were immediately returned to the river and exotic species were euthanised.

Sampling was conducted monthly between December 2009 and September 2011.

Assessments started with two sites (KENDS and KENUS) with other sites added to the program to elucidate conditions extending further upstream. As illustrated in Table 4, sites ODELL and GOS were added to the study in July 2010 (however the GOS site was monitored for most of the preceding period as part of a separate study, Norton et al. 2010) and sites CIV and HEST were added in November 2010.

Table 4 Sampling periods for ecological assessment sites



[1] GOS data from December 2009 to April 2010 was obtained from a separate study (Norton et al. 2010).

Reference condition for aquatic macroinvertebrates

Data was compared to a previous study by Storey and Rippingale (2000) which examined macroinvertebrate assemblages at four sites between KSW and Nicholson Road, and also against known traits (see Rolls et al. 2012), particularly tolerance to salinity.

Aquatic macroinvertebrate sampling

The Australian River Assessment System (AUSRIVAS) sampling method was employed (see Halse et al. 2001) with assessment of channel habitat only and use of the box sub-sampler to calculate relative abundance following a live pick of 200 specimens. Note: assessment of channel habitat alone provides a standard for comparison between sites where different habitat types may be expected. This may underestimate richness and abundance within a site, in particular where macrophytes occur, however accounts for the fact that not all habitats are naturally expected at all sites.

Data were examined based on species richness, abundance and a general review of traits and functional feeding groups[3].

[3] Note: the south-west Western Australian AUSRIVAS model was not used as recent assessment of the model's ability to detect ecosystem health demonstrated it was weakly correlated with stressors relevant to this study (Storer et al. 2011b).

Macroinvertebrates were assessed in March 2011 at three sites: CIV, HEST and GOS. When analysed, the sample collected at GOS showed signs of degradation[4] and a second GOS sample was collected in April.

Supplementary information

A range of site-specific data relating to catchment disturbance, physical form, water quality, hydrology, fringing vegetation and habitat features were collected for interpretation of biological data but, with the exception of water quality (Section 6), are not directly reported in this study. Proforma field sheets are provided in Appendix A, for reference, and information is available through the Department of Water.

3.2 Results: finfish and decapods

Results summary

Thirty species of fish (finfish and decapods) were collected:

- seven native freshwater species (four finfish, three decapods)
- six exotic freshwater species (five finfish, one decapod)
- 17 estuarine species (13 estuarine finfish including five species known to move into freshwater areas, four decapods).

Seventeen species common to environments above and below the KSW were collected:

- four freshwater species (native and exotic) were found below the KSW, however occurrences were rare and abundance low
- 13 estuarine species were recorded above the KSW; however, with the exception of those species known to migrate to freshwater environments, species numbers were very low and their presence temporary (typically following overtopping events)
- nightfish and freshwater cobbler were limited to upper freshwater environments (GOS and ODELL) and marron were rarely seen downstream of GOS and only ever in low numbers (e.g. only one adult and one juvenile marron were recorded at KENUS).

The number of taxa was depauperate within the weir pool (sites KENUS, CIV and HEST) and also the ODELL site. Of these sites, richness was higher at KENUS, however this was due to the temporary occurrence of species following overtopping events.

Swan River goby, western hardyhead and mosquitofish were dominant (relative abundance) at all sites except GOS, where there was co-dominance with native freshwater species.

Size-class distribution suggests all freshwater species were viable. A complete size-class range was observed in most estuarine species, including for all species known to migrate into freshwater areas.

[4] insufficient preservative (ethanol) appeared to be the likely cause of degradation; due to leakage

Spatial variability

Fauna data for each site within each season for both 2010 and 2011 are presented in Figure 8 to Figure 11. A depth-profile plot of the Canning River system is provided in each figure to provide a reference of site location and depth. Salinity conditions present within each season have been incorporated for reference, with data taken from a single sampling event within each season representing the general condition observed in the period.

All fish species collected within this study are listed (Latin and common names) in the *List of species* presented at the end of this report.

Throughout the study period 23 species of fish were collected below the KSW and 24 above it (including exotic species). This included 17 species common to both environments.

Native freshwater species

Seven freshwater fish species were collected, comprising four finfish (western pygmy perch, western minnow, nightfish, freshwater cobbler), two crayfish (marron, gilgie) and a freshwater shrimp.

Freshwater fish were largely absent from the weir pool area (KENUS through to ODELL), with species present only represented by a few individuals. Freshwater cobbler and nightfish were absent from the Canning River below ODELL.

Marron were recorded infrequently and always in low numbers, primarily limited to spring and summer. Catches were higher at GOS and ODELL.

Freshwater shrimp (not included on figures) were in high abundance at all sites except GOS – averaging 10.3±20 individuals per sampling event at GOS compared with around 200 individuals at all other sites (maximum count = 1962 in one fyke at KENDS).

Exotic freshwater species

Several exotic freshwater species were collected, dominated by mosquitofish at all sites (more abundant between KSW and HEST) and one-spot livebearers at GOS. A few yabbie were present at most sites, koi were collected in low numbers at HEST and goldfish were typically rare and largely restricted to the weir pool (predominantly KENUS and HEST) with 91% of the total 145 caught during the study being in this region (not recorded at GOS).

Two adult spangled perch were collected at GOS. Note: this was the first recording of this species in the Canning River.

Estuarine species

Seventeen estuarine species were collected during the study period.

Nine of these species were confined downstream of the KSW or had a temporary presence immediately upstream of the weir following tidal intrusion. These species were bridled goby, silver biddy, gobbleguts, western striped trumpeter, yellow-eye mullet, blowfish, Australian anchovy, yellowtail grunter and black bream. Yellowtail grunter distribution extended to HEST in January 2011, remaining in the area until May; corresponding with the extent of tidal intrusion. A spike in abundance was recorded in black bream at KENUS in January 2011

(~300 individuals, all below 100 mm total length) following a series of tidal intrusions, however the species was absent in the subsequent sampling period. No more than two individual black bream were recorded in any sampling period above KENUS during the trial outside of the event described above.

The remaining four finfish species recorded were found primarily upstream of the KSW: Swan River goby were common at all sites except GOS; western hardy head were common throughout all sites (primarily at KENUS/DS and ODELL); south-western goby were generally restricted to GOS and to a lesser extent at KENUS/DS (absent in other sites); and sea mullet were largely restricted to KENDS and KENUS following intrusion, however a few individuals were found in ODELL and GOS in spring 2011 (following removal of the weir boards).

Four estuarine decapods were also recorded. Oval spider crab were relatively rare in the study area and primarily limited to the KSW sites (upstream and downstream) and through to CIV, although were collected through to GOS. The other three species were western king prawn, western school prawn and the blue swimmer crab, which were restricted to below KSW and only found in low numbers (<10 individuals in total during the trial). Accordingly these three species are not incorporated Figure 8 to Figure 12.

Richness, relative abundance and Fish Health Index score

Examination of the species richness at each site, over the entire study period, highlights a general dearth of species at CIV and HEST, with KENUS displaying marginally higher numbers due largely to temporary occurrence of some estuarine species following tidal intrusion (moving downstream again shortly afterwards) (Figure 5). Freshwater species typically inhabited the upstream sites of GOS and, to a lesser extent, ODELL (Figure 5).

Relative abundance showed a dominance of euryhaline species (generally Swan River goby and western hardyhead) at all sites except GOS, where freshwater species were most abundant. Exotic species were abundant at all sites, becoming co-dominant at CIV and HEST (Figure 5). Of the total abundance of fish recorded in the KENUS, CIV and HEST sites, native freshwater finfish species contributed 1% proportionally, with 96% from goby and mosquitofish combined. The distribution of species was more even at GOS, where distribution was 45% native freshwater species, 4% migratory/euryhaline species (Swan River goby) and approximately 50% exotics (mosquitofish and one-spot livebearer).

The Fish Health Index highlighted CIV as the most impacted (based on number and abundance of exotic species and generally low species richness), however slight modification was apparent at all sites – with GOS appearing the least impacted (Figure 5).

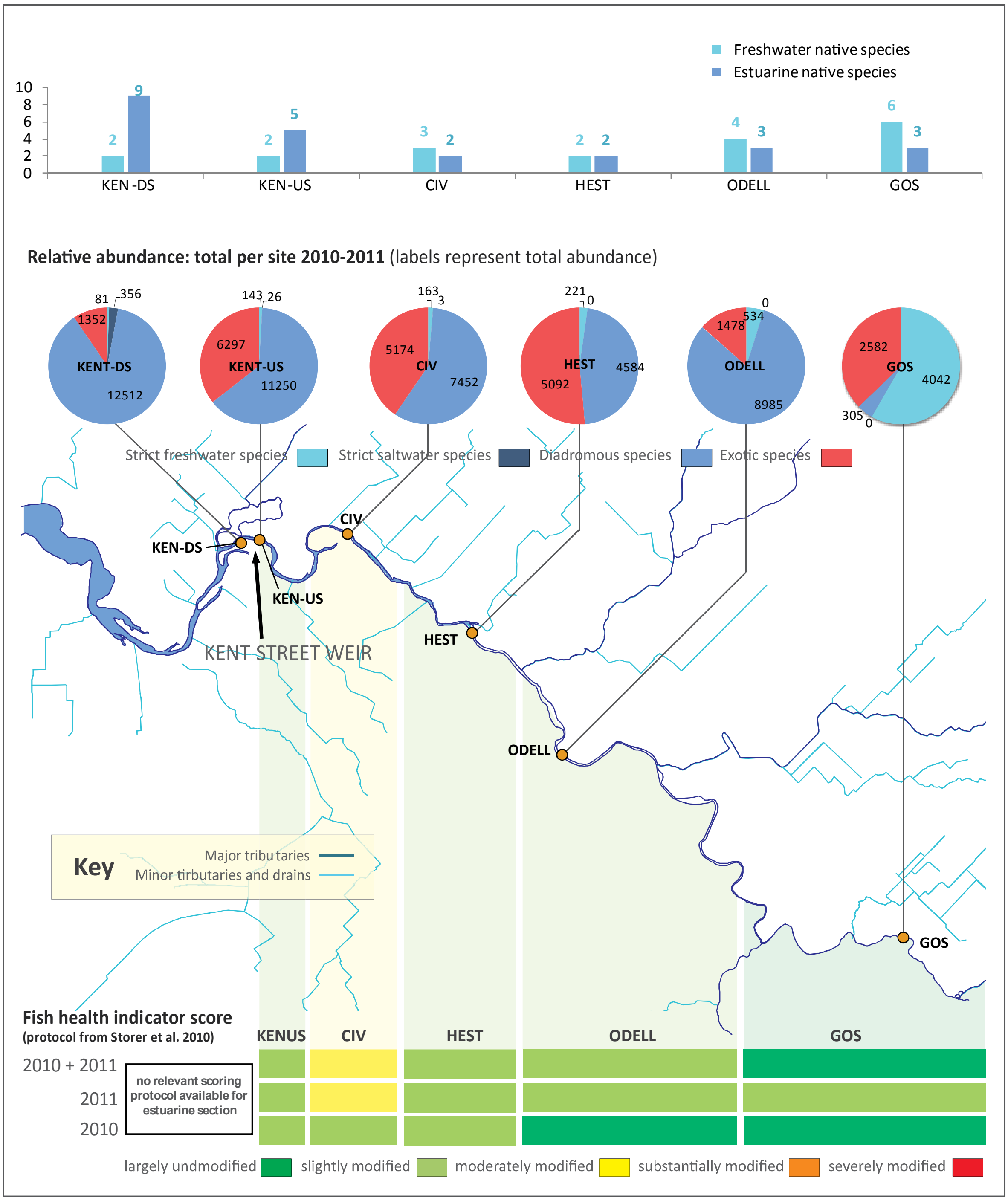


Figure 5 Total richness, relative abundance and Fish Health Index score for each site (all data).

Temporal dynamics

Seasonal conditions

A number of seasonal fluctuations in abundance were apparent (Figure 8 to Figure 11, *Note: the 2011 spring assessment only included sampling in September*).

Spikes in abundance were seen during spring for western minnow (September at the GOS site), freshwater cobbler (November at ODELL), western pygmy perch (October–December at GOS), nightfish (October–December at GOS), freshwater shrimp (all sites except GOS) and south-western goby (October–December at GOS). The increased abundance was largely related to upstream movement for western minnow, freshwater cobbler and nightfish. Freshwater shrimp and south-western goby were in high abundance in both fykes. Western pygmy perch were more prevalent in the upstream fyke (moving downstream).

Spikes in abundance were detected during summer/autumn in Swan River goby (in all sites except GOS), black bream, bridled goby, gobbleguts, western striped trumpeter, silver biddy and yellowtail grunter (at KENDS) moving upstream towards the KSW. Note: western striped trumpeter were not collected in 2011. The exotic mosquitofish and one-spot livebearer also displayed spikes in abundance during late summer and autumn in 2011; however this trend was not apparent in the previous year.

Numbers of mosquitofish declined during the winter months and also at the GOS site.

No obvious seasonal trends were apparent in freshwater crayfish species or in western hardyhead.

A number of visual observations were made during the trial (not represented by catch data), which were: juvenile yellowtail grunter congregated in large numbers in February and April below KSW, typically at points of flow through the weir; black bream and mullet were observed in high numbers (hundreds of bream and thousands of mullet) schooling below the weir between November and April; juvenile bream were recorded in January downstream and upstream of the KSW; and juvenile mullet were schooling below the weir in August.

Variability between 2010 and 2011

Little variability in biotic assemblages was recorded between 2010 and 2011. The most notable differences are summarised below:

- abundance of western hardyhead and mosquitofish was higher in areas upstream of the KSW, and lower downstream of it in 2011 (refer Figure 6 and Figure 7)
- abundance of one-spot livebearers was higher at GOS in 2011
- sea mullet were found in ODELL and GOS in spring 2011 – not previously present above KENUS during the trial
- a spike in abundance of black bream was recorded at KENUS in January 2011 following a series of tidal intrusions, however the species was absent in the subsequent sampling period (no black bream recorded upstream in 2010)

- yellowtail grunter reached HEST in January 2011 (no record upstream in 2010), remaining in the area until May (previously limited to KSW sites – corresponds with extent of tidal intrusion)
- yellow-eye mullet and western striped trumpeter were not recorded in 2011
- abundance of bridled goby was significantly reduced in 2011
- oval spider crab were only recorded at the GOS site in 2011.

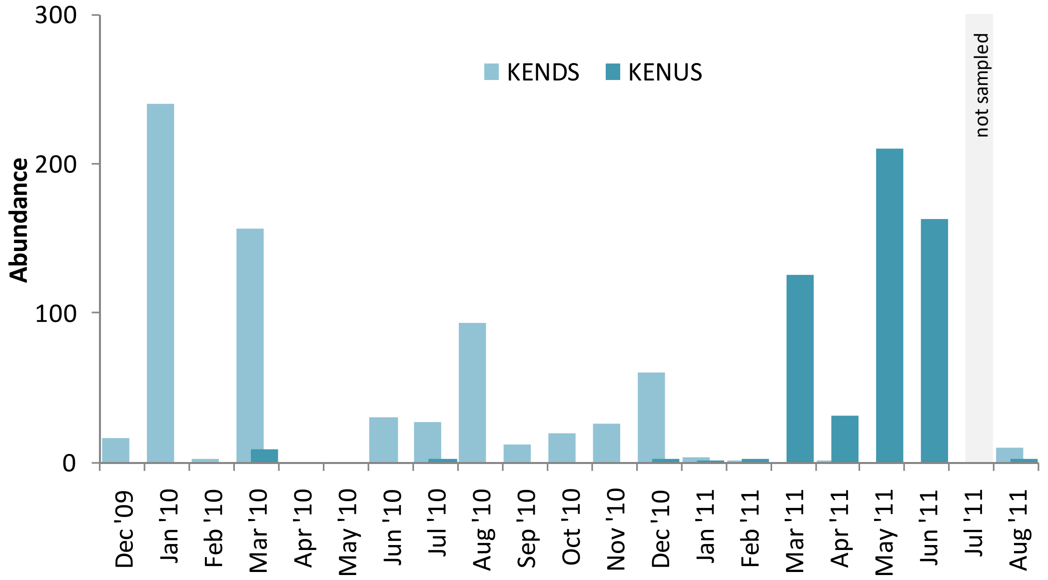


Figure 6 Western hardyhead catches in the estuary (KENDS) and weir pool (KENUS).

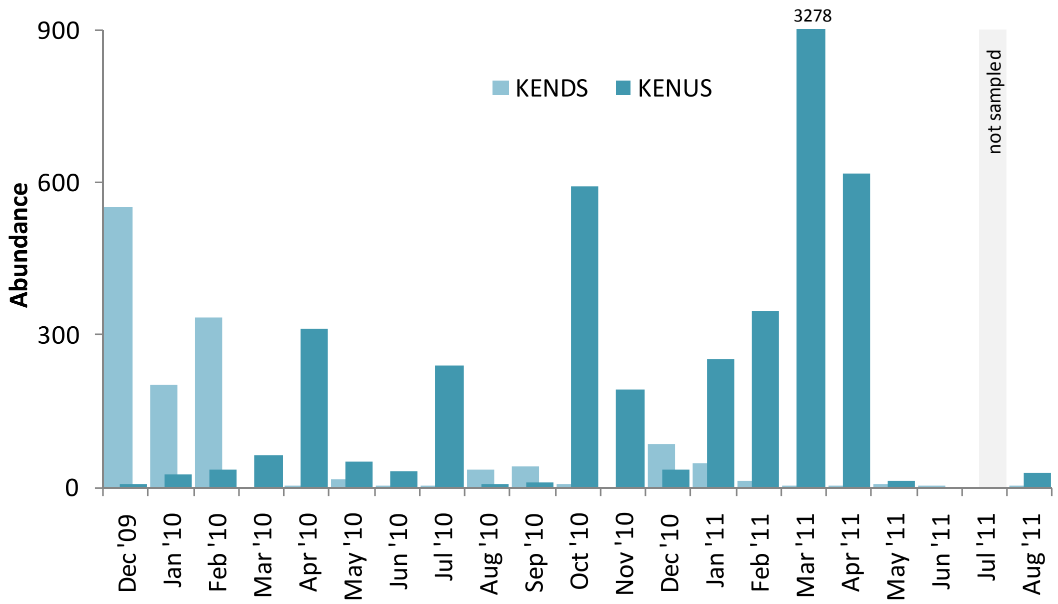


Figure 7 Mosquitofish catches in the estuary (KENDS) and weir pool (KENUS).

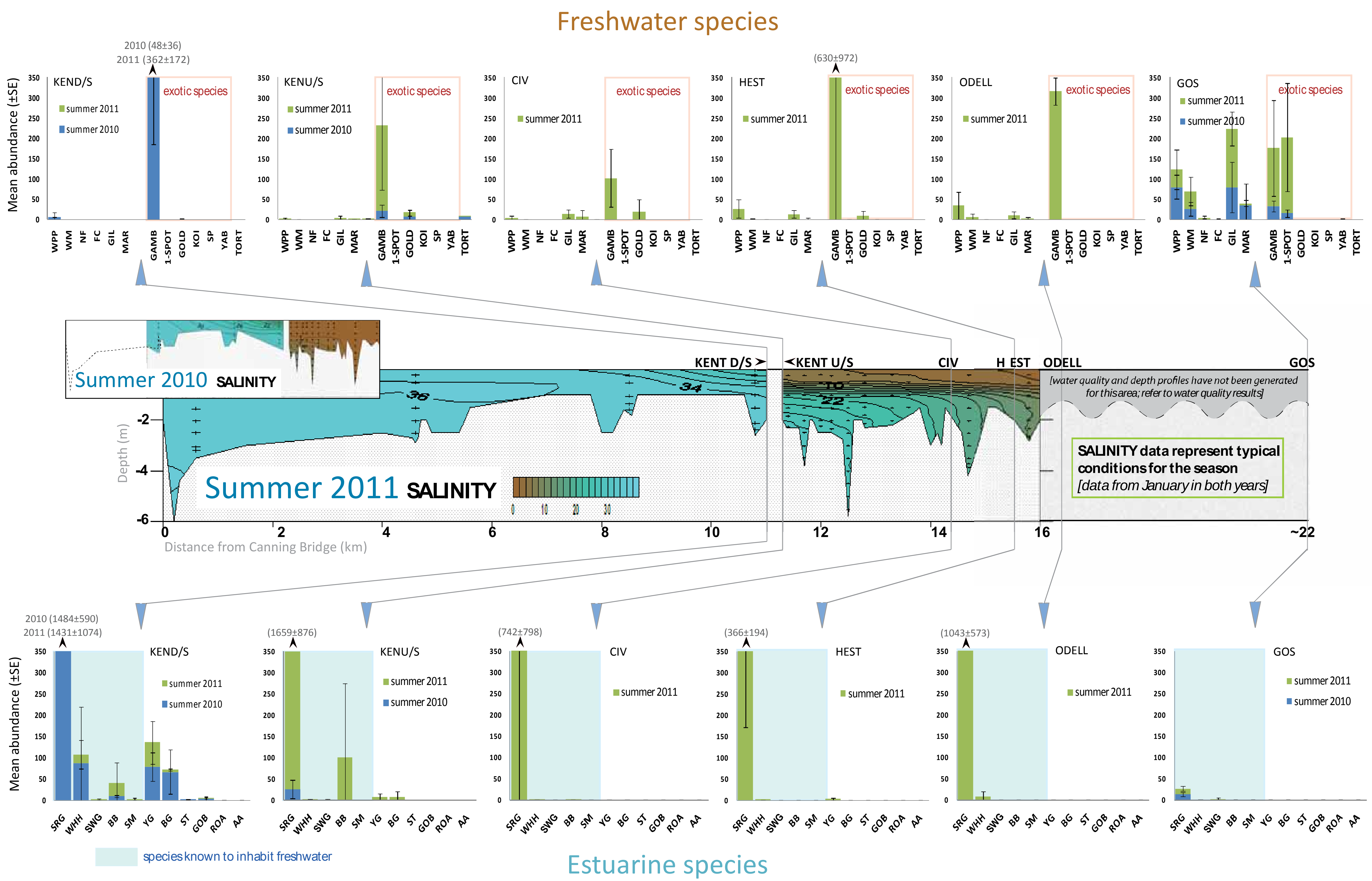


Figure 8 Species collected during summer months (Dec–Feb) in 2010–11.

Species with <10 individuals collected during the trial have not been presented (discussed in the narrative). Average of US and DS fyke nets taken for CIV, HEST, ODELL and GOS sites.

Biota names: WPP – western pygmy perch, WM – western minnow, NF – nightfish, FC – freshwater cobbler, GIL – gilgie, MAR – marron, GAMB – Gambusia (mosquitofish), 1-SPOT – one-spot livebearer, GOLD – goldfish, KOI – koi, SP – spangled perch, YAB – yabbie, TORT – long-necked tortoise, SRG – Swan River goby, WHH – western hardyhead, SWG – south-western goby, BB – black bream, SM – sea mullet, YG – yellowtail grunter, BG – bridled goby, ST – western striped trumpeter, GOB – gobbleguts, ROA – roach, AA – Australian anchovy. Biota sampling sites: KEN (US/DS) – Kent Street Weir (upstream/downstream of weir), CIV – Civic Gardens, HEST – Hester Park, ODELL – Odell Street, GOS – Gosnells. Mean abundance and standard error for data extending outside the limit of the axis are stated above respective columns.

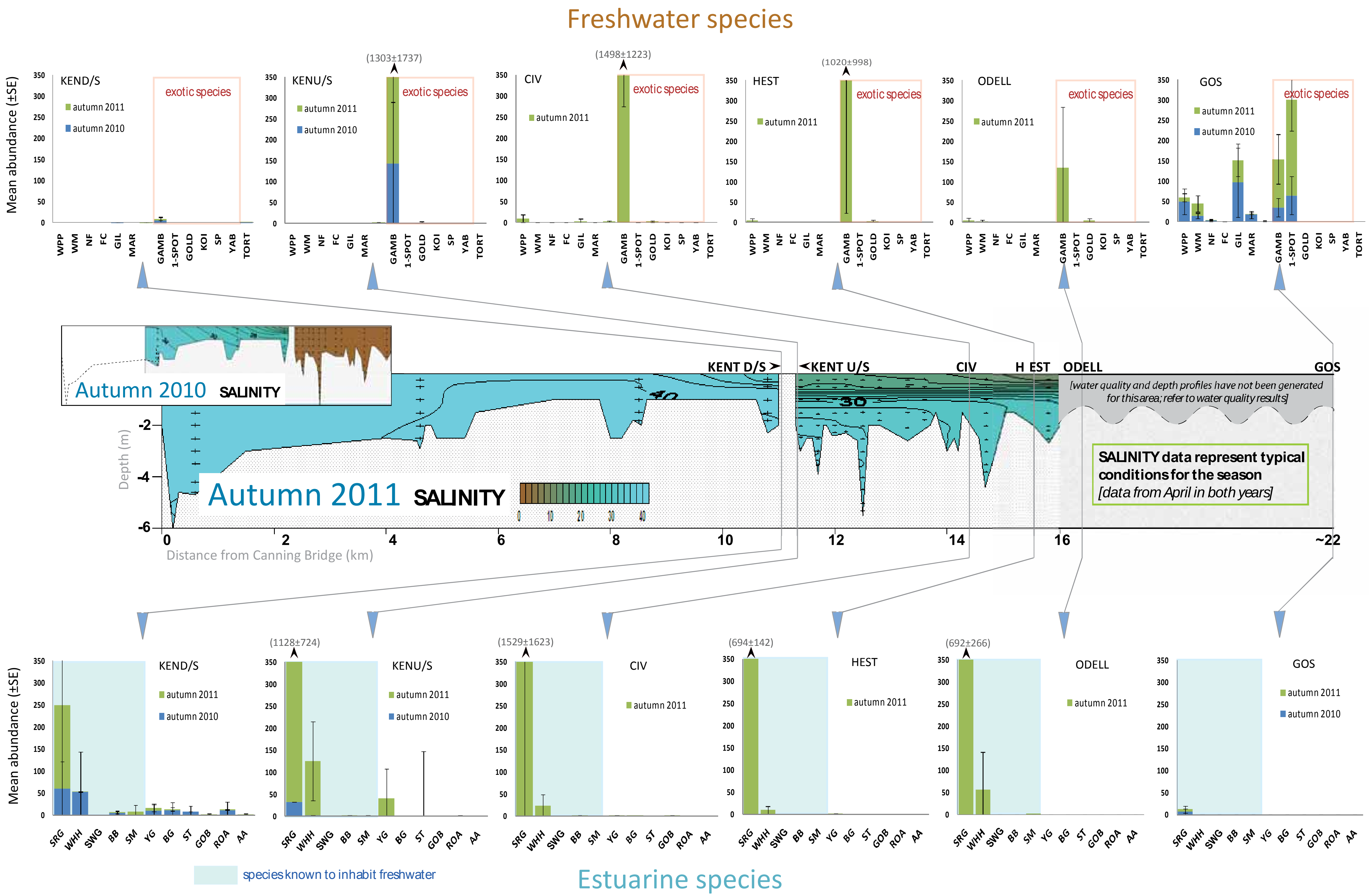


Figure 9 Species collected during autumn months (Mar–May) in 2010–11.

Species with <10 individuals collected during the trial have not been presented (discussed in the narrative). Average of US and DS fyke nets taken for CIV, HEST, ODELL and GOS sites.

Biota names: WPP – western pygmy perch, WM – western minnow, NF – nightfish, FC – freshwater cobbler, GIL – gilgie, MAR – marron, GAMB – Gambusia (mosquitofish), 1-SPOT – one-spot livebearer, GOLD – goldfish, KOI – koi, SP – spangled perch, YAB – yabbie, TORT – long-necked tortoise, SRG – Swan River goby, WHH – western hardyhead, SWG – south-western goby, BB – black bream, SM – sea mullet, YG – yellowtail grunter, BG – bridled goby, ST – western striped trumpeter, GOB – gobbleguts, ROA – roach, AA – Australian anchovy. Biota sampling sites: KEN (US/DS) – Kent Street Weir (upstream/downstream of weir), CIV – Civic Gardens, HEST – Hester Park, ODELL – Odell Street, GOS – Gosnells. Mean abundance and standard error for data extending outside the limit of the axis are stated above respective columns.

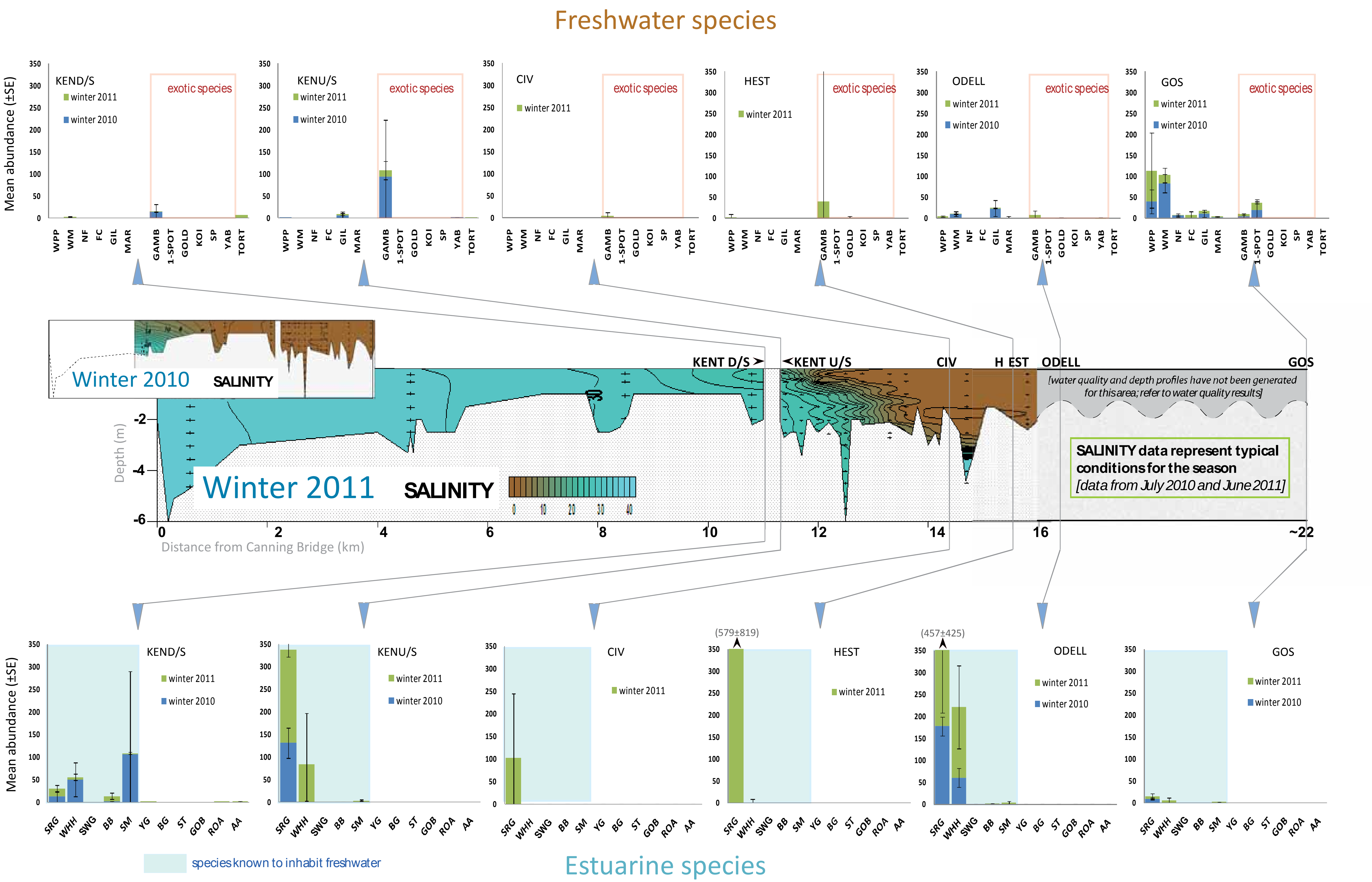


Figure 10 Species collected during winter months (Jun–Aug) in 2010–11.

Species with <10 individuals collected during the trial have not been presented (discussed in the narrative). Average of US and DS fyke nets taken for CIV, HEST, ODELL and GOS sites.

Biota names: WPP – western pygmy perch, WM – western minnow, NF – nightfish, FC – freshwater cobbler, GIL – gilgie, MAR – marron, GAMB – Gambusia (mosquitofish), 1-SPOT – one-spot livebearer, GOLD – goldfish, KOI – koi, SP – spangled perch, YAB – yabbie, TORT – long-necked tortoise, SRG – Swan River goby, WHH – western hardyhead, SWG – south-western goby, BB – black bream, SM – sea mullet, YG – yellowtail grunter, BG – bridled goby, ST – western striped trumpeter, GOB – gobbleguts, ROA – roach, AA – Australian anchovy. Biota sampling sites: KEN (US/DS) – Kent Street Weir (upstream/downstream of weir), CIV – Civic Gardens, HEST – Hester Park, ODELL – Odell Street, GOS – Gosnells. Mean abundance and standard error for data extending outside the limit of the axis are stated above respective columns.

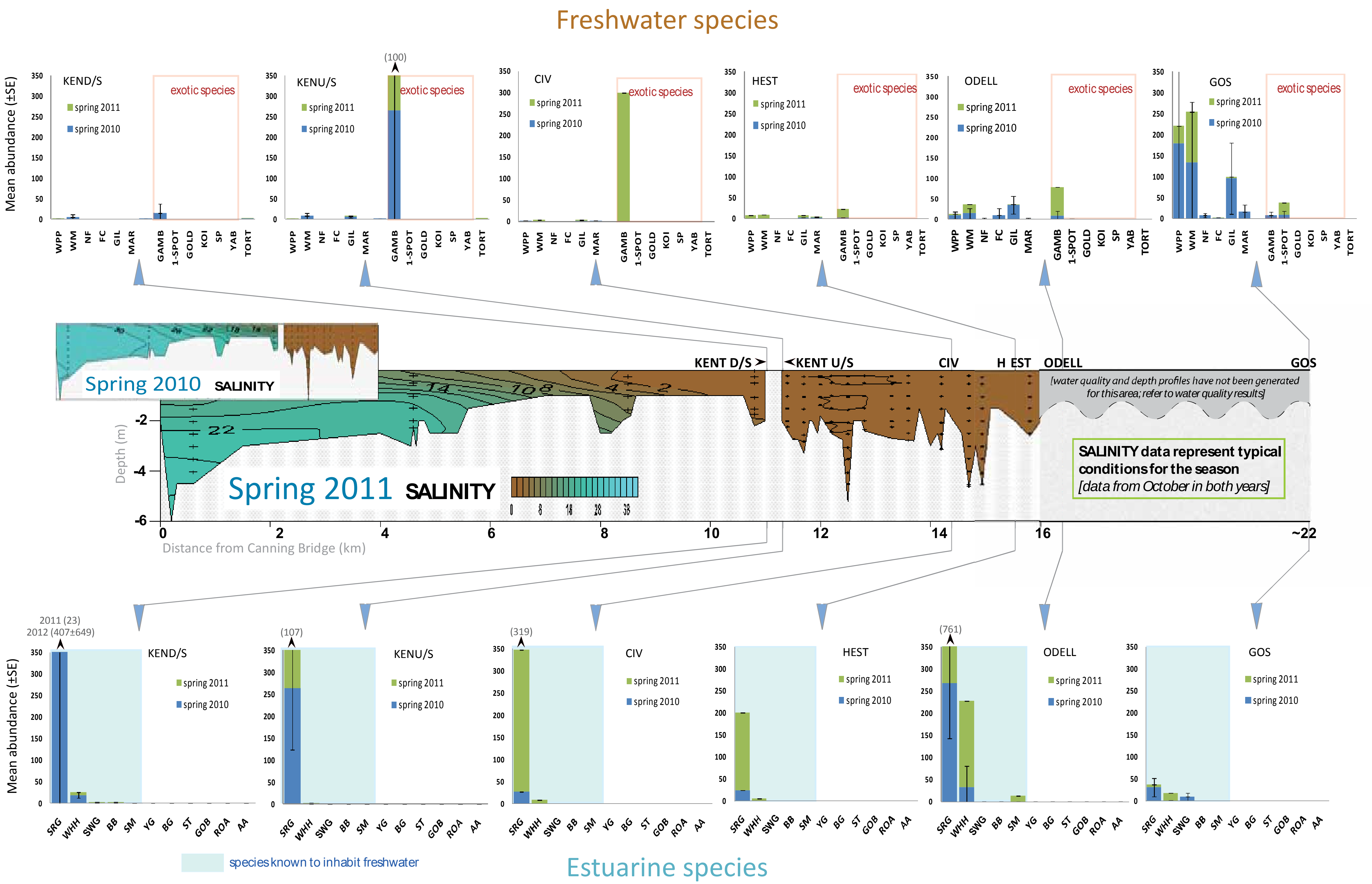


Figure 11 Species collected during spring months (Sep–Nov) in 2010–11.

Species with <10 individuals collected during the trial have not been presented (discussed in the narrative). Average of US and DS fyke nets taken for CIV, HEST, ODELL and GOS.

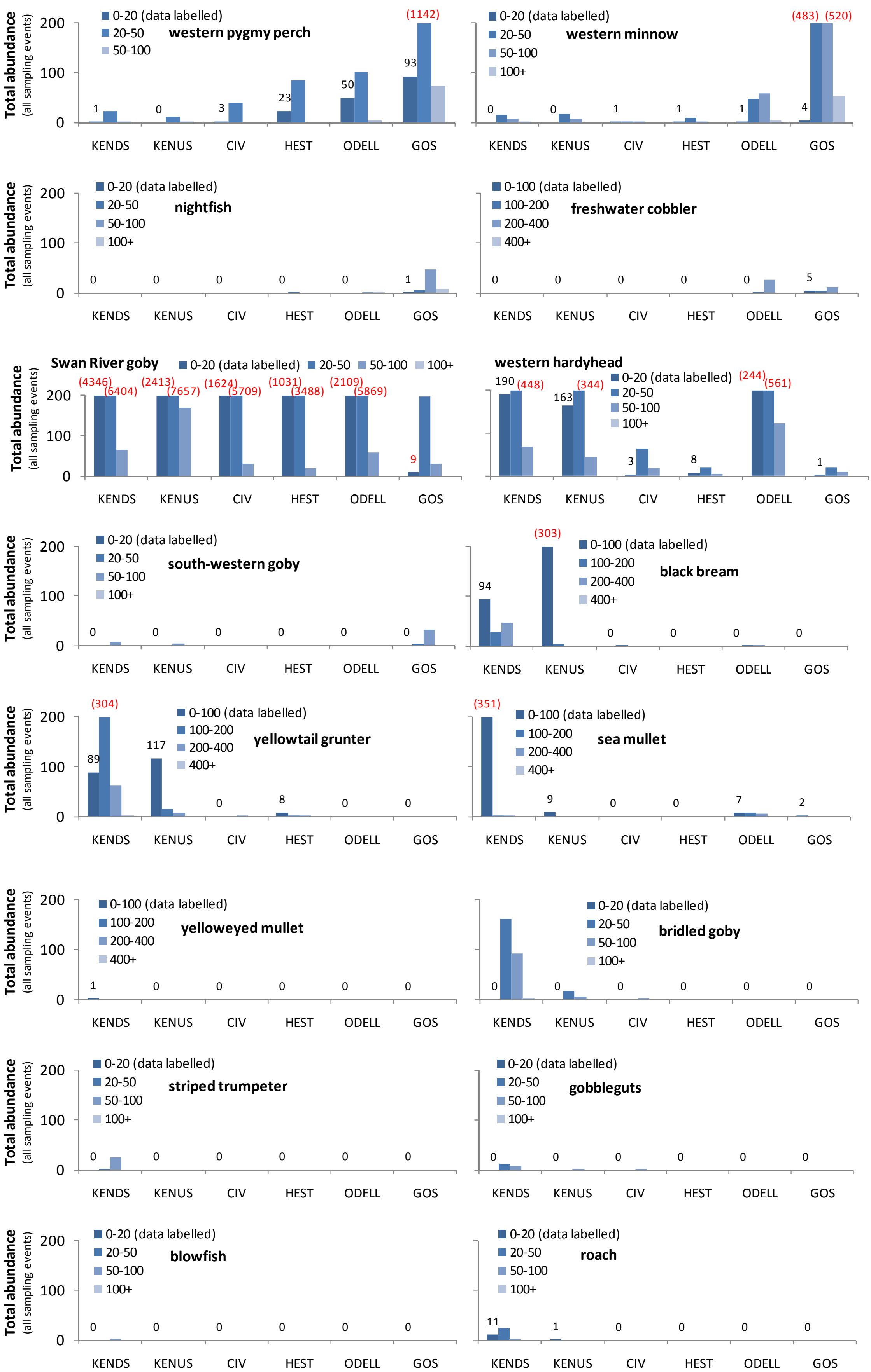
Biota names: WPP – western pygmy perch, WM – western minnow, NF – nightfish, FC – freshwater cobbler, GIL – gilgie, MAR – marron, GAMB – Gambusia (mosquitofish), 1-SPOT – one-spot livebearer, GOLD – goldfish, KOI – koi, SP – spangled perch, YAB – yabbie, TORT – long-necked tortoise, SRG – Swan River goby, WHH – western hardyhead, SWG – south-western goby, BB – black bream, SM – sea mullet, YG – yellowtail grunter, BG – bridled goby, ST – western striped trumpeter, GOB – gobbleguts, ROA – roach, AA – Australian anchovy. Biota sampling sites: KEN (US/DS) – Kent Street Weir (upstream/downstream of weir), CIV – Civic Gardens, HEST – Hester Park, ODELL – Odell Street, GOS – Gosnells. Mean abundance and standard error for data extending outside the limit of the axis are stated above respective columns.

Size-class distribution

All freshwater fish (native and exotic) were present in size-classes from young-of-year through to adult – based on the assessment of species within their primary range (sites where only a few individuals were recorded were not assessed). Oval spider crab were not assessed as the size range is unknown and freshwater shrimp were not sized.

All species known to migrate from estuaries into freshwater areas (black bream, Swan River goby, western hardyhead, sea mullet and south-western goby) were represented by young-of-year through to adults, with the exception of south-western goby in which no juveniles (individuals under 20 mm total length) were recorded. A spike in juvenile black bream (<100 mm) was recorded in January 2011 at both KENDS and KENUS (note: juvenile black bream were not recorded in 2010).

A full range of sizes were seen in the estuarine species yellowtail grunter, silver biddy, bridled goby and western striped trumpeter, with the exception of juveniles of the western striped trumpeter. Assessment of size distribution was not applicable for blowfish, yellow-eye mullet and gobbleguts given low numbers.


Total abundance
(all sampling events)
0
100
200
KENDS
KENUS
CIV
HEST
ODELL
GOS
western pygmy perch
0-20 (data labelled)
20-50
50-100
1
0
3
23
50
93
(1142)
western minnow
0-20 (data labelled)
20-50
50-100
100+
0
0
1
1
1
4
(483)
(520)
nightfish
0-20 (data labelled)
20-50
50-100
100+
0
0
0
0
0
1
freshwater cobbler
0-100 (data labelled)
100-200
200-400
400+
0
0
0
0
0
5
Swan River goby
0-20 (data labelled)
20-50
50-100
100+
(4346)
(6404)
(2413)
(7657)
(1624)
(5709)
(1031)
(3488)
(2109)
(5869)
9
western hardyhead
0-20 (data labelled)
20-50
50-100
100+
190
(448)
163
(344)
3
8
(244)
(561)
1
south-western goby
0-20 (data labelled)
20-50
50-100
100+
0
0
0
0
0
0
black bream
0-100 (data labelled)
100-200
200-400
400+
94
(303)
0
0
0
0
yellowtail grunter
0-100 (data labelled)
100-200
200-400
400+
89
(304)
117
0
8
0
0
sea mullet
0-100 (data labelled)
100-200
200-400
400+
(351)
9
0
0
7
2
yelloweyed mullet
0-100 (data labelled)
100-200
200-400
400+
1
0
0
0
0
0
bridled goby
0-20 (data labelled)
20-50
50-100
100+
0
0
0
0
0
0
striped trumpeter
0-20 (data labelled)
20-50
50-100
100+
0
0
0
0
0
0
gobbleguts
0-20 (data labelled)
20-50
50-100
100+
0
0
0
0
0
0
blowfish
0-20 (data labelled)
20-50
50-100
100+
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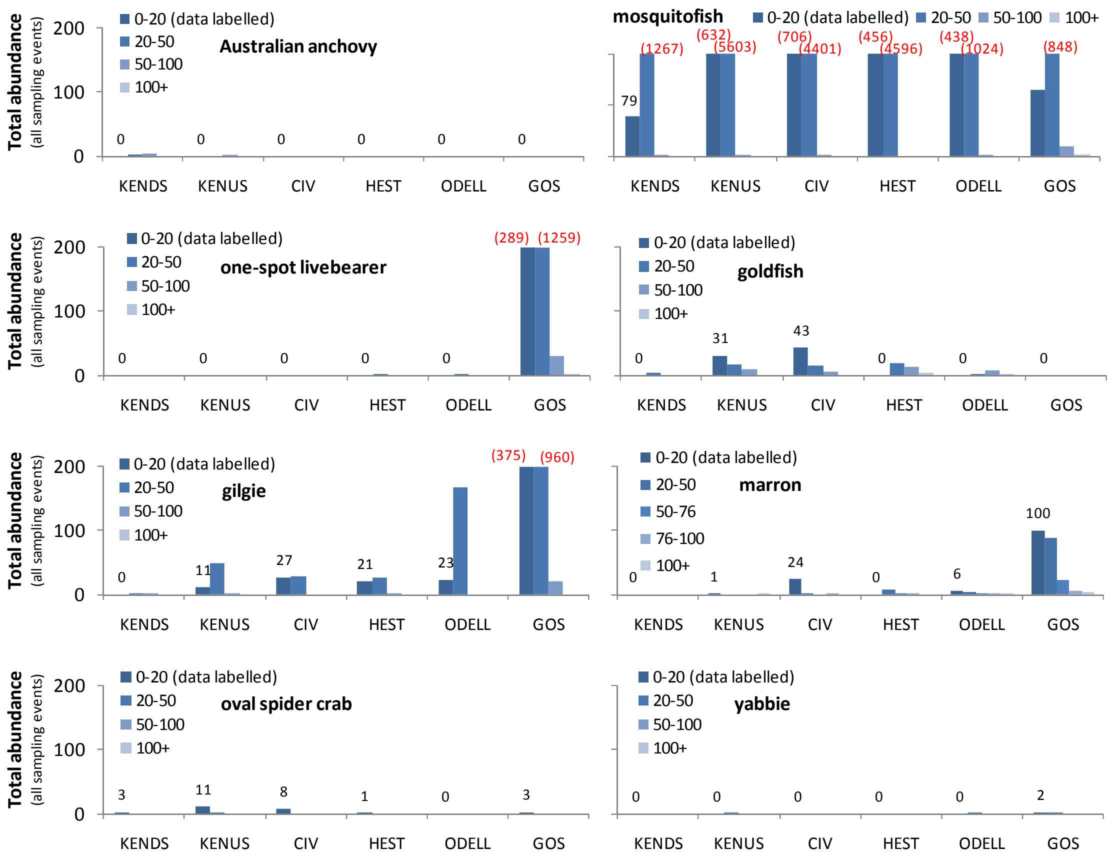

Figure 12 Size-class distribution for all fish species collected at each study site (combined totals from all sampling periods). Labels represent total abundance, provided for smallest size-class (typically representing young-of-year) and for data extending beyond the fixed x-axis range of 200 individuals (red text). Note: comparison of data between sites must consider disparity in sampling effort.

Reproductive condition

Observations of nuptial colouring and distended abdomens indicating possible egg development were recorded in a number of species. These signals of reproductive condition were evident in western minnow, western pygmy perch and nightfish around spring (slightly earlier for nightfish). Further, distended abdomens, reddened vents and obvious urogenital papillae were observed in freshwater cobbler during the early summer months coinciding with their increased presence in downstream fyke nets (potentially indicating movement of fish upstream to spawning habitat). Reproductive condition was not quantified.

Additional comments

A cursory assessment for conspicuous symptoms (physical and behavioural) of the presence of disease, parasite infection or physical injury was conducted. No obvious signs of poor condition were apparent, with the exception of estuarine bivalves found growing on the only large marron collected within the KENUS site, see Figure 13 – noting damage to the right eye (only two individual marron, one of them juvenile, were collected at KENUS throughout the study).

Figure 13 Bivalves found growing on marron at KENDS in January 2010: in cavity around eyes (left) and underside of tail (right).

3.3 Results: aquatic macroinvertebrates

Results summary

Sixteen species (12 families) were recorded at GOS in March and fifteen species (14 families) in April (total of 28 species across the two periods):

- comprised mostly of insects (typical in freshwater environments) and oligochaetes
- detritivores dominant (~80–90% composition)
- the general salt tolerance of species collected was low to moderate.

Twelve species (12 families) were recorded in CIV and HEST:

- comprised mostly of polychaetes, crustaceans, molluscs (typical of estuarine environments)
- predators dominant (~40–50%)
- the general salt tolerance of species collected was moderate to high.

Macroinvertebrate assemblages recorded at CIV, HEST and GOS demonstrated a clear distinction in community composition (see species list in Appendix E and Figure 14).

The GOS site was composed of 16 species in 12 families in March and 15 species in 14 families in April, with a total abundance of 48 and 387 individuals respectively – comprised primarily of insecta, as expected for a freshwater system, and predominately chironomids. A significant proportion of the taxa present were freshwater species. Oligochaetes were absent in the March sample although abundant in April (accounting for a significant proportion of the increased total abundance). The lack of oligochaetes in the March sample could be due to seasonal variation or from insufficient preservative (due to leakage of ethanol from sample container), and subsequent desiccation (oligochaetes are known to desiccate rapidly in the absence of preservative, Emma van Looij pers. comm.).

CIV and HEST sites, in comparison, had a combined total of 12 species in 12 families and with 203 and 28 individuals respectively. The CIV and HEST sites were dominated by polychaetes, crustaceans and molluscs, which is typical of estuarine and marine systems. This is supported by the dominance of salt-tolerant animals (Table 5).

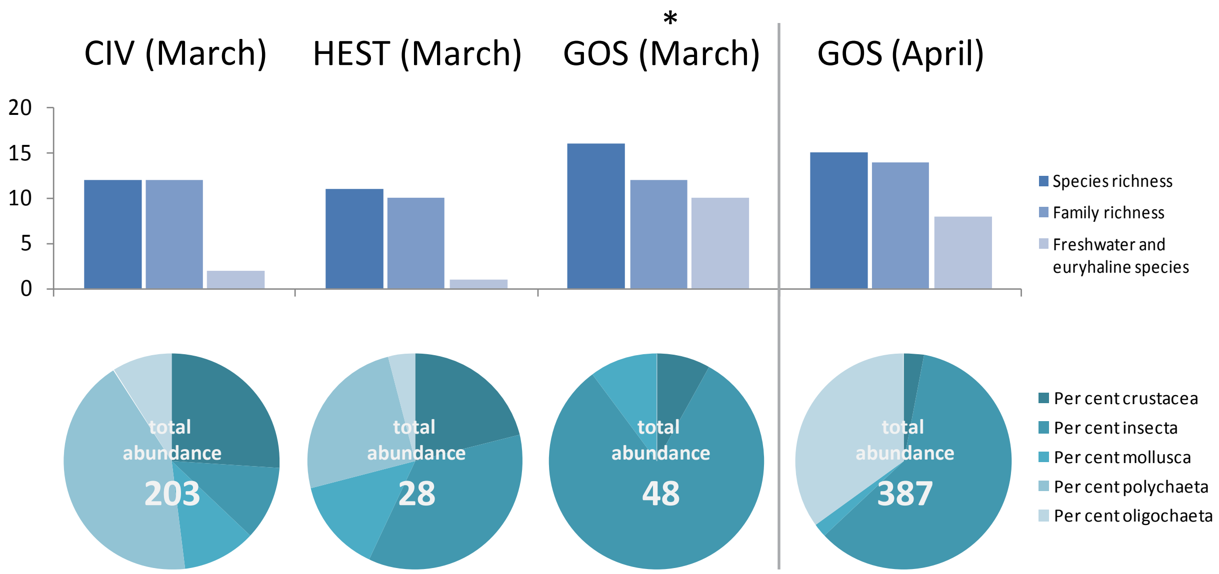

Figure 14 Summary data of aquatic macroinvertebrate assemblages at KENUS and GOS.

** The March GOS sample degraded. A repeat sample, collected in April, is presented for comparison.*

Table 5 Aquatic macroinvertebrate salinity tolerance trait (see Rolls et al. 2012).

Salinity tolerance (% species/category)	**CIV**	**HEST**	**GOS***	**GOS**
Sample month	March	March	March	April
Low	1	4	13	37
Medium–low	20	15	21	1
Medium	12	26	67	59
High	50	26	0	0
Species not listed	17	30	0	3

** The March GOS sample was degraded (unknown cause). A repeat sample, collected in April, is presented for comparison.*

An assessment of trophic levels revealed a dominance of detritivores at the GOS site, with significantly less predators compared with CIV and HEST (Table 6).

Table 6 Aquatic macroinvertebrate food source trait (see Rolls et al. 2012).

Food source (% species/category)	**CIV**	**HEST**	**GOS***	**GOS**
Sample month	March	March	March	April
Generalist	0	0	4	0
Detritivore	26	30	81	93
Predator	54	37	8	2
Herbivore	3	4	6	2
Carrion	0	0	0	0
Species not listed	17	30	0	3

** The March GOS sample was degraded (unknown cause). A repeat sample, collected in April, is presented for comparison.*

No discernible variability existed between sites under assessment of the following traits: voltinism, reproduction type (e.g. aquatic, terrestrial), respiration method (e.g. plastron-spiracle, gills, pneumostone), duration of life stages out of water, occurrence in drift, adult dispersal method, and minimum and maximum time to reproduction. These data are available on request from the Department of Water.

3.4 Results: other aquatic fauna

Results summary

Tortoises:

- native freshwater long-necked tortoises were found throughout system, including below KSW
- long-necked tortoises were abundant below GOS
- one Murray River tortoise (exotic) was collected (KENUS) – first known occurrence in the system.

Water rats:

- observed at KENUS and GOS – not captured.

Two species of tortoise were collected during the study: the native western long-necked tortoise and the exotic Murray River tortoise.

The western long-necked tortoise was observed at all sites, with the largest catches in summer at KENUS and ODELL, and in spring at CIV and HEST. Following large catches and signs of predation on other species captured in fyke nets, 100 mm flexible mesh screens were placed across the fyke net openings to restrict the entry of long-necked tortoises (and they were not captured thereafter).

One exotic Murray River tortoise (approximately 100 mm shell diameter) was collected at KENUS in September 2011 (Figure 15). This species is native to the Murray-Darling river system in south-eastern Australia. Identification of the specimen was confirmed by the Department of Environment and Conservation (DEC). The animal was euthanised according to DEC protocols[5].

Figure 15 Murray River tortoise collected from KENUS, September 2011

No water rats were collected although a number were observed at both the KENUS and GOS sites.

[5] The discovery of this species in the Swan-Canning river system raised significant concern given the potential for exotic biota to transfer disease and compete with native species. DEC has no record of any exotic populations of this species existing in Western Australia. In line with DEC procedure the specimen was euthanised. Given only one individual was found and regular sampling was already being undertaken in the area, further action was not warranted (as agreed by DEC, DoF and the Department of Water). However future collection may warrant an incident response by the relevant local and state government agencies. As this species is commonly kept as a pet in the eastern states, it is most likely this individual was brought into Western Australia and then released into the waterway after its owners learned it could not be kept here.

4 Phytoplankton: 2009–11

4.1 Methods

Phytoplankton was assessed in this study as species and abundance can provide an indication of general ecosystem health (particularly through nutrient, dissolved oxygen and temperature changes), aesthetic impact (through blooms) and human health implications. Further, phytoplankton is influenced by the system's flushing capability, which is a management consideration for the KSW.

Phytoplankton was monitored weekly within the Swan-Canning Environmental Monitoring and Reporting (SCEMR) program (see description in Section 6.1) and identified at the Department of Water Phytoplankton Ecology Unit. The detailed methodology for phytoplankton collection and analysis is provided within the sampling and analysis plan for this program, available through the department's Water Information Branch. Data were analysed and reported by Hellriegel (2011).

Phytoplankton data were assessed at four sites: Canning Bridge, Salter Point, KSW and at Nicholson Road Bridge (Figure 3).

4.2 Results

Results summary

- Phytoplankton abundance increased above KSW between 2009–10 and 2010–11.
- Increased abundance was largely due to diatoms, chlorophytes and dinoflagellates, all groups common in estuarine waters below KSW; during the saline intrusion period.
- Phytoplankton populations during the period of saline intrusion were similar to those recorded below the weir.

A marked increase in phytoplankton activity in 2010–11 compared with 2009–10 was apparent (Figure 16). Passive chlorophyte and dinoflagellate groups increased in cell densities by two to three orders of magnitude. More estuarine species were also reported to appear following saltwater intrusions above the weir (brackish species assemblages include dinoflagellates which are mobile and may include potentially toxic species) (Hellriegel 2011).

Some harmful species were recorded below Kent Street Weir during the study period (*Karlodinium veneficum,* a potential karlotoxin-producing ichthyotoxic dinoflagellate and *Heterosigma akashiwo*, a potentially icthyotoxic raphidophyte), although were at moderate to low densities and their presence was sporadic and short-lived.

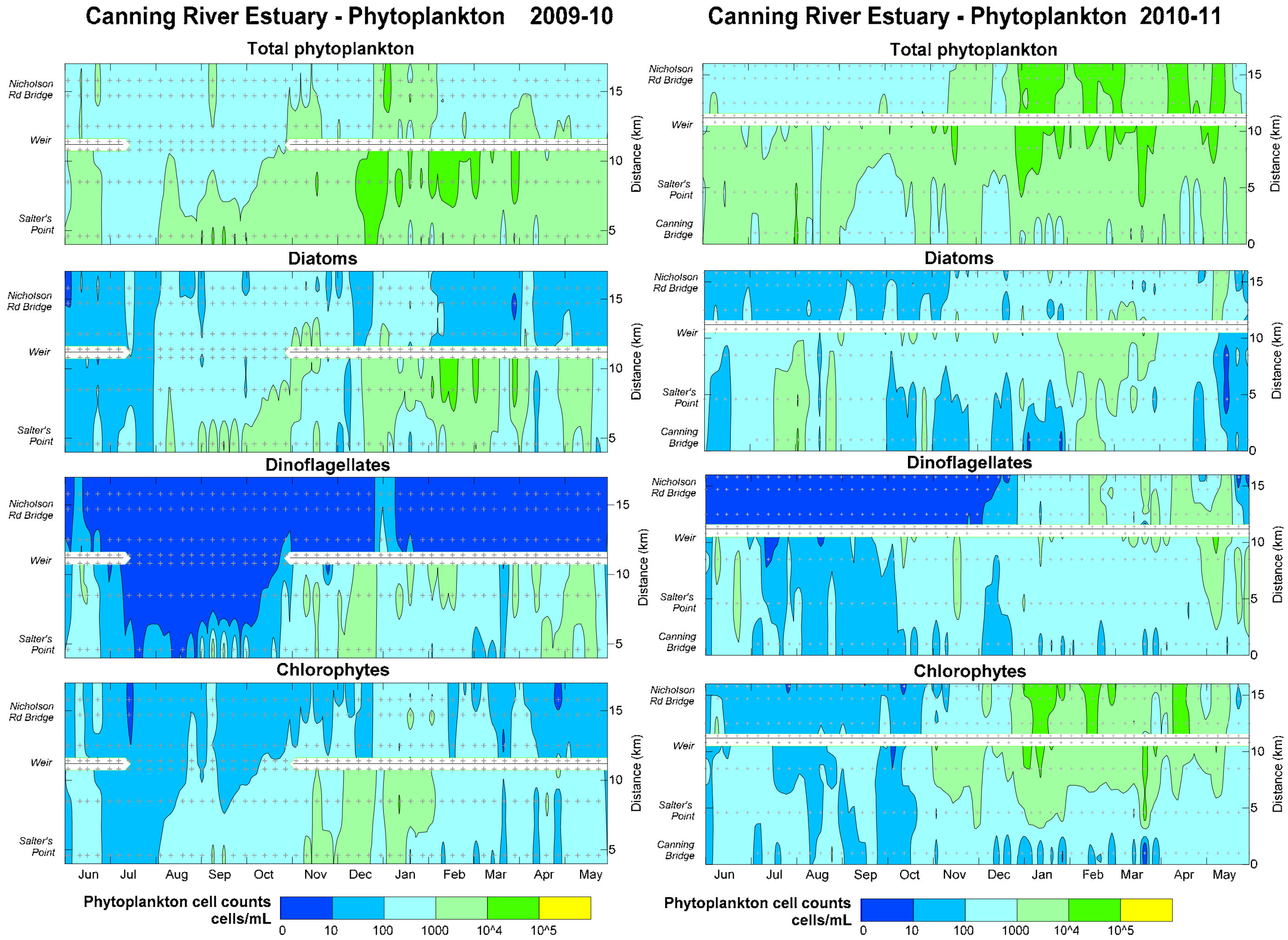

Figure 16 Integrated phytoplankton counts (cells/ml) for Canning River for 2009–10 (June–May) (left) and 2010–11 (June–May) (right). Prepared by Department of Water and soon to be available (at time of this report) on SRT website: Hydrology: 2009–11 (SRT 2011b)

5 Hydrology: 2009-2011

5.1 Flow data

River and stream flow was continuously measured throughout the catchment at both Department of Water and Water Corporation gauging stations, including two department sites established to directly measure flow over the weir in either direction.

The hydrological information collated in this report provide a direct assessment of the KSW's effectiveness in maintaining the upstream water level under the various climatic and management conditions throughout this study. Hydrological data also provide interpretive information for changes observed in the water quality and biota.

Mean hourly stage heights were assessed from data collected from the two gauging stations situated directly above (reference AWRC 616093) and below (reference AWRC 616094) the KSW. Rainfall data were collected from Bickley rain gauge (reference 009240), approximately 6 km upstream of the weir.

5.2 Results

Results summary

- Low rainfall compared with the long-term average, particularly through winter 2010
    - associated reduction in streamflow.
- Weir boards were not removed in 2010 given insufficient flows to prevent intrusion of salt water.
- A few tidal intrusions occurred during 2009–10, with resulting saline conditions above the KSW short-lived (generally <1 week), typical of long-term trend.
- Due to high tides and low streamflow, tidal intrusions in late 2010 and through 2011 were common and resulted in a significantly increased extent (longitudinally and through the water column) and persistence of saltwater conditions above the KSW – compared with long-term conditions.
- Water levels upstream of the KSW remained stable during the study period.

2009–10 (before the decision not to remove weir boards in 2010)

Rainfall through this period was low compared with previous years (BoM 2011a), triggering a corresponding reduction in streamflow volumes (DoW 2011); however, the changes were insufficient to trigger a change in management strategies in place for the KSW. Weir boards were removed for 15 weeks between 9 July and 22 October 2009 (following the long-term management pattern, see Appendix C) and replaced approximately two months before the ecological assessments reported in this study.

A stable water level was maintained upstream of the KSW for the entire period of the weir boards being in place (stage height 10.53±0.13, based on hourly data from gauging station 616093). Figure 17 shows stabilising of the water levels upstream of the weir immediately after the boards were replaced.

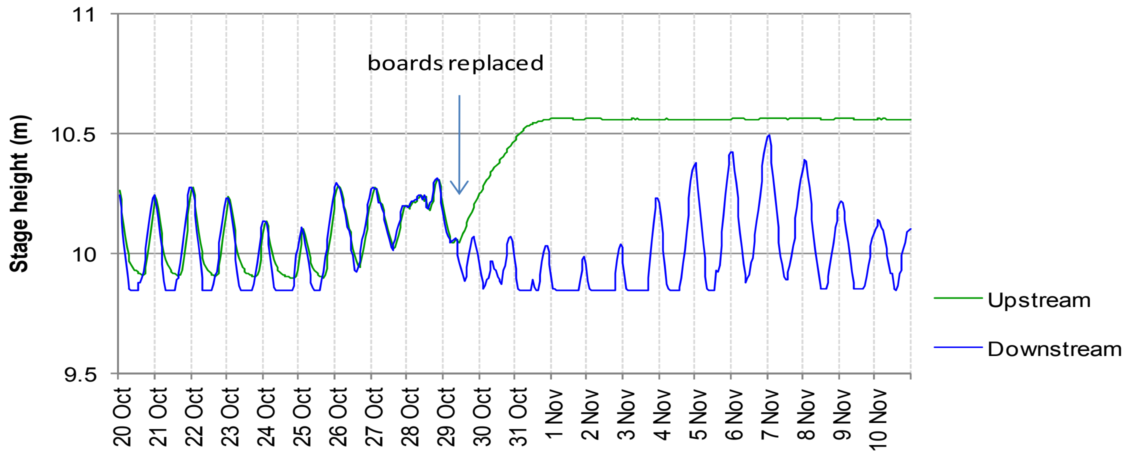

Figure 17 Water levels in the Canning River upstream and downstream of the KSW before and after replacement of the weir boards in 2009.

Tidal intrusions above the KSW were recorded during this period (Figure 18), although streamflow was sufficient to flush the resulting salinity (discussed in Section 6.2), and freshwater conditions rapidly returned.

Figure 18 Overtopping of the KSW: illustrating flooding of upstream banks (A) and the mixing line of saline and fresh water (B)

2010-11

Freshwater streamflows

Freshwater streamflows during 2011 were below average (DoW 2011) – a function of reduced rainfall (driest winter on record since records began in 1900, BoM 2011a) and following the drying climate trend in south-west Western Australia (IOCL 2005). Note: flows to the Canning River are also restricted by the Canning Dam in the upper catchment and vary depending on associated environmental water releases.

The streamflow in late 2010 was assessed (by SRT) as insufficient to resist tidal pressure and maintain fresh water upstream of the KSW with weir boards removed, and therefore the weir boards were not removed for the first time since the weir's construction.

Tidal intrusions above KSW

A marked change in climate pattern, attributed to a significant *La Niña* event (see Figure 19), combined with storm surges throughout 2010–11 (DoT 2011), produced a significant increase in the frequency (Figure 20) and magnitude (see extent of salinity intrusion upstream in Section 6) of overtopping events between September 2010 and May 2011 at KSW compared with the previous period.

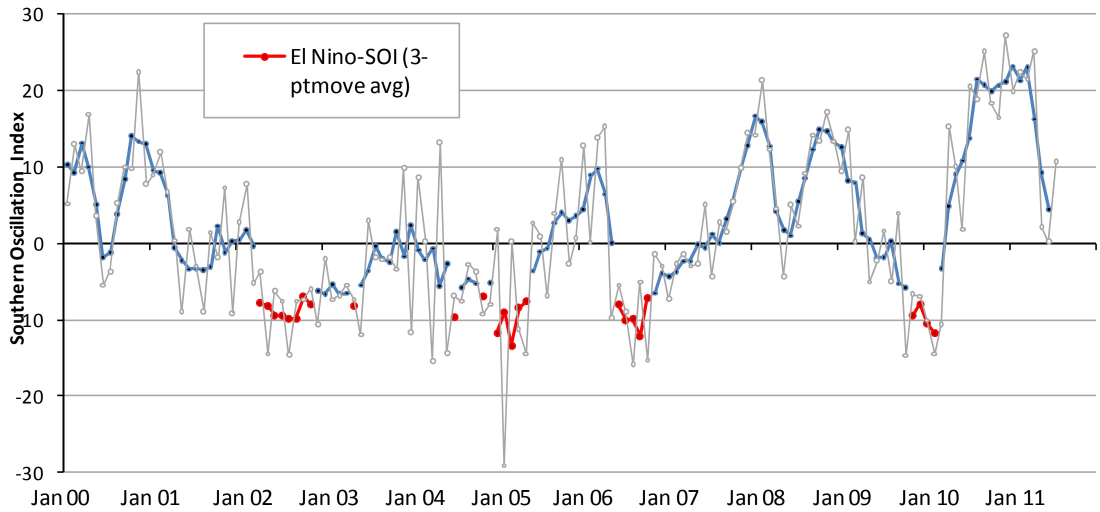

Figure 19 Southern Oscillation Index – January 2000 and June 2011 (BoM 2011b)

The La Nina conditions recorded in 2010/2011 were among the highest on record for the area (BOM 2011b) This corresponds with increases in sea levels and extensive spring tides (DOT 2011).

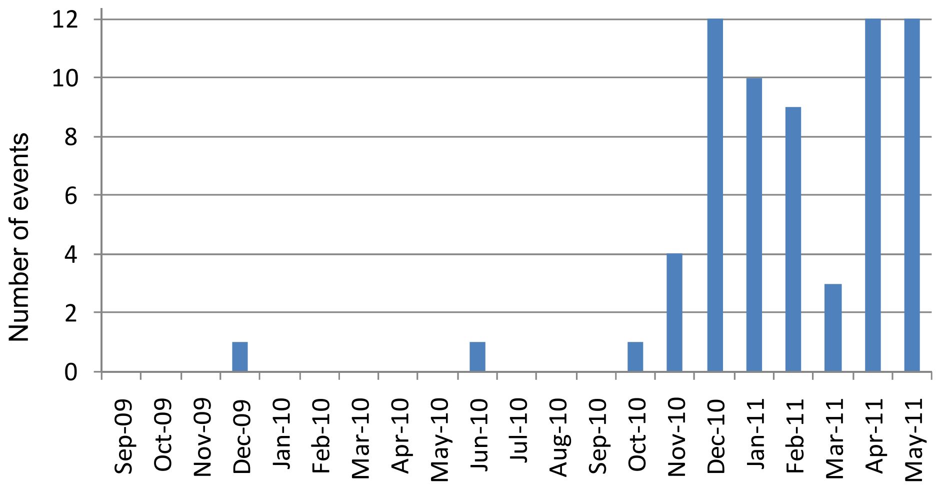

Figure 20 Tidal intrusions (number of overtopping events) at the KSW between September 2009 and May 2011.

The number of tidal intrusions upstream of the KSW increased from three events between November 2009 and October 2010 (12 months) to 66 events between November 2010 and May 2011 (seven months)[6]. Note: many of the events during the latter period were minor and would likely have contributed little to the salinity level upstream. Weir boards were removed in July 2011.

Water quality data (discussed in Section 6.2) demonstrate that water travelling upstream in overtopping events includes water from the bottom of the water column – implying that bottom waters are pushed upwards as flow meets the KSW.

Weir integrity

Although not directly assessed in this study, leakage of water through the KSW does occur (see decline in stage height when the weir boards are in place in Figure 26). This is noteworthy because it may reflect the ability for some degree of saltwater intrusion while boards are in place. The degree of leakage appears to have been higher before 2007, which coincides with repairs to the weir's board structure (wood boards replaced with concrete) in late 2005. The significant drop in stage height above the KSW in summer 2004–05 was due to a large hole in the weir board structure, which was subsequently plugged in January 2005. The drop in levels the following year was due to a water release trial conducted by the Department of Water and SRT. Water levels remained relatively stable thereafter.

Mixing and flushing in the weir pool

Water quality data (see Section 6.2) indicates a generally low capacity for mixing of the water column and flushing of water in the Canning River upstream of the KSW during the study period. This is based on evidence of persistent stratification (oxygen, temperature, salinity) in deeper sections of the river, particularly in the weir pool. The

[6] A single intrusion event incorporated the period from where water levels rose above the height of the KSW to when they dropped below the height of the KSW.

system’s ability to mix and flush water (and sediment) downstream would be further reduced in 2011 due to the sustained period without the weir boards being removed.

6 General water quality: 2009–11

6.1 Methods

Water quality variables were chosen to directly target general ecological risks associated with weirs. In particular, this included possible sites of accumulation of sediments, nutrients and other contaminants from the catchment and potential for deoxygenation of bottom waters due to reduced flushing and stratification.

Water quality was measured under two separate regimes:

1. This study measured water quality monthly at each aquatic fauna monitoring site (Figure 21 - *Water quality sampling sites: KSW project*) in conjunction with sampling events. Variables were electrical conductivity (m^S/cm, compensated), temperature (◦C), dissolved oxygen (mg/L and percentage saturation) and pH. Data was collected using a YSI 6600 multi-parameter probe. Depth profiles were generated through measurements taken at surface (top 0.2 m), bottom (0.2 m from river bed) and at 0.5 m increments in between. Salinity was calculated from conductivity, with salinity data primarily referred to within this report (in place of conductivity) for consistency across assessments.
2. Routine sampling and oxygenation plant operations measured water quality weekly at Swan-Canning Environmental Monitoring and Reporting program[7] (SCEMR) monitoring locations (Figure 21, *Water quality sampling sites: SCEMR program*). A subset of the variables monitored in the SCEMR program were examined for this study, which were dissolved oxygen (mg/L), temperature (◦C), electrical conductivity (m^S/cm, compensated) and pH. Water quality was also measured weekly at a number of sites corresponding with the location of oxygen spargers illustrated in Figure 21. Data are combined with SCEMR data to generate the profiles shown in Section 6.2. Salinity was calculated from conductivity, with salinity data primarily referred to within this report (in place of conductivity) for consistency across assessments.

Water quality sampling methods (and long-term data from SCEMR sampling) are available through the Department of Water's WIN database.

[7] The SCEMR was implemented in 1994 by the SRT and Department of Water (then Water and Rivers Commission) as part of the Swan-Canning Cleanup Program Action Plan. The project currently falls under the SRT's Healthy Rivers Action Plan and is jointly operated by the department's Water Science Branch and the SRT. The Canning River component (WIN project code SG-E-CANEST) consists of weekly sampling at eight fixed sites from South Canning Bridge upstream to Ellison Drive (Figure 21). Sampling began in January 1995. Sampling methods (and long-term data) are available through the department's WIN. Depth profiles for salinity, temperature and dissolved oxygen (used in this report) are available from the SRT website, SRT 2011a.

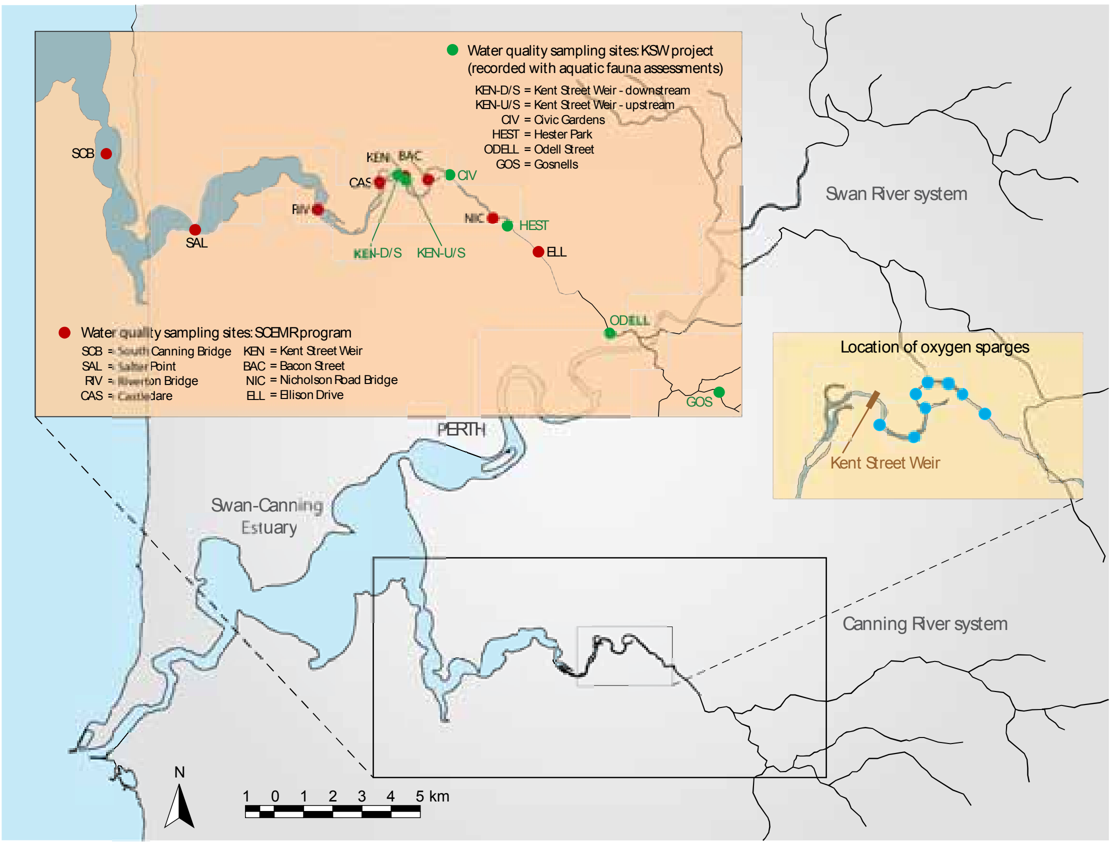

Figure 21 Location of water quality monitoring sites and oxygen spargers.

As illustrated in Figure 21, the Canning River has eight oxygen spargers oxygenating approximately 2 km of river upstream of the KSW (program managed by the Department of Water and SRT). This includes a sparger located adjacent to the CIV site (1.7 km above the KSW). Operation frequency of the oxygenation plants is considered in interpretation of water quality.

6.2 Results

Results summary

2009–10

Conditions were generally typical of long-term water quality conditions since the KSW was installed and oxygenation plants became operational.

- The KSW was the general point of separation between fresh water and estuarine influence.
- Sporadic overtopping events and short-lived saline conditions in the pool directly above the KSW were recorded.
- Saline bottom water up to 12.34 ppt (monthly average) was recorded in deeper pools in January, February and June. Salinity of bottom waters in other month did not exceed 0.55 ppt and did not exceed 0.88 ppt in surface waters in any months.
- A freshwater surface lens was common below the KSW through the winter months (June–October), extending through the water column after significant flow events and changing to marine salinities between February and April.

2010–11

The effect of an increased number of overtopping events during the period, weir boards remaining in place and reduced streamflows are reflected in the observations:

- persistence and spatial extent of saltwater conditions above the KSW increased markedly (from historic conditions)
- saline water reached ODELL in April (~5 km upstream of the KSW)
- marine level salinity sustained for ~30 weeks in the KSW pool's bottom waters
- surface water salinities above the KSW reached 14 ppt through March–April 2011
- surface temperatures followed ambient conditions and typical seasonal patterns
- only minor temperature stratification was evident throughout the system (few degrees cooler at the bottom of the water column)
- temperature variability was greatest at KENDS due to tidal dynamics and freshwater flows over the KSW
- dissolved oxygen reached near anoxic conditions on several occasions, typically at the bottom of the water column in deeper pools, although extending throughout the column in rare periods

Saltwater/freshwater dynamics

December 2009 to October 2010: preceding significant tidal intrusions

Data from 2010, before the magnitude and frequency of saline intrusions increased (see Section 5.2), were generally representative of typical water quality conditions in the Canning River around the KSW (post its construction). The weir was a point of separation between the freshwater environment upstream and seasonally saline estuarine environment downstream (Table 7).

Table 7 Monthly average salinity (ppt) occurring at the top and bottom of the water column above and below the KSW between December 2009 and September 2010 – before significant increases in tidal intrusions. Surface data were calculated from the top 20 cm and bottom data from 20 cm above the river bed.

Salinity (ppt)	DEC (2009)	JAN (2010)	FEB (2010)	MAR (2010)	APR (2010)	MAY (2010)	JUN (2010)	JUL (2010)	AUG (2010)	SEP (2010)	OCT (2010)
KENDS surface	4.08	13.77	12.64	20.65	14.08	23.38	1.99	1.63	2.59	1.89	1.74
KENDS bottom	21.28	29	29.58	34.37	28.64	29.2	27.96	21.82	22.28	13.96	21.55
KENUS surface	0.5	0.81	0.88	0.78	0.43	0.38	0.5	0.48	0.32	0.36	0.55
KENUS bottom	0.49	9.71	3.21	0.92	0.43	0.38	12.34	0.48	0.32	0.36	0.55

Data from CAS (Casteldare) and KEN sites within the SCEMR program for KSW downstream and upstream respectively.

As shown in Table 7, a surface freshwater lens was present below the KSW through most of winter and spring. Data from the SCEMR program showed this lens typically extending through to Riverton Bridge (~3 km downstream of the weir) and mostly being limited to the top 1 m of the water column (SRT 2011a). However, sampling conducted on 13 July 2010 (following a significant rainfall event[8]) revealed fresh water dominating the entire water column between the KSW and Riverton Bridge, and with a surface freshwater lens reaching over 11 km to Canning Bridge (Figure 10). Condition returned to previous levels the following week.

Tidal intrusions above the KSW did occur within this period (Figure 20) however salinity rapidly dissipated. Figure 22 shows the presence of saline conditions following an intrusion reported in the 15 June 2010 sample and a subsequent return to freshwater conditions throughout the water profile after about two weeks.

[8] 145.2 mm recorded between 9 July and 13 July. This is approximately 25% of the 2010 total rainfall for Perth (recorded at Bickley rain gauge 009240).

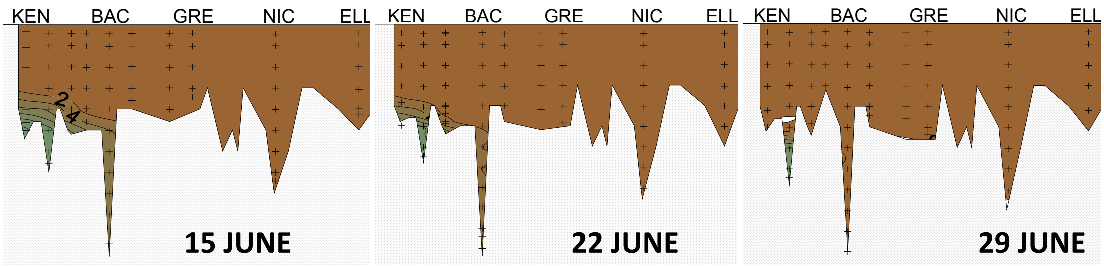

Figure 22 Salinity (ppt) above the KSW following an intrusion event recorded on 15 June 2010 and subsequent assessment on 22 June and 29 June. Data from the SCEMR program (see Section 6.1.)

November 2010 to September 2011: period of significant tidal intrusion

Salt levels in the river above the KSW increased in concentration, upstream extent and duration in direct association with the magnitude of intrusion and length of interval between events (see Figure 23 for an example).

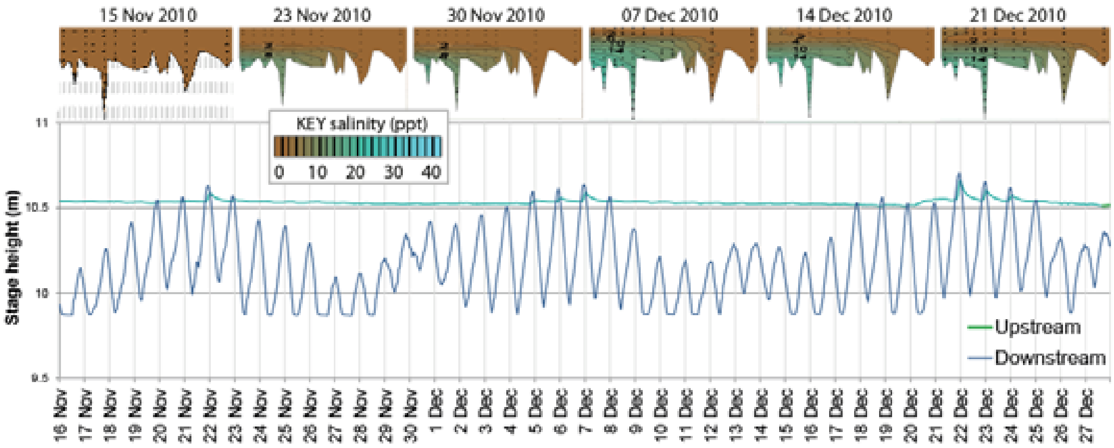

Figure 23 Tidal water intrusion events (arrows) at the KSW, upstream and downstream stage heights and associated weekly salinity profile (ppt): snapshot between 16 November 2010 and 27 December 2010 following first evidence of persistent salinity above the weir. Data from the SCEMR program (see description in Section 6.1).

Saline conditions were most common in the weir pool between KENUS and HEST, although salinity reached almost 15 ppt through to ODELL (~5 km upstream of the KSW) in April 2011. During the study period, maximum salinity values (ppt) recorded at aquatic fauna monitoring sites were 35.9 at KENUS, 31.7 at CIV, 33.0 at HEST, 14.9 at ODELL and 0.7 at GOS (see data summary in Table 25 and Table 26, Appendix F).

During 2011, flushing of salinity was limited due to reduced flows and increased frequency of saltwater intrusion (Section 5.2). As a consequence, salinity remained at near seawater concentrations above the KSW in excess of 30 weeks (November 2010 to June 2011). Figure 24 highlights the prolonged persistence of saline conditions above the KSW during March 2011 (between intrusion events) compared to 2010 conditions depicted in Figure 22.

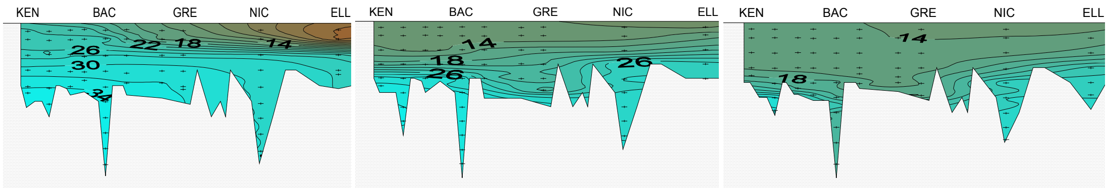

Figure 24 Persistent saline conditions above the KSW between tidal intrusion events correlated with reduced flushing capacity under low-flow conditions in 2011. Data from 1, 15 and 29 March 2011, from the SCEMR program (see description in Section 6.1).

Saline conditions occurring throughout the study area within each season for 2010 and 2011 are shown in Figure 8 to Figure 11, and in Table 25 and Table 26 (tables include data at ODELL and GOS which are not covered in the figures). These data demonstrate the typical (historical) divide between freshwater and saltwater environments at the KSW and the intrusion of saltwater above the KSW from November 2010 and general persistence under low-flow conditions through to July 2011 (when the boards were removed). Figure 8 and Figure 9 demonstrate the full extent of saline intrusion, which reached more than 5 km upstream during periods of summer and autumn 2011 and occurred through the entire water column (especially through autumn).

Data from the SCEMR program also illustrate the potential for rapid stratification of the water column, see example in Figure 25 demonstrating the formation of halocline between April and May 2011.

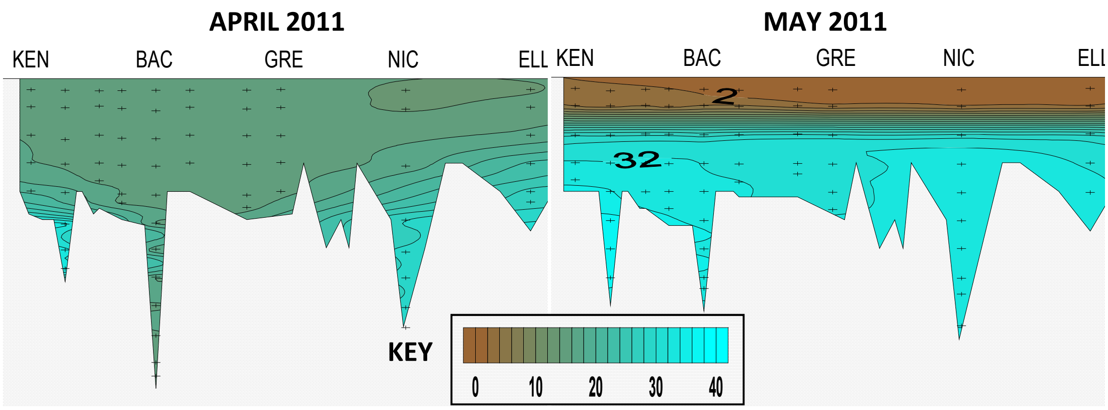

Figure 25 Salinity profile (ppt) of the weir pool on 5 April and 3 May 2011. Data from the SCEMR program (see description in Section 6.1).

Figure 26 and Figure 27 show the uncharacteristically high salt levels experienced in the weir pool in 2011, compared with the previous 10 years. Intrusion of salt past Nicholson Bridge is not uncommon although primarily occurred during periods where weir boards were absent.

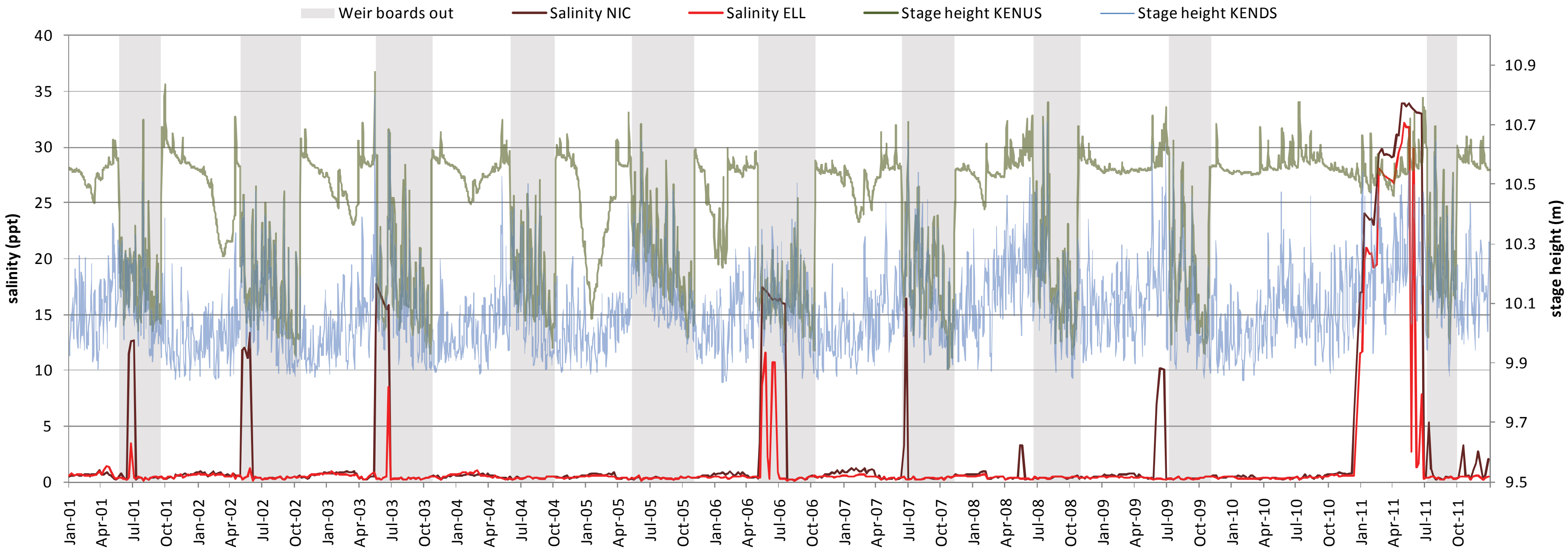

Figure 26 Stage heights above and below the KSW (secondary y axis) and periods of weir board removal/replacement. Salinity levels at bottom of water column at NIC and ELL sites (primary y axis).

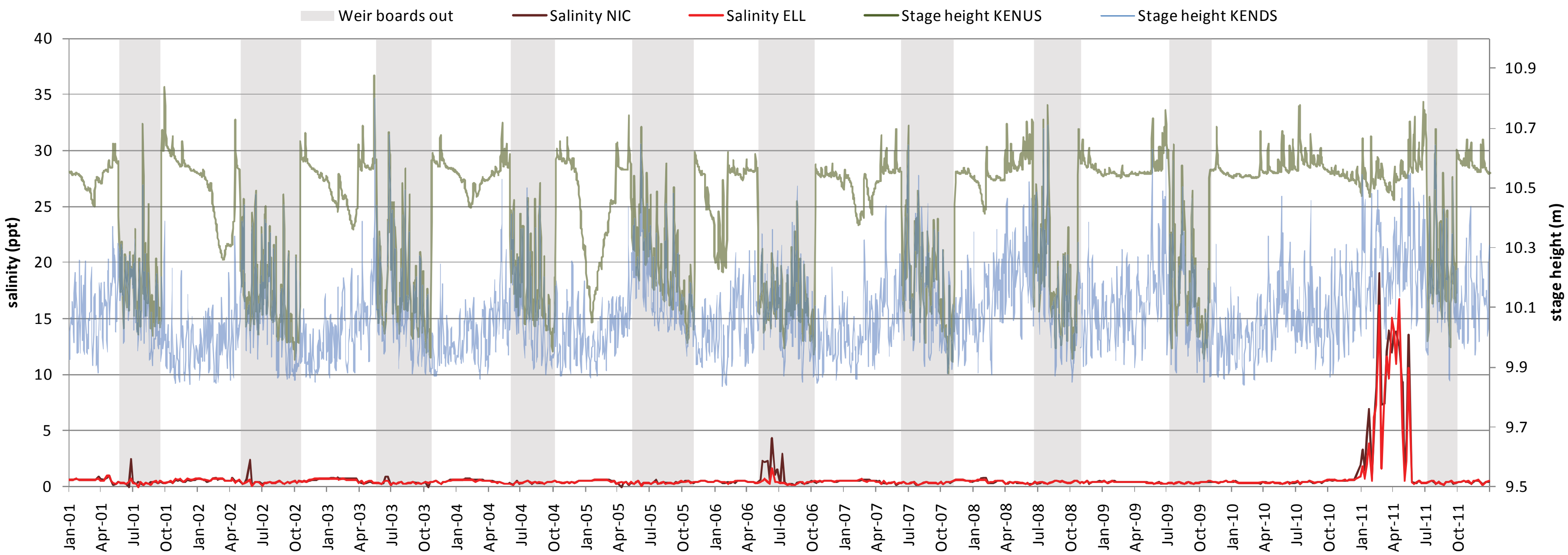

Figure 27 Stage heights above and below the KSW (secondary y axis) and periods of weir board removal/replacement. Salinity levels at surface of water column at NIC and ELL sites (primary y axis).

Temperature

Temperature followed typical seasonal conditions (Table 8 and Figure 28). Minor stratification was evident in most sites upstream of the KSW (with temperature at the bottom of the water column generally a few degrees cooler than the surface); however, downstream conditions at KENDS were often a few degrees warmer at the bottom compared with the surface (particularly obvious in 2010, see Figure 28).

Table 8 Seasonal median temperature for surface and bottom waters. Data from ecological monitoring sites.

Temp (◦C)	Surface water (20 cm)						Bottom water (depth variable)					
	KENDS	KENUS	CIV	HEST	ODELL	GOS	KENDS	KENUS	CIV	HEST	ODELL	GOS
Summer	28.5	27.0	26.8	26.8	26.7	21.4	29.3	27.5	26.5	19.6	24.1	21.4
Autumn	22.5	21.7	21.6	21.4	21.3	23.1	23.5	23.5	23.1	22.7	20.4	23.1
Winter	14.9	15.5	14.3	14.2	14.8	13.7	16.9	14.0	13.9	13.6	14.7	13.7
Spring	17.9	18.2	19.7	18.7	17.4	14.1	22.6	15.5	15.2	16.3	16.5	14.1

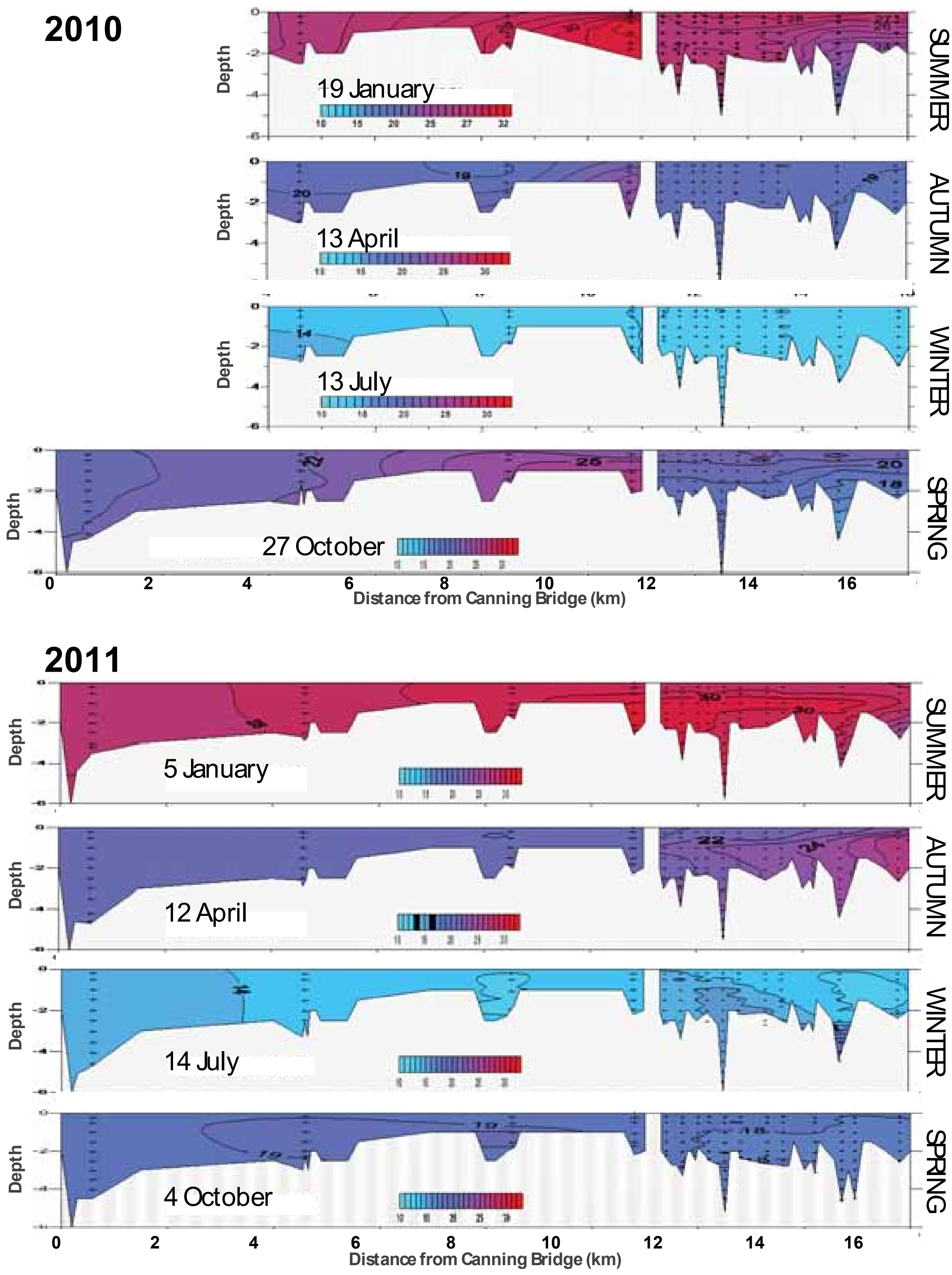

Figure 28 Temperature profiles for the Canning River system between Canning Bridge and Gosnells between 2010 and 2011: seasonal conditions represented by data from one week in each season generally representative of that season.

Note: additional sites were added to the SCEMR program downstream of the KSW as of spring 2010.

Dissolved oxygen

Low dissolved oxygen, reaching near-anoxic levels at several locations, was evident following seasonal patterns (declining during summer and autumn) and event-based responses throughout the study period. Figure 29 shows low oxygen conditions after a significant rainfall event[9]; including conditions occurring when the Bacon Street oxygenation plant was not operating (23 March 2011).

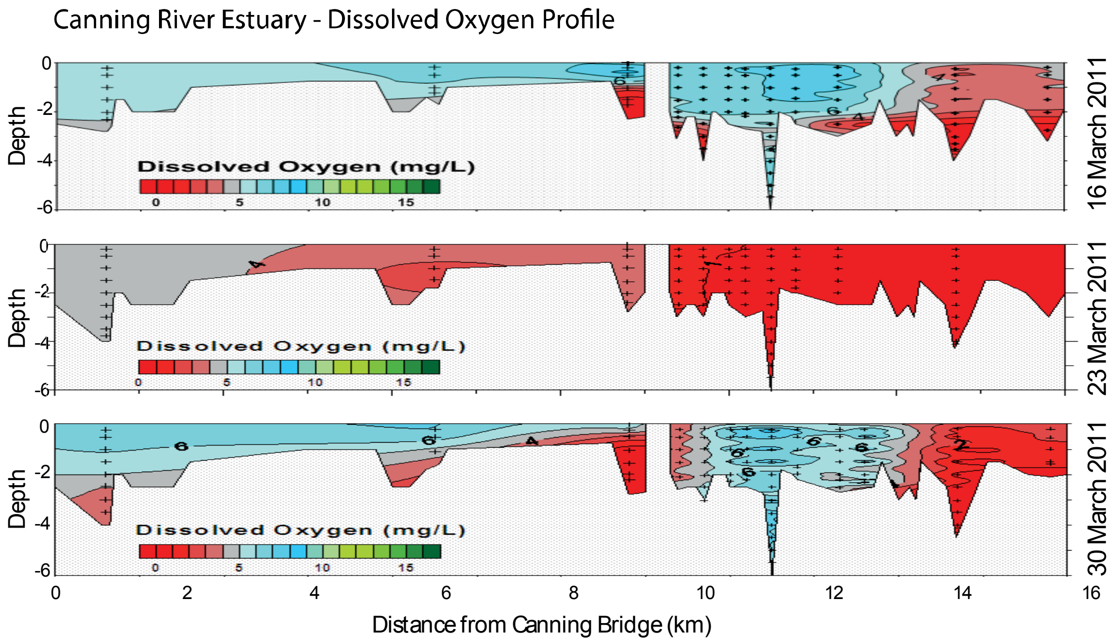

Figure 29 Dissolved oxygen concentrations (mg/L) in the Canning River following a rainfall event on 22–23 March 2011. Bacon Street oxygenation plant stopped running on 22 March due to power outages.

Stratification was regularly observed, with low oxygen conditions primarily confined to the bottom of the water column (Table 9 and Table 10) and mostly in deeper pools between Nicholson Road Bridge and Ellison Road (Figure 31) beyond the range of the oxygenation plants. As Figure 29 demonstrates, the oxygenation plants are effective at increasing oxygen across a wide area of the system, similarly, when plants are not in operation oxygen levels can decline rapidly, Figure 30.

[9] 31 mm recorded between 22 and 23 March, following a total of 1.2 mm for the previous 121 days (as recorded at the Bickley rain gauge 009240).

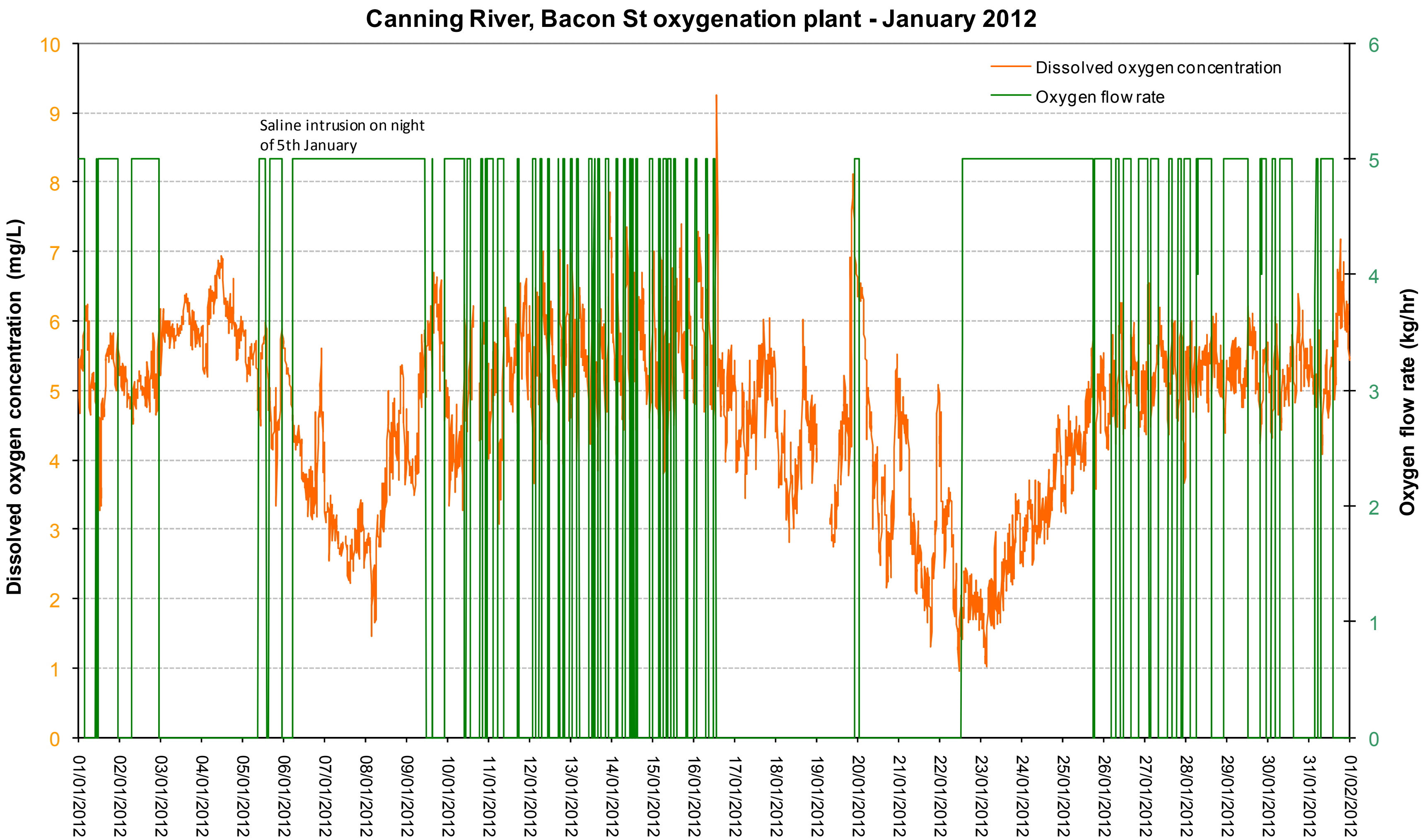

Figure 30 Oxygen levels in the Canning River adjacent to the Bacon Street oxygenation plant (January 2012) (DoW 2012).

Low dissolved oxygen was less evident in the higher rainfall periods through 2010, with a similar although less pronounced relationship in 2011 where low dissolved oxygen conditions persisted in some areas throughout the year. Oxygen conditions were also shown to respond to phytoplankton abundance (see next paragraph) and displayed stratification consistent with haloclines (see summer/autumn conditions through 2011). The relationship between salinity stratification and oxygen was not direct, with low dissolved oxygen conditions appearing independently of salt; for example, Figure 29 demonstrates low dissolved oxygen conditions occurring while conditions above the KSW were fresh.

Increases in the abundance of phytoplankton were correlated with supersaturation of dissolved oxygen on a number of occasions; for example Figure 32 demonstrates two separate events (9 March and 27 April 2011) consisting of estuarine diatoms and chlorophytes at the surface and potentially toxic dinoflagellates and raphidophytes throughout the water profile (SRT 2011b).

Table 9 Seasonal median dissolved oxygen (mg/L) for surface and bottom waters, calculated between summer 2009-10 through to winter 2011.

[mg/L]	Surface water (20cm)						Bottom water (depth variable)					
	KENDS	KENUS	CIV	HEST	ODELL	GOS	KENDS	KENUS	CIV	HEST	ODELL	GOS
Summer	5.4	7.0	7.1	5.1	4.8	4.9	0.7	0.4	4.7	0.2	3.5	4.9
Autumn	4.6	7.0	7.1	4.7	4.9	6.0	0.7	0.6	5.6	0.4	4.5	6.0
Winter	7.6	8.3	7.0	7.1	7.6	9.6	1.7	6.9	6.9	5.7	7.5	9.6
Spring	7.9	7.9	8.4	5.7	7.0	8.4	1.0	0.7	6.6	0.4	6.1	8.4

Sites with less than 5 mg/L recorded are highlighted in red; based on breach of guideline value set in Storer et al. 2011a.

Table 10 Seasonal median dissolved oxygen (percentage saturation) for surface and bottom waters, calculated between summer 2009-10 through to winter 2011.

[%sat]	Surface water (20cm)						Bottom water (depth variable)					
	KENDS	KENUS	CIV	HEST	ODELL	GOS	KENDS	KENUS	CIV	HEST	ODELL	GOS
Summer	74.1	87.0	88.7	63.6	60.0	56.2	10.5	4.7	61.7	2.6	41.5	56.2
Autumn	62.8	82.5	84.5	48.9	58.6	70.2	10.4	9.0	63.8	6.3	50.8	70.2
Winter	74.4	80.5	67.4	69.7	75.6	90.3	20.2	66.0	66.1	53.7	74.1	90.3
Spring	81.9	81.9	90.2	60.7	72.9	86.3	13.4	7.4	72.3	3.6	63.1	86.3

Data below 25% percentage saturation of dissolved oxygen has been highlighted in red.

Stratified low dissolved oxygen conditions followed similar patterns below the KSW. Notably, dissolved oxygen profiles displayed in Figure 31 demonstrate the zone of effect of the oxygenation plant at Bacon Street while under operation.

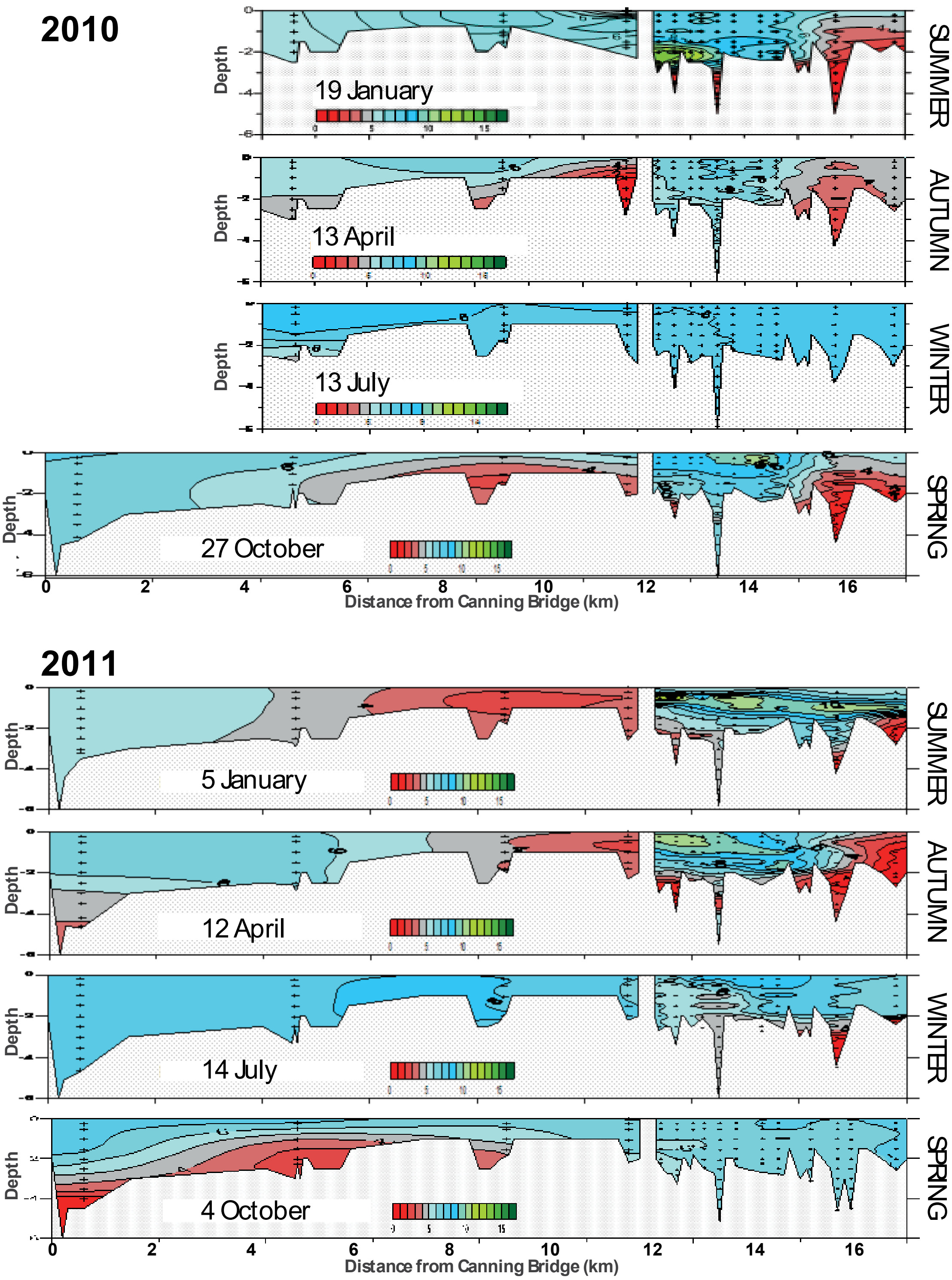

Figure 31 Dissolved oxygen profiles for the Canning River system between Canning Bridge and Gosnells between 2010 and 2011: seasonal conditions represented by data from one week in each season generally representative of that season.

Note: additional sites were added to the SCEMR program downstream of the KSW as of spring 2011.

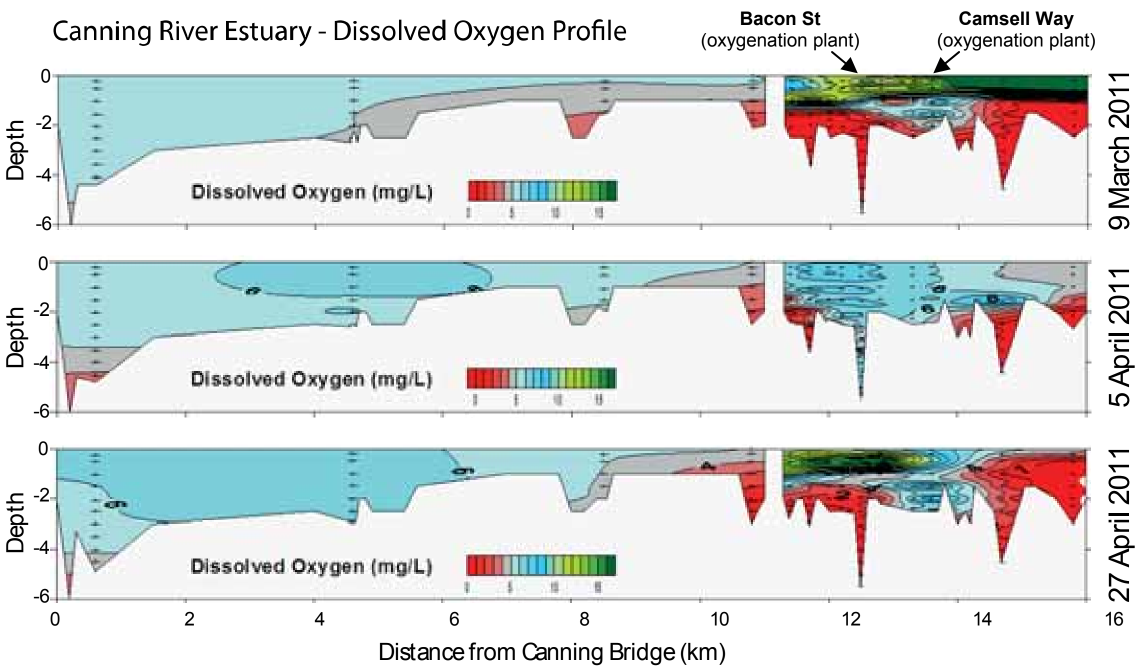

Figure 32 Examples of supersaturated oxygen layer above anoxic conditions throughout most of the Canning River study area above the KSW.

Notably, dissolved oxygen profiles displayed in Figure 32 demonstrate the effect of the oxygenation plant at Bacon Street operating on 5 April and following periods of reduced operation on 9 March and 27 April (Camsell Way oxygenation plant operational during the entire period).

pH

Data for pH showed little variation through the study period (Table 11), with levels remaining within guideline values (ANZECC & ARMCANZ 2000a).

Minor stratification was evident, with 0.1 to 0.4 difference in pH between bottom (lower value) and surface waters at most sites, with the exception of CIV in summer where a 0.9 difference was recorded. No significant spatial trends were apparent.

Table 11 Seasonal median pH for surface and bottom waters. ANZECC and ARMCANZ (2000a) trigger values for pH are 6.6 (lower) and 8.0 (upper) for lowland and upland rivers in south-western Australia.

[%sat]	**Surface water (20cm)**						**Bottom water (depth variable)**					
	KENDS	KENUS	CIV	HEST	ODELL	GOS	KENDS	KENUS	CIV	HEST	ODELL	GOS
Summer	7.1	7.2	7.6	7.3	7.2	7.0	7.1	6.8	6.7	6.9	7.0	7.0
Autumn	7.3	7.3	7.3	7.3	7.0	6.9	7.2	7.0	7.1	6.9	6.9	6.9
Winter	7.3	7.3	7.1	7.1	7.3	7.2	7.1	7.0	7.0	7.1	7.2	7.2
Spring	7.3	7.4	7.2	7.2	7.2	6.9	7.1	7.2	7.1	6.9	7.1	6.9

7 Water quality: weir pool contaminants December 2010–April 2011

Reducing conditions from low oxygen in bottom waters can lead to remobilisation of metals bound to sediment. Deoxygenation of bottom waters is often exacerbated under stratified salinity where mixing with oxygenated surface waters is restricted.

To assess the influence of saltwater intrusions on water chemistry in the weir pool, bottom water was sampled on 3 and 16 December 2010, 21 January and 13 April 2011 to coincide with periods when salt water was present in the weir pool. A number of surface water measurements were also collected for comparison.

7.1 Methods

Nine sites were sampled in a gradient from KSW through to Hester Park, shown in Figure 33. The selection of sites aimed to target deeper areas in the river stretch, as these were the sites most prone to experience induced hypoxia in bottom waters due to stratification, and therefore the greatest effects associated with saltwater intrusion. In the December 2010 sampling events, the Bacon Street site (BAC) was the upstream extent of the sampling. The extent of the study area was expanded to include the KS9 site in the January and April sampling events to capture regions of the river where Phoslock™ [10] had been applied in the previous year.

Bottom water samples were collected from approximately 20 cm above the sediment surface with a 1L Niskin bottle. Surface water samples were collected in the top 50 cm using a grab pole sampler. Unfiltered water was analysed for total nitrogen (TN) and total phosphorus (TP). Filtered water (0.45 μm) was analysed for dissolved nutrients (ammonium (NH_4^+), nitrate and nitrite (NOx), dissolved organic nitrogen (DON), filterable reactive phosphorus (FRP) and dissolved metals and metalloids: aluminium (Al), arsenic (As), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), sodium (Na), vanadium (V), zinc (Zn) and lanthanum (La). Analysis was conducted by the National Measurement Institute.

Lanthanum was included in the analytical suite due to use of Phoslock™ within the study area. Lanthanum present in the lattice of the Phoslock™ clay causes phosphorus to bind to the clay. Under saline conditions any lanthanum not already bound to phosphorus can be released from the clay lattice thus preventing Phoslock™ from binding additional phosphorus. Phoslock™ was applied to the KSW pool in February 2010 at least 7 months prior to the saline intrusion.

[10] Phoslock™ is a modified clay product which removes soluble phosphorus by the binding of lanthanum with phosphate. For more information about Phoslock™ see www.phoslock.com.au

Figure 33 Sampling locations in the Canning River for the assessment of saline intrusion on bottom water chemistry.

Application of guidelines

The nutrient concentrations measured in the bottom and surface waters in the Canning River study area were compared with the ANZECC and ARMCANZ (2000a) guidelines for south-western Australia. Both the estuarine and lowland river trigger values were used as the increased salinity present in 2010–11 meant the normally freshwater body was more typical of an estuarine environment.

Metal concentrations were compared with the lowest (hence more conservative) of either the marine or freshwater trigger value (ANZECC & ARMCANZ 2000a) at 95% ecosystem protection level.

7.2 Results

Results summary

Water was sampled on four occasions (from December 2010 to April 2011) from up to nine sites and showed:

- significant salinity stratification on all occasions
- consistently higher nutrient concentrations in bottom waters compared with surface waters
- soluble reactive phosphorus up to four times greater than that measured for the river reach historically (as part of the SCEMR project)
- copper and zinc concentrations often above ANZECC & ARMCANZ (2000a) trigger values

Salinity stratification

Water was sampled during conditions when salinity stratification was evident (Figure 34). Salinity stratification was commonly, but not always, associated with an oxygen depletion in the bottom waters.

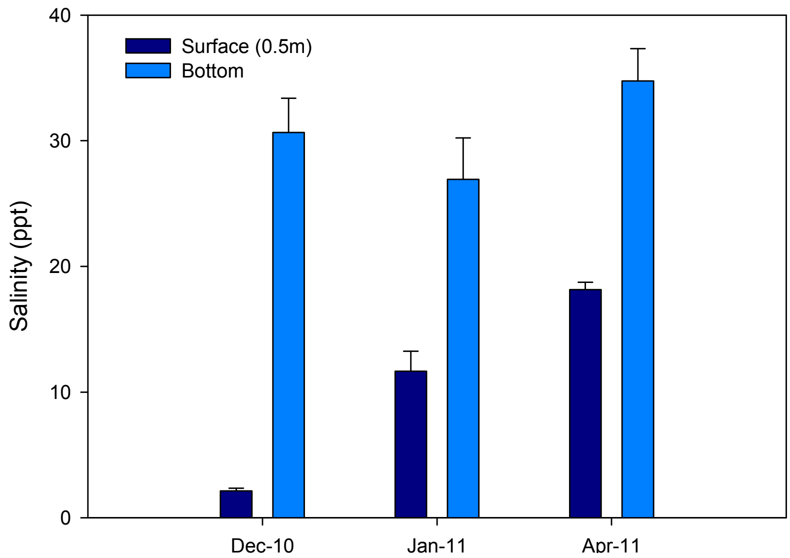

Figure 34 Salinity (average +SD) of surface water and bottom water for Canning River sites sampled during saltwater intrusion – shows salinity stratification.

Nutrient concentrations

The bottom waters had consistently higher nutrient concentrations than the surface waters, except for DON which was similar in both. Table 12 provides the minimum and maximum concentrations measured in bottom and surface waters, and the relevant guideline values from ANZECC and ARMCANZ (2000a). Both the lowland river and estuarine guideline for south-western Australian waters are shown, since the waterbody typically behaves as a freshwater system with the KSW closed, but during the 2010–11 period was commonly more estuarine.

Table 12 Minimum and maximum recorded concentrations for nutrients in surface and bottom waters within the Kent Street Weir pool

Analyte	TN	TP	NO_x	NH_4	SRP	DON
	mg N L^{-1}	mg P L^{-1}	mg N L^{-1}	mg N L^{-1}	mg P L^{-1}	mg N L^{-1}
Lowland river guideline*	1.2	0.065	0.15	0.08	0.04	N/A
Estuarine guideline*	1.5	0.03	0.045	0.04	0.005	N/A
Bottom water – minimum	0.62	0.05	<0.01	0.015	<0.005	0.44
Bottom water – maximum	3.7	2.4	0.02	3.0	1.7	0.73
Surface water – minimum	0.64	0.03	<0.01	<0.01	<0.005	0.55
Surface water – maximum	1.8	0.15	0.065	0.73	0.074	0.77

** ANZECC and ARMCANZ 2000a for south-western Australia (exceedences of one guideline shaded in blue and two guidelines in red)*

Nutrient data collected during this study was compared with data collected over five years in the SCEMR program (described in Section 6.1) to determine whether the regular exceedences recorded in this study were typical for the area – see results in Figure 35. For this analysis, the SCEMR sites above the KSW (KEN, BAC, ELL, NIC) were grouped to provide a range of concentrations observed during the past five years at any given month (10th to 90th percentile ranges are shown). The data collected in this study was overlayed as box-plots, again grouped by month. This directly assessed whether data observed during the salt-intrusion periods were within or exceeded the range most commonly observed during the past five years.

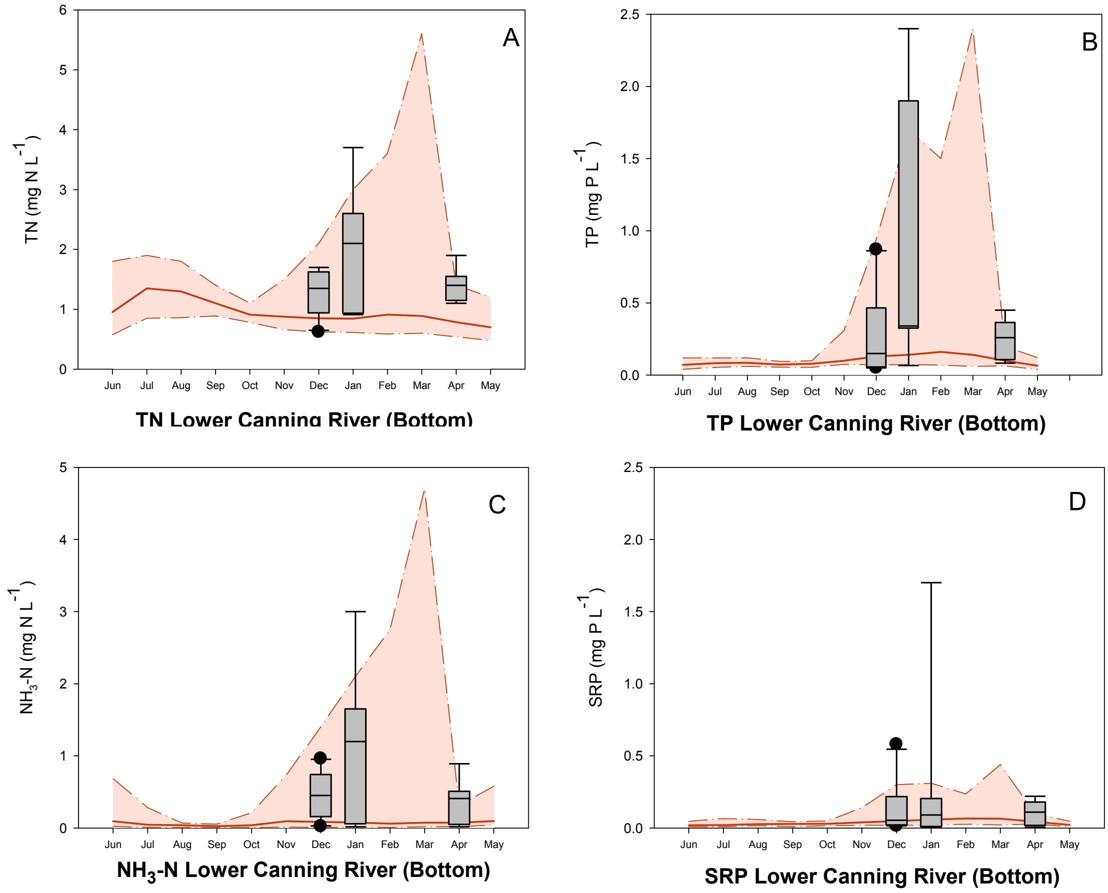

Figure 35 Bottom water concentrations from saltwater intrusions (in boxes) compared with the 10th to 90th percentile ranges (shaded regions) and medians (solid red line) observed in regular monitoring from 2006–10.

The box-plot describes the median, 25th to 75th percentiles (grey box) and 10th and 90th percentiles (whiskers) and 5th and 95th percentiles (solid dot). TN – total nitrogen, TP – total phosphorus, NH3-N – ammonia nitrogen, SRP – soluble reactive phosphorus.

Compared with the seasonal 10th and 90th percentiles observed over five years (Figure 35), the data for nutrient concentrations collected during the saltwater intrusions exceeds the range expected and is consistently above the long-term average. This is particularly evident for soluble reactive phosphorus, which showed a range that was sometimes more than four times greater than the historical range.

Notably, oxygenation plants, through oxygenation of bottom waters, have a significant mitigative effect on phosphorous levels, which is not reflected in these data (as data confounded by measurements collected outside of oxygenated areas and when oxygenation plants were not operating). The role of oxygenation in reducing available phosphorous is shown in Figure 36 and Figure 37, for Bacon Street and Nicholson Bridge sites respectively. Oxygen has also been shown to decrease local ammonium levels (Greenop et al. 2001).

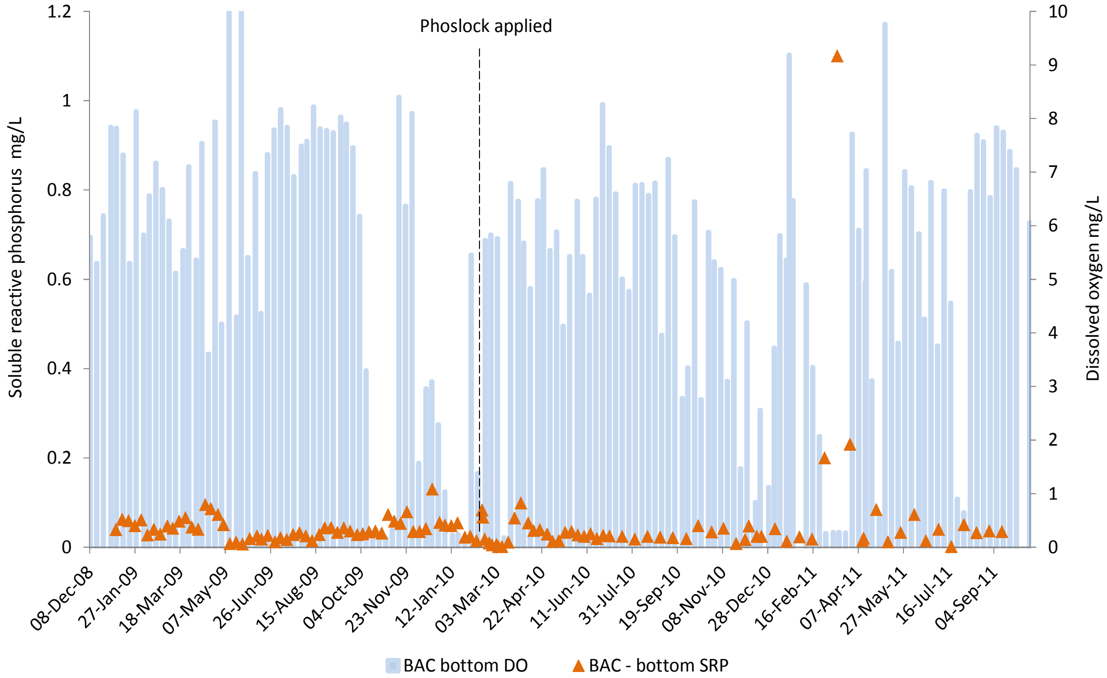

Figure 36 Bottom SRP concentrations against bottom dissolved oxygen concentrations at BAC, including date of Phoslock™ application (Robb and Rennie, in preparation).

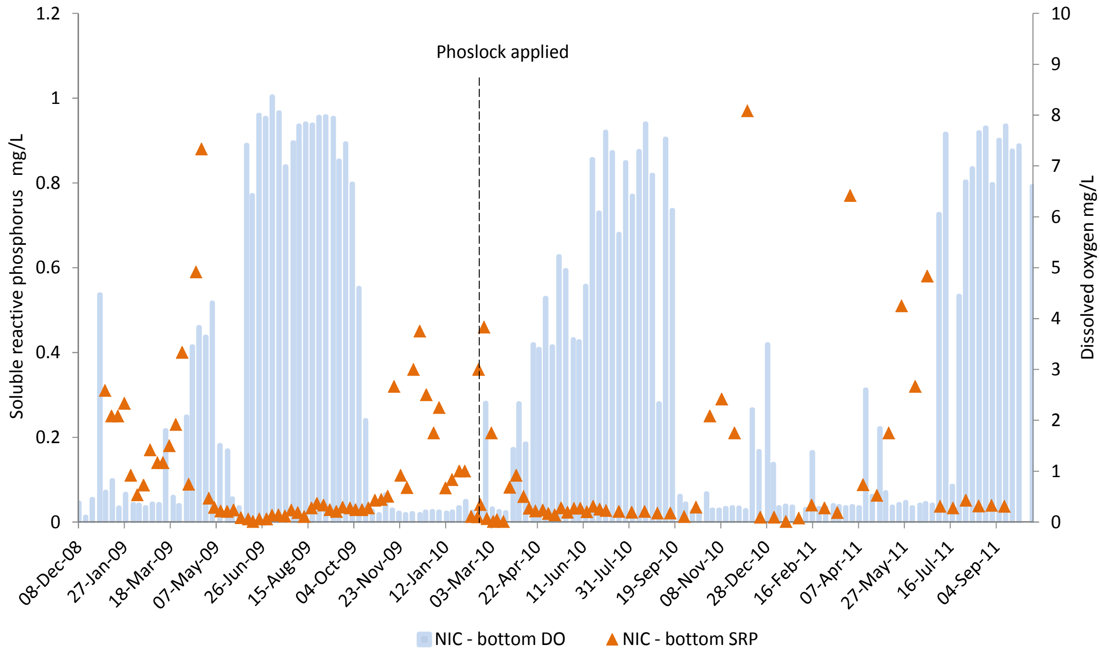

Figure 37 Bottom SRP concentrations against bottom dissolved oxygen concentrations at NIC, including date of Phoslock™ application (Robb and Rennie, in preparation).

Dissolved metal concentrations

The concentrations of dissolved metals in bottom waters and surface waters are shown in Table 13 and Table 14. These measured concentrations were compared with the lowest-available trigger value for either marine or freshwater (at the 95% protection level) since the waterbody displayed estuarine characteristics during the sampling period. Copper and zinc concentrations were most often above trigger values, with zinc exceeding trigger values in bottom waters more frequently than in the surface water samples. Nickel, lead and cobalt exceeded guideline levels at sites KS2, KS9 and KS8 respectively. Arsenic, although not above guideline values, was measurable only in the bottom waters.

Table 13 Dissolved metal concentrations (mg L^{-1}) observed in bottom water samples, where samples at or exceeding trigger values are highlighted

Site	Date	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Mo	Ni	Se	V	Zn	La
Trigger value[1]		0.055[2]		0.0002		0.001	0.0013		0.0034	1.9	0.0006		0.011		0.1	0.008	
KS1	3/12/10	0.009	<0.001	<0.0001	<0.001	<0.001	0.003	0.05	<0.001	0.23	<0.0001	0.005	<0.001	<0.001	<0.001	0.007	<0.001
KS2	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.004	0.018	<0.001	0.27	<0.0001	0.009	<0.001	<0.001	<0.001	0.011	<0.001
KS2	3/12/10	0.01	0.001	<0.0001	<0.001	<0.001	0.002	0.1	<0.001	0.23	<0.0001	0.003	0.001	<0.001	<0.001	0.007	<0.001
KS2	16/12/10	<0.005	<0.001	<0.0001	<0.001	<0.001	0.002	0.024	<0.001	0.11	<0.0001	0.004	0.002	<0.001	<0.001	0.011	<0.001
KS2	21/1/11	0.005	0.001	<0.0001	<0.001	<0.001	<0.001	0.12	<0.001	0.59	<0.0001	0.006	<0.001	<0.001	0.001	0.008	<0.001
KEN6	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.003	0.02	<0.001	0.27	<0.0001	0.009	0.002	<0.001	<0.001	0.009	<0.001
KEN7	3/12/10	0.005	0.001	<0.0001	<0.001	<0.001	0.003	0.065	<0.001	0.23	<0.0001	0.004	0.001	<0.001	<0.001	0.006	<0.001
KEN8	16/12/10	<0.005	0.001	<0.0001	0.002	<0.001	0.002	0.078	<0.001	0.19	<0.0001	0.005	0.005	<0.001	0.002	0.003	<0.001
KEN9	21/1/11	<0.005	0.001	<0.0001	<0.001	<0.001	0.003	0.32	<0.001	0.32	<0.0001	0.007	<0.001	<0.001	0.001	0.005	<0.001
KS3	3/12/10	<0.005	0.001	<0.0001	<0.001	<0.001	0.002	0.12	<0.001	0.23	<0.0001	0.004	0.001	<0.001	0.001	0.006	<0.001
KS4	13/4/11	0.009	<0.001	<0.0001	<0.001	<0.001	0.001	0.08	<0.001	0.33	<0.0001	0.007	<0.001	<0.001	<0.001	0.034	<0.001
KS4	16/12/10	<0.005	0.001	<0.0001	<0.001	<0.001	0.002	0.22	<0.001	0.35	<0.0001	0.006	<0.001	<0.001	0.003	0.008	<0.001
KS4	21/1/11	0.014	0.002	<0.0001	0.001	<0.001	<0.001	0.23	<0.001	0.32	<0.0001	0.002	<0.001	<0.001	0.004	0.002	<0.001
KS5	13/4/11	0.009	<0.001	<0.0001	<0.001	<0.001	0.001	0.076	<0.001	0.34	<0.0001	0.008	<0.001	<0.001	<0.001	0.008	<0.001
KS5	16/12/10	<0.005	0.002	<0.0001	<0.001	<0.001	0.001	0.29	<0.001	0.45	<0.0001	0.005	<0.001	<0.001	0.002	0.007	<0.001
KS5	21/1/11	<0.005	0.001	<0.0001	<0.001	<0.001	<0.001	0.12	<0.001	0.42	<0.0001	0.007	<0.001	<0.001	<0.001	0.009	<0.001
BAC	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.003	0.024	<0.001	0.33	<0.0001	0.008	<0.001	<0.001	<0.001	0.008	<0.001
BAC	3/12/10	<0.005	<0.001	<0.0001	<0.001	<0.001	0.004	0.17	<0.001	0.53	<0.0001	0.004	0.004	<0.001	<0.001	0.008	<0.001
BAC	16/12/10	<0.005	0.001	<0.0001	<0.001	<0.001	0.003	0.34	<0.001	0.48	<0.0001	0.006	<0.001	<0.001	<0.001	0.013	<0.001
BAC	21/1/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.003	0.27	0.001	0.42	<0.0001	0.006	<0.001	<0.001	<0.001	0.014	0.001
KS6	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.002	0.095	<0.001	0.44	<0.0001	0.006	<0.001	<0.001	<0.001	0.011	<0.001
KS6	21/1/11	<0.005	0.002	0.0001	<0.001	<0.001	0.003	0.64	<0.001	0.85	<0.0001	0.006	<0.001	<0.001	0.002	0.008	<0.001
KS7	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.004	0.065	<0.001	0.41	<0.0001	0.006	<0.001	<0.001	<0.001	0.009	<0.001
KS7	21/1/11	<0.005	0.002	<0.0001	0.002	<0.001	0.002	0.48	<0.001	0.58	<0.0001	0.007	0.001	<0.001	0.002	0.009	<0.001
KS8	13/4/11	0.009	<0.001	<0.0001	<0.001	<0.001	0.006	0.035	<0.001	0.52	<0.0001	0.007	<0.001	<0.001	<0.001	0.013	<0.001
KS8	21/1/11	<0.005	<0.001	<0.0001	0.001	0.001	0.013	3.9	<0.001	0.98	<0.0001	0.007	0.002	<0.001	<0.001	0.009	<0.001
KS9	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.005	0.089	0.001	0.62	<0.0001	0.005	<0.001	<0.001	0.001	0.017	<0.001
KS9	21/1/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.002	5.1	<0.001	1.00	<0.0001	0.007	0.012	<0.001	<0.001	0.012	<0.001

[1]ANZECC and ARMCANZ (2000a) trigger value (lowest of either marine or freshwater at 95% ecosystem protection level).

[2] Trigger value for waters with pH>6.5

Table 14 Dissolved metal concentrations (mg L^{-1}) observed in surface water samples, where samples at or exceeding trigger values are highlighted

Site	Date	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Mo	Ni	Se	V	Zn	La
Trigger value[1] (mg.L^{-1})		0.055[2]		0.0002		0.001	0.0013		0.0034	1.9	0.0006		0.011		0.1	0.008	
KS2	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.003	0.015	<0.001	0.24	<0.0001	0.004	<0.001	<0.001	<0.001	0.011	<0.001
KS2	3/12/10	0.025	<0.001	<0.0001	0.001	<0.001	0.002	0.24	<0.001	0.025	<0.0001	0.001	0.011	<0.001	<0.001	0.006	0.001
KS2	16/12/10	0.006	<0.001	<0.0001	<0.001	<0.001	0.004	0.05	<0.001	0.015	<0.0001	0.001	0.004	<0.001	<0.001	<0.001	<0.001
KS2	21/1/11	0.008	<0.001	<0.0001	<0.001	<0.001	0.002	0.082	<0.001	0.046	<0.0001	0.004	0.001	<0.001	<0.001	0.003	<0.001
BAC	13/4/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.005	0.019	<0.001	0.27	<0.0001	0.004	<0.001	<0.001	<0.001	0.006	<0.001
BAC	3/12/10	<0.005	<0.001	<0.0001	<0.001	<0.001	0.002	0.2	<0.001	0.017	<0.0001	0.001	<0.001	<0.001	<0.001	0.004	<0.001
BAC	16/12/10	0.007	<0.001	<0.0001	<0.001	<0.001	0.004	0.03	<0.001	0.003	<0.0001	0.001	<0.001	<0.001	<0.001	0.011	<0.001
BAC	21/1/11	<0.005	<0.001	<0.0001	<0.001	<0.001	0.003	0.12	<0.001	0.068	<0.0001	0.003	0.001	<0.001	<0.001	0.007	<0.001
KS9	13/4/11	0.01	<0.001	<0.0001	<0.001	<0.001	0.009	0.093	0.004	0.79	<0.0001	0.002	<0.001	<0.001	<0.001	0.062	<0.001
KS9	21/1/11	0.006	<0.001	<0.0001	<0.001	<0.001	0.004	0.1	<0.001	0.18	<0.0001	0.002	<0.001	<0.001	<0.001	0.02	<0.001

[1]ANZECC and ARMCANZ (2000a) trigger value (lowest of either marine or freshwater at 95% ecosystem protection level).

[2] Trigger value for waters with pH>6.5

8 Sediment quality: weir pool contaminants January–June 2011

Two sediment quality investigations were undertaken as part of this study: the first was designed to assess contaminant accumulation in sediment trapped behind the weir, and the second to quantify the spatial extent and possible source of any contaminants through targeting drain outfalls. These studies targeted the potential accumulation of sediment (associated with contaminants) due to the presence of the KSW.

8.1 Methods

Investigation 1: Assessment of sediment contamination above the KSW

This investigation assessed sediment contamination directly upstream of the KSW.

Sediment was sampled in January, April and June 2011 from a 2 to 2.5 m depression behind the KSW, approximately 100 m long and 50 m upstream from the weir. On each sampling occasion, six sites were randomly chosen that were no closer than 5 m from each other (Figure 38). Sediment was cored with an Uwitec gravity corer (core internal diameter = 5.9 cm) and sectioned with an Uwitec core extruder. To minimise the oxidation of acid volatile sulfur, samples were placed immediately in glass jars (on ice and in a dark environment) and homogenised in the laboratory. Each sample was a composite of three cores; that is, the top 3 cm of each core collected. A deeper section (3–6 cm) was also taken from one of the six sample sites and selected randomly (also a composite of three cores). Particle size was measured at one of these sites, with collection of three additional cores. Table 15 outlines the sampling and analysis procedure. Detailed methods are given in Appendix G.

Figure 38 Location of sample sites from the deeper area behind the KSW where yellow, red and green dots indicate sites sampled January, April and June 2011 respectively.

Table 15 Overview of sediment sampling and analysis for investigation 1

Date	Number of sites	Surface sediment (0–3cm)	Deeper sediment (3–6 cm)	Surface sediment (0–3cm)	Deeper sediment (3–6 cm)
		Chemical analysis		Particle size	
11 Jan 2011	Chemical analysis – 6 Particle size analysis	A composite of three cores/site homogenised in the laboratory.		A composite of three cores homogenised in the laboratory.	
20 Apr 2011	Chemical analysis – 6 Particle size analysis	Deeper sediment only sampled at one of the six sites on any occasion.			
21 Jun 2011	Chemical analysis – 6 Particle size analysis				
Analysis information		National Measurement Institute Total metals, OC pesticide suite, PAH suite (16 priority pollutants), PCBs (Jan, Apr only as none detected), TOC, AVS, CRS, Total S, Moisture content		*CSIRO Minerals laboratory* Particle size <4 um (clay) <62 um (silt) <250 um (fine sand) <500 um (medium sand) <2000 um (coarse sand) <10 000 um (gravel)	

For a detailed contaminant list and relative limits of reporting, see Appendix G.

Investigation 2: Spatial extent of sediment contamination

The objective of this study was to investigate the extent of sediment contamination within the KSW pool. Sediment sampling was targeted at the outfall of 16 drains entering the Canning River within a 5 km stretch upstream of the weir (Figure 39) For a description of these drains and sampling coordinates, see Appendix H.

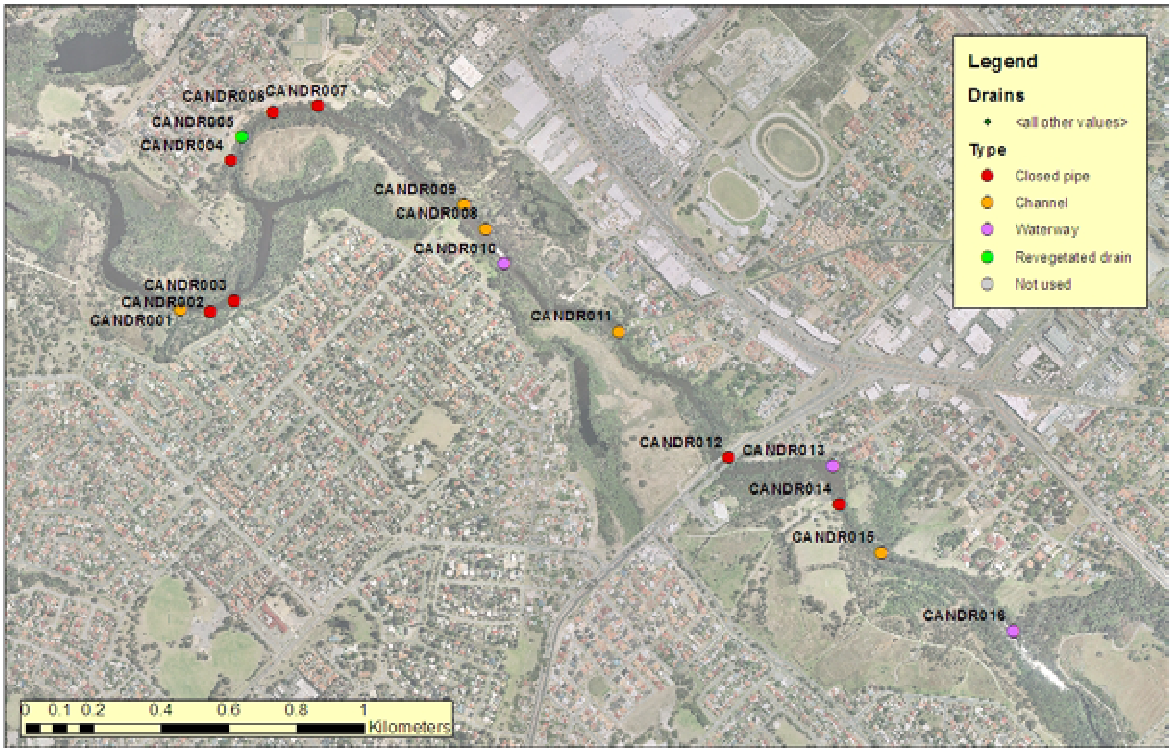

Figure 39 Location of sampling sites within the Canning River, upstream of the KSW.

At each site five cores (5.9 cm internal diameter) were collected using an Uwitec gravity corer. The top 3 cm of each core was collected and composited into a single sample, placed immediately in glass jars (to minimise oxidation) and homogenised. The homogenised sample was divided into two samples: one for particle size analysis and one for all other analyses. An overview of the sampling and analysis is shown in Table 16; detailed methods are provided in Appendix I.

Table 16 Overview of sediment sampling and analysis for investigation 2

Date	Number of sites	Surface sediment (0-3cm)	
11 Jan 2011	16	Chemical analysis	Particle size
		One sample each site (composite of five cores/site)	
Analysis information		*National Measurement Institute*	*CSIRO Minerals laboratory*
		Bioavailable metals	Particle size
		OC pesticide suite	<4 um (clay)
		PAH suite (16 priority pollutants)	<62 um (silt)
		TOC	<250 um (fine sand)
		TN and TP	<500 um (medium sand)
		Moisture content	<2000 um (coarse sand)
			<10 000 um (gravel)

For a detailed contaminant list and relative limits of reporting refer to Appendix I.

Application of guidelines

Sediments can be considered both a sink and (subsequently) a source of contaminants and, under certain conditions; these contaminants may become available to biota (ingestion of sediment, via food chain or through direct contact with burrowing animals). To assess the likelihood of ecological harm, concentrations of metals and organic contaminants were compared with the interim sediment quality guidelines (ISQG) from ANZECC and ARMCANZ (2000a). Note: if concentrations of contaminants are below the ISQG low trigger value, then the frequency of adverse biological effects is expected to be very low. If concentrations are above the ISQG high trigger value, adverse biological effects are expected to occur more frequently. For organic contaminants, data were normalised to 1% organic carbon before the comparison to guidelines (according to Simpson et al. 2005).

The top 3 cm of sediment was sampled – instead of the top 2 cm as recommended in Simpson et al. (2005) – to allow for direct comparison of data to those previously collected in the Swan-Canning estuary (Nice 2009).

Guidelines are not available for all contaminants measured and so, where appropriate, alternative guidelines have been applied – such as the selenium guideline proposed by Lemly (1996).

8.2 Results

Results summary

[both studies]

- Silt (particles 4–62 µm size fraction) dominated the surficial sediment in the KSW.
- Concentration of reduced sulfides (particularly acid volatile sulfur) appeared to increase during the six-month period (January – June 2011).
- Lead and zinc concentrations exceeded the low interim sediment quality guideline (ISQG) trigger values, and did not show a strong spatial or temporal pattern. Zinc values exceeded the high ISQG at most of the sites located where drains enter the weir pool.
- PAHs were below the low ISQG trigger values except for one sample.
- The organochlorine pesticide *chlordane* was found commonly exceeding the low ISQG trigger value and at a concentration above the high ISQG trigger value at one site on one occasion

Assessment of potential accumulation of contaminants

Sediment sampled from the depression behind the KSW was dominated by silt and showed no clear differences in composition over time or with depth (comparing 0–3 cm and 3–6 cm fractions) (Figure 40). The organic matter content of surface sediments (0–3 cm fraction) was between 1.3% and 7.6% with an average concentration of 5.4%. The deeper fraction (3–6 cm) had an average organic matter content of 5.6%. This organic matter content of the sediment is within the range recorded for the Swan-Canning in other studies during the past 25 years (Hill et al. 1991; Gerritse et al. 1998; Rate et al. 2000).

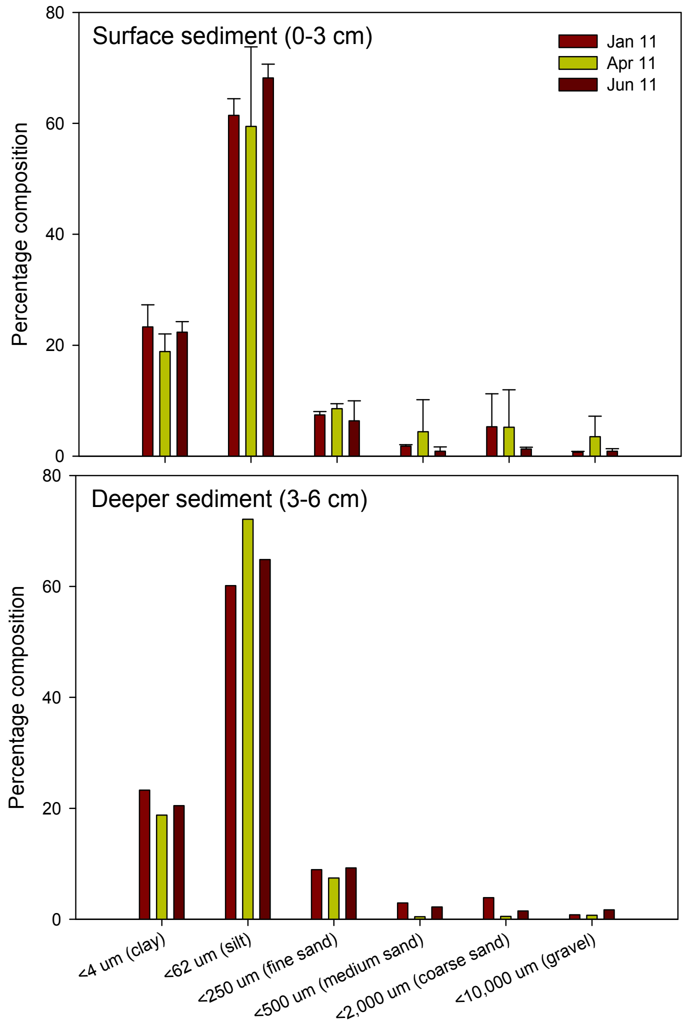

Figure 40 Particle size results for sediment near the KSW. For surface sediment (top) the average of three cores plus standard deviation is displayed.

Total metal concentrations are reported in Table 17, with the median concentrations shown for surface sediments (where n=6) and the single sample reported for each time period for the deeper sediment. There was no evidence of a pattern for increasing metal concentrations across the six-month period. Lead and zinc were above the ANZECC and ARMCANZ (2000a) ISQG low trigger in almost all samples, with the ISQG high trigger for zinc exceeded in January and June 2011. Copper marginally exceeded guideline value in the deeper sediment fraction in January.

Table 17 Median total metal results (mg kg^{-1}) for sediment samples from the Kent Street Weir pool at three time periods.

	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Ni	Se	Zn
ISQG low trigger value	NA	20	1.5	80	NA	65	NA	50	NA	0.15	21	2*	200
ISQG high trigger value	NA	70	10	370	NA	270	NA	220	NA	1	52	3**	410
Jan 2011 – (0–3 cm)	21400	7.1	0.72	37	10.5	62	38200	81	115	<0.2	14	1.7	560
Apr 2011 – (0–3 cm)	18700	5.1	0.65	24	9.1	38	31500	49	100	<0.2 [1]	11	1.3	340
Jun 2011 – (0–3 cm)	23000	5.4	0.67	29	11.4	44	46500	72	130	<0.2	12	1.5	420
Jan 2011 – (3–6 cm)	22400	7.5	0.87	39	12	66	39900	91	180	<0.2	14	1.3	620
Apr 2011 – (3–6 cm)	17900	4.8	0.62	24	7.9	41	37800	56	120	<0.2	11	1.4	400
Jun 2011 – (3–6 cm)	25000	5.4	0.80	30	12	46	51000	67	120	<0.2	12	1.5	470

**Se low hazard concentration 2–3 mg kg^{-1} (Lemly 1996) (ISQG not available), ** Se high hazard concentration 3–4 mg kg^{-1} (Lemly 1996) (ISQG not available). NA = no guideline available.*

[1]One sample had Hg = 1.5 mg kg^{-1}

The median concentrations of total sulfur, acid volatile sulfur (AVS) and chromium reducible sulfur for the surface fraction (0–3 cm; n=6) all increased by the final sampling period in June 2011 (Table 18). Most notably the concentration of AVS had approximately doubled in the June sampling compared with the previous two time periods, for both surface and deeper sediment samples.

Table 18 Median total sulfur (TS), acid volatile sulfur (AVS) and chromium reducible sulfur (CRS) sediment samples from the Kent Street Weir pool at three time periods.

	Total sulfur (%)	AVS (%)	CRS (%)
Jan 2011 – (0–3 cm)	1.9	0.34	1.05
Apr 2011 – (0–3 cm)	2.3	0.32	1.05
Jun 2011 – (0–3 cm)	3.1	0.79	1.65
Jan 2011 – (3–6 cm)	1.9	0.72	1.6
Apr 2011 – (3–6 cm)	3.2	0.51	1.5
Jun 2011 – (3–6 cm)	3.4	1.3	1.5

Polycyclic aromatic hydrocarbons (PAHs) were present in sediment samples, usually at concentrations below levels of concern (Table 19). The sediment sample collected (particularly for April and June) were gelatinous in nature with a low proportion of total solids, and unfortunately this resulted in an increase in the achievable limit of reporting (by tenfold). Due to this, PAHs were often reported above limits of reporting (LOR) in January, but not the April and June sampling periods. It is likely that PAHs present in January would have been reported in April and June if the same LOR had been achievable. The total concentration of PAHs was below detection limits (0.16 and 1.6 $\mu g\ kg^{-1}$). Dibenzo(a,h)anthracene was occasionally recorded just above ISQG low trigger values for both surface (0–3 cm) and deeper (3–6 cm) samples.

Organochlorine pesticides were present in all sediment samples analysed (Table 20). Total chlordane was present above the ISQG low trigger in all samples, and was dominated by the trans-chlordane fraction. Dieldrin was present above the ISQG low trigger in approximately half of the samples. DDD, DDE and DDT were occasionally present, however not at concentrations of ecological concern.

Polychlorinated biphenyls were sampled on two occasions, but did not record concentrations above reporting limits for any sample (data not shown).

Table 19 Median concentrations (µg kg^{-1}) of polycyclic aromatic hydrocarbons (PAHs; normalised to 1% organic carbon) present in sediment behind the KSW for samples from three time periods and two depths. Only those PAHs with at least one sample above reporting limits are displayed; samples exceeding trigger values are highlighted.

	Benzo(a) anthracene	Benzo(a) pyrene	Benzo (g,h,i) perylene	Benzo(b) and (k) fluoran-thene	Dibenzo (a,h) anthracene	Fluorene	Fluoran-thene	Chrysene	Indeno (1,2,3-cd) pyrene	Pyrene	Phenan-threne
ISQG low trigger value	261	430	NA	NA	63	19	600	384	NA	665	240
ISQG high trigger value	1600	1600	NA	NA	260	540	5100	2800	NA	2600	1500
January 2011 (0–3 cm)	7.3	2.4	26.1	4.6	59	4.2	8.8	5.9	9.9	11.8	3.9
Not detected above LOR in	3/6 samples	2/6 samples	0/6 samples	2/6 samples	0/6 samples	0/6 samples	0/6 samples	3/6 samples	0/6 samples	0/6 samples	0/6 samples
April 2011 (0–3 cm)	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Not detected above LOR in	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples
June 2011 (0–3 cm)	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Not detected above LOR in	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples	6/6 samples
Deeper (3–6 cm)	<LOR	2.6	33	5.4	75	<LOR	7.8	<LOR	<LOR	<LOR	<LOR
Not detected above LOR in	3/3 samples	2/3 samples	2/3 samples	2/3 samples	2/3 samples	3/3 samples	2/3 samples	3/3 samples	6/6 samples	6/6 samples	6/6 samples

In April and June sampling periods, sediment collected contained a large proportion of water relative to sediment and thus the limit of reporting achievable for PAHs was actually higher than in January 2011 by an order of 10. Deeper sample data is a median of samples taken in the three sampling events.

Table 20 Median concentrations (μg kg^{-1}) of organochlorine (OC) pesticides (normalised to 1% organic carbon) present in sediment behind the KSW for samples from three time periods and two depths. Only those OC pesticides with at least one sample above reporting limits are displayed; samples exceeding trigger values are highlighted.

	Trans-chlordane	Total chlordane	DDD	DDE	DDT	Dieldrin
ISQG low trigger value	NA	0.5	2	2.2	1.6	0.02
ISQG high trigger value	NA	6	20	27	46	8
January 2011 (0–3 cm)	4.5	4.5	0.4	0.7	0.4	1.7
Not detected above LOR in	0/6 samples	0/6 samples	0/6 samples	0/6 samples	3/6 samples	5/6 samples
April 2011 (0–3 cm)	1.8	2.2	<LOR	<LOR	<LOR	0.37
Not detected above LOR in	0/6 samples	0/6 samples	6/6 samples	6/6 samples	6/6 samples	4/6 samples
June 2011 (0–3 cm)	1.6	1.9	<LOR	<LOR	<LOR	0.36
Not detected above LOR in	0/6 samples	0/6 samples	6/6 samples	6/6 samples	6/6 samples	0/6 samples
Deeper samples (3–6	1.9	1.9	0.4	0.8	0.3	0.39
Not detected above LOR in	0/3 samples	0/3 samples	2/3 samples	2/3 samples	2/3 samples	1/3 samples

Spatial extent of sediment contamination above KSW

The sediment at most sites (except CANDR008 and CANDR013) was dominated by silt (Table 21).

Table 21 Particle size results for samples from 16 sites in the KSW pool show that silt was the dominant size fraction for most samples

Site name	Clay	Silt	Fine sand	Medium sand	Coarse sand	Gravel
	<4 µm	4–62 µm	62–250 µm	250–500 µm	500–2000 µm	>2000 µm
	Proportion of sediments (% by weight)					
CANDR001	16.3	67.14	7.46	0	5.90	3.20
CANDR002	5.12	75.77	16.22	0	1.70	1.20
CANDR003	26.03	66.20	5.67	0	1.30	0.80
CANDR005	5.65	49.23	20.55	6.18	6.90	11.50
CANDR006	3.09	53.20	21.29	2.23	10.10	10.10
CANDR007	6.78	34.73	16.88	12.11	24.20	5.30
CANDR008	0	0	9.98	63.42	24.50	2.10
CANDR009	16.13	67.68	9.39	0.40	2.60	3.80
CANDR010	3.93	59.32	26.02	3.43	3.50	3.80
CANDR011	6.18	29.03	18.34	25.15	19.30	2.00
CANDR012	2.80	66.75	15.27	3.08	11.30	0.80
CANDR013	0	0	1.21	51.99	45.50	1.30
CANDR014	7.20	60.78	18.36	4.96	4.10	4.60
CANDR015	7.69	66.32	19.44	3.04	0.70	2.80
CANDR016	18.38	72.46	7.67	0	0.60	0.90

NB – grey shading indicates dominant fraction.

Organic matter varied between sites, ranging from 0.66 to 15%. The average organic content measured was 7.9%. The recorded organic matter content of the sediment is within the range previously reported for the Swan-Canning river system (Hill et al. 1991; Gerritse et al. 1998; Rate et al. 2000).

ANZECC and ARMCANZ (2000a) ISQG triggers were exceeded for zinc, lead and occasionally for mercury (Table 22). Of the 16 sites assessed, zinc exceeded the ISQG high trigger at 10 sites and the ISQG low at two sites, and lead exceeded the ISQG low at 10 sites. Mercury exceeded the ISQG low trigger at two sites. Although no ANZECC and ARMCANZ (2000a) guideline exists for selenium, compared with the guideline value proposed by Lemly (1996), concentrations were most commonly between the low and high hazard guideline, indicating the possibility of some degree of ecological effect.

PAHs were occasionally detected above reporting limits, however at concentrations well below the guidelines (Table 23). Organochlorine pesticides were more commonly detected (Table 24), with most samples exceeding the ISQG low trigger value for total chlordane; site

CANDR011 recording a concentration of 22.44 ug kg^{-1} compared with the ISQG high trigger value of 6 ug kg^{-1}. DDT was above the ISQG low trigger at CANDR007.

Generally, the spatial extent of contaminants was relatively homogeneous, with no marked spikes in concentrations or gradients away from an obvious source (e.g. drain) (Table 22 to Table 24 and Figure 41). A notable exception was the spike in chlordane at CANDR011.

Table 22 Bioavailable (acid-extractable) metal results (mg kg^{-1}) for sediment samples from 16 sites in the KSW pool.

Site ref no.	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Ni	Se	Zn
ISQG low trigger value	NA	20	1.5	80	NA	65	NA	50	NA	0.15	21	2*	200
ISQG high trigger value	NA	70	10	370	NA	270	NA	220	NA	1	52	3**	410
CANDR001	2630	<0.5	0.51	5.3	1.6	25	11500	58	45	<0.1	4.1	1.6	450
CANDR002	3600	0.5	0.84	7.3	2.7	31	16500	79	91	<0.1	6.4	2.2	650
CANDR003	3670	0.6	0.8	7.8	3	30	22400	73	89	<0.1	5.6	2.6	530
CANDR004	2620	<0.5	0.54	6.4	2.2	20	28300	60	98	<0.1	4.9	2.9	640
CANDR005	2850	0.58	0.6	6.2	2.8	32	21100	64	69	<0.1	6.7	2.3	520
CANDR006	1950	0.63	<0.5	5.6	2.4	15	24300	43	120	<0.1	3.9	1.9	320
CANDR007	700	<0.5	<0.5	2.1	0.97	8.4	4080	43	50	<0.1	1.6	<0.5	170
CANDR008	180	<0.5	<0.5	1.1	<0.5	2	1470	5.2	18	<0.1	<0.5	<0.5	89
CANDR009	3280	1.2	0.93	7.3	3.2	40	19200	91	160	0.2	6.4	2.1	740
CANDR010	3450	<0.5	0.81	7.2	3.2	36	28000	150	83	<0.1	7.5	1.9	790
CANDR011	680	<0.5	<0.5	1.3	<0.5	8.8	2830	26	20	<0.1	1.1	<0.5	190
CANDR012	2650	0.89	0.56	8	2.2	39	17500	97	150	<0.1	6	1.9	580
CANDR013	200	<0.5	<0.5	0.82	<0.5	7.9	930	11	8.5	<0.1	0.98	<0.5	94
CANDR014	3780	<0.5	<0.5	6.2	2.7	21	45100	35	230	0.26	4.7	3.7	350
CANDR015	3880	<0.5	0.91	8.5	3.6	33	31400	79	110	<0.1	7.5	3.1	720
CANDR016	3460	<0.5	1.2	8.9	4.4	35	23500	71	160	<0.1	6.9	1.9	840

**Se low hazard concentration 2–3 mg kg^{-1} (Lemly 1996) (ISQG not available); ** Se high hazard concentration 3–4 mg kg^{-1} (Lemly 1996) (ISQG not available); NA = no guideline available.*

Table 23 Polycyclic aromatic hydrocarbon (PAH) results (µg kg^{-1}) for sediment samples from 16 sites in the KSW pool, normalised to 1% organic carbon. ND = not detected above reporting limits. Only those PAHs with at least one sample above reporting limits are displayed.

Site ref no.	Acenaphthylene	Phenanthrene	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b+k) fluoranthene	Benzo(a) pyrene	Total PAHs
ISQG low trigger value	44	240	600	665	261	384	NA	430	4000
ISQG high trigger value	640	1500	5100	2600	1600	2800	NA	1600	45000
CANDR001	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR002	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR003	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR004	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR005	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR006	23	ND	ND	ND	ND	ND	ND	ND	ND
CANDR007	ND	ND	5.6	5.6	ND	ND	ND	ND	ND
CANDR008	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR009	ND	11	43	31	16	15	24	12	ND
CANDR010	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR011	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR012	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR013	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR014	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR015	ND	ND	ND	ND	ND	ND	ND	ND	ND
CANDR016	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 24 Organochlorine (OC) pesticide results (µg kg^{-1}) for sediment samples from 16 sites in the KSW pool, normalised to 1% organic carbon. ND = not detected above reporting limits. Only those OC pesticides with at least one sample above reporting limits are displayed.

Site ref no.	Heptachlor epoxide	Aldrin	trans-chlordane	cis-chlordane	Total chlordane	pp-DDE	pp-DDD	Total DDT	Surrogate OC rec.
ISQG low trigger value	NA	NA	NA	NA	0.5	2.2	2	1.6	NA
ISQG high trigger value	NA	NA	NA	NA	6	27	20	4.6	NA
CANDR001	ND	0.34	1.71	0.39	2.10	0.69	0.29	0.97	104
CANDR002	ND	ND	1.36	0.26	1.63	0.35	ND	0.35	97
CANDR003	ND	0.25	1.10	0.24	1.34	0.30	ND	0.30	97
CANDR004	ND	ND	1.17	ND	1.17	ND	ND	ND	94
CANDR005	ND	ND	0.68	0.19	0.88	0.35	0.30	0.65	80
CANDR006	ND	ND	0.58	ND	0.58	ND	ND	ND	105
CANDR007	ND	15	2.61	0.83	3.44	1.61	1.39	3.00	97
CANDR008	ND	ND	ND	ND	ND	ND	ND	ND	87
CANDR009	ND	ND	0.61	ND	0.61	0.29	ND	0.29	121
CANDR010	0.13	0.55	3.87	0.93	4.8	0.41	0.13	0.55	118
CANDR011	2.56	0.94	19.38	3.06	22.44	ND	ND	ND	114
CANDR012	ND	0.42	0.79	0.26	1.05	0.31	ND	0.31	112
CANDR013	ND	ND	1.97	ND	1.97	ND	ND	ND	110
CANDR014	ND	ND	ND	ND	ND	ND	ND	ND	117
CANDR015	ND	0.22	0.95	0.24	1.19	0.29	ND	0.29	108
CANDR016	ND	ND	1.58	0.32	1.89	0.29	ND	0.29	121

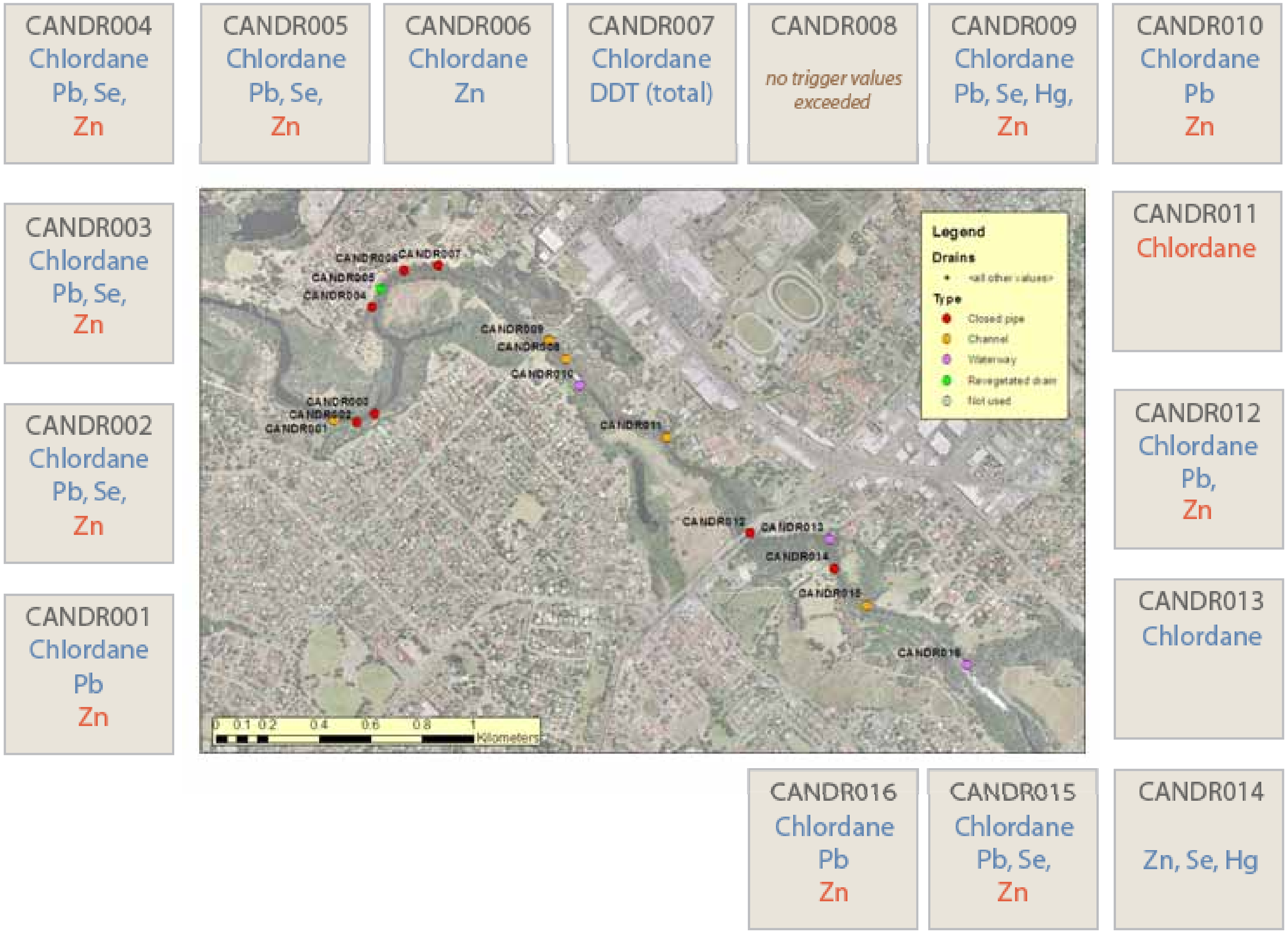

Figure 41 Spatial summary showing sites where guideline values were exceeded (ISQG low in blue, and ISQG high in red).

9 Discussion

Divided into an examination of:

- the KSW's ability to maintain water level and fresh water upstream
- the current status of ecosystem health of the Canning River near the KSW
- future predictions for ecosystem health given 2010–11 data and the climate forecast
- status and sustainability of social values supported by the Canning River ecosystem.

9.1 Maintenance of fresh water and depth above KSW

The KSW has proven effective in maintaining water level upstream since its construction in 1927 (example in Figure 26), and despite reduced streamflows during 2010–11 this function was sustained. However, its ability to maintain fresh water upstream was reduced through late 2010 and 2011, with saltwater trapped upstream following overtopping events.

Tidal intrusions above the KSW were not uncommon before 2011 (SRT 2011a), being reported in this study on three occasions through 2010. In the past 10 years, saline conditions above 5 ppt rarely reached more than a few kilometres upstream and rapidly dissipated through flushing from freshwater flow (example in Figure 22), typically lingering for less than a week. However, during 2011 (and late 2010) saline water as high as 14.9 ppt was reported at ODELL (~5 km upstream of KSW), marine salinity levels were recorded within deeper sections of the KSW pool and were sustained between late December 2010 and June 2011 (~30 weeks), and the entire water column between KSW and ELL became brackish for almost two months (March and April). These results followed increases in the frequency and magnitude of tidal intrusions above the KSW during 2011, combined with reduced freshwater streamflow – a situation expected to continue into the future based on climate predictions (CSIRO 2009).

The altered water quality conditions described above are not a result of weir management, as regardless of the weir boards' presence or absence, saltwater intrusion would have extended significantly further and persisted significantly longer, than has previously occurred (since the KSW's installation) due to climatic conditions. With the weir boards removed, persistence may have been reduced in all but the deeper pools; however this would have been at the expense of significant drying (loss of water level) and perhaps disconnection (likely resulting in isolated pools). As such, it is unlikely that an altered management strategy for the KSW (given current capacity being limited to manipulation of weir boards) could have improved freshwater conditions upstream of the KSW.

Preventing tidal incursions above KSW, or purging salinity thereafter, may be possible through modification or replacement of the current weir structure. This is discussed in more detail in conclusions.

9.2 Ecosystem condition

The current state of health of the aquatic ecosystem of the Canning River around KSW was assessed through consideration of aquatic biota, water quality and sediment quality.

Water quality

The Canning River above the KSW has been a predominantly freshwater system since the weir was constructed. Saltwater intrusion above the KSW over at least the last two decades is relatively common (Figure 26, Figure 27, SRT 2011a); for instance, salinity levels have reached greater than 5 ppt near Ellison Road (site ELL) in nine of 14 years between 1996 and 2009 and at Nicholson Bridge (site NIC) in four of 14 years (SRT 2011a). However, saltwater events have been almost always short-lived and largely confined to the bottom water in deeper areas. Considering this, the salinity conditions recorded during this study represent a significant departure from previous conditions (prior to 2010).

Assuming the ecology of the Canning River above KSW has adapted to the altered, freshwater-dominated state (85 years since the KSW was built) the likelihood of a departure in ecosystem function and associated health is expected.

Although the salinity thresholds of south-west systems are poorly understood, the general understanding of species tolerances in Australian freshwater waterways suggests that the salinity levels experienced in the weir pool exceeds the tolerance capabilities of many of the expected component species (aquatic plants, invertebrates and fish). Osmotic stress from elevated salt levels is known to elicit deleterious effects on growth and reproduction, which are not always easy to detect through short-term exposure, and can cause mortality (see review of salinity tolerances in Appendix L). Salinity was suggested as the cause of death of approximately 200 freshwater mussels reported on 25 February 2011 near Royal Street Bridge (immediately upstream of the ODELL site) while salinities were 8–11 ppt (SRT 2011a).

In addition to the direct effects of salinity on biotic assemblages, the potential exists for secondary water quality effects due to both the effect of salinity itself on expression of other elements in the system (see discussion on the influence of salinity on bottom water chemistry later in this section) and the salinity stratification effect on dissolved oxygen concentration and release of nutrients and other contaminants from sediments.

Oxygen depletion in bottom waters is a significant issue in the Canning River and is a direct function of temperature or salinity stratification (typically in response to saltwater intrusion) which prevents mixing of atmospheric oxygen exacerbated by reduced flushing (caused by the physical presence of the KSW and the reduced flows) Oxygen is depleted in bottom waters due to both biological oxygen demand from breakdown of organic matter and possibly chemical oxygen demand from introduced contaminants.

During the lengthy persistence of saline water above the KSW recorded in this study, near-anoxic levels were evident throughout the system, particularly in the deeper pools around Nicholson Road Bridge, and displayed the greatest decline during summer and autumn – in direct correlation with haloclines[11]. When oxygen plants were in operation, anoxia did not occur in the oxygenated reaches but did occur outside these areas. Several periods were observed where the entire water column was deoxygenated at some sites to levels near anoxia, thus temporarily reducing biological refugia occurring within the system.

The problems experienced with low oxygen have been previously recognised and addressed by the building of oxygenation plants (as discussed in Section 6.1). Although the oxygenation plants are effective in improving oxygen levels in the immediate area of the diffusers, the plants are insufficient to counter deoxygenation processes throughout the entire system, particularly in pools between Civic Gardens (CIV) and Hester Park (HEST). To that end the Swan River Trust and the Department of Water are installing a third oxygen plant to treat this region.

Anoxia and hypoxia did occur independently of salinity: see example of low dissolved oxygen in spring 2010 (Figure 31), which occurred under freshwater conditions and mild temperature stratification. Sustained low dissolved oxygen in bottom waters is typically due to high organic loading and breakdown of organic materials which also release nitrogen and phosphorus. In the KSW this situation is likely exacerbated by inhibited flushing due to reduced flows (low rainfall and dams in the upper catchment).

There is a potential for metal release from sediments into water under reducing conditions resulting from sustained low oxygen however, as discussed in the following section, no significant release of metals was evident. It should be noted that, with the exception of selenium and mercury, all metals analysed in water within the KSW pool were detected. However, only zinc and copper were consistently over ANZECC and ARMCANZ (2000) guidelines, and both metals are relatively ubiquitous in south-west western Australian systems (Kilminster et al 2011) and were not at levels indicative of metal release from sediment.

Sediment quality

The sediment in the KSW pool contained contaminants above ANZECC and ARMCANZ (2000a) guideline concentrations for four metals (zinc, lead, copper and mercury) and organochlorine pesticides (chlordane, dieldrin and for one sample DDT). Notably, copper only marginally exceeded the guideline value and only in January. For the other contaminants, which are generally persistent in the environment, there was no evidence of an increase in concentrations over the six-month time period, suggesting that not removing the weir boards in spring 2010 did not change the concentration of these groups of contaminants (detectable over this timeframe).

Bioavailable selenium was consistently recorded over the low hazard concentration suggested by Lemly (1996). As this guideline has not been calibrated to south west Western Australian systems it is difficult to ascertain whether the concentrations recorded are of concern or that the guideline value is not relevant locally. The presence of selenium could be

[11] Low oxygen conditions are not uncommon in the system however are typically confined to deeper pools only and less persistent than seen through this period.

naturally driven (atmospheric or geological source) or anthropogenically elevated, e.g. through use of certain phosphate fertilisers in the catchment (USGS 2010).

This was not the case for reduced sulfur, with both AVS and CRS showing increases over the time period. It is likely the supply of sulfate from saline intrusions resulted in a greater degree of conversion to sulfides by sulfate-reducing bacteria, a shift away from the freshwater environment which would normally have had very little sulfate present for sulfate-reduction. At sites where low oxygen conditions persisted, the reducing-potential of sediments will likely have increased. The process of sulfate-reduction removes certain metals from the water column, binding them into the sediment as metal sulfides; however reducing environments can also cause a release of other metals species into the water via redox processes (Billon et al 2001).

The accumulation of AVS, however, is not desirable for the KSW. If disturbed or resuspended by, for example, increased flows or dredging the AVS could de-oxygenate and contribute acidity to the water column and subsequently has the potential to remobilise metals that were previously bound to the sediment (Burton et al. 2006). AVS disturbance events have the potential to cause significant fish kills (ASSAY 2008). This would seem unlikely given the concentration reported here, but would be a risk over repeated annual saline intrusions. Provisions of oxygenated bottom waters from the oxygenation plants would substantially mitigate this potential outcome.

The spatial pattern of contamination demonstrated that relatively low concentrations of contaminants were found throughout the KSW pool. The organochlorine pesticides that exceeded guidelines (chlordane, dieldrin and DDT) have each been banned from use in Australia and are considered persistent pollutants. Their presence may indicate a historical source of these contaminants, although a study of water currently within the drains would be advisable to ensure ongoing contamination is not occurring.

It should be noted that although the total DDT of 3.00 ug/kg^{-1} is between the low and high ISQG trigger values it is derived as the sum of the two cogeners pp-DDE (1.61 ug kg^{-1}) and pp-DDD (1.39 ug kg^{-1} at concentrations below the low ISQG trigger value for pp-DDE (2.2 ug kg-1) and pp-DDD (2.0 ug kg^{-1}). In other words no toxic effects are likely from such low concentrations.

The higher than trigger value concentrations of lead and zinc in the KSW sediments is most likely attributable to sources such as vehicles, industry and building materials, and enter the waterbody with road and roof runoff through stormwater drainage.

Chlordane and dieldrin are both persistent insecticides that were used for agriculture and against termites, but their use in Australia was ceased in 1994. All species tested for sensitivity to chlordane and dieldrin (which contributed to development of the ANZECC & ARMCANZ 2000a guidelines) showed high to very high toxicity. Additionally, both insecticides are considered bioaccumulating organic pollutants. The guideline concentrations provided in ANZECC and ARMCANZ (2000a) do not account for the potential of these pesticides to bioaccumulate. DDT is another persistent insecticide that bioaccumulates – its use was banned in Australia in 1987. The presence of these organochlorine pesticides in the KSW (in particular the high concentration of chlordane in one sample, 22.4 ug kg^{-1}) is likely to result in ecological damage. Endocrine disruption, immune system damage and carcinogenic and mutagenic effects are potential ecological impacts (ANZECC & ARMCANZ 2000b). The bioaccumulation of these contaminants should also be considered with possible effects on animals higher up the food chain (e.g. birds, fish and humans) (ANZECC & ARMCANZ (2000b). However, only one value from one site (CANBR011) recorded a concentration above the ISQG high trigger, suggesting a possible local source. The need for investigation of potential sources is indicated by this finding.

Exceedence of ANZECC and ARMCANZ (2000b) guidelines indicates the potential for ecological effects. Accordingly, toxicity assessment of the sediment accumulating in the weir pool would be required to investigate this further. Additionally, bioaccumulation of contaminants in fish, particularly those residing in likely sediment deposition areas (e.g. weir pool), may be occurring and thus bioaccumulation assessments of relevant biota should be conducted to confirm this. An ecological risk assessment is advisable before any additional sampling or testing is undertaken to guide any additional sampling or toxicity testing. The ecological studies described in this report will assist in identifying appropriate receptors for such a risk assessment which assesses the potential toxicity of a contaminant in relation to the potential exposure pathway for a given group of organisms (receptors).

Influence of salt water on bottom water chemistry

Soluble reactive phosphorus and ammonia were higher in bottom waters than surface waters when sampled during periods of saltwater inundation. It is most likely that stratification associated with saltwater intrusion prolonged periods of anoxia in the KSW. Certainly in the deeper areas sampled closer to the KSW in this study, this stratification likely resulted in reducing conditions in the sediments, leading to the release of ammonia and phosphate. Ammonia build-up is typically seen in de-oxygenated water where the aerobic oxidation to nitrate is inhibited and especially where stratification prevents wind mixing.

There was a concern that saltwater intrusion might result in metal release from the sediment (due to subsequent stratification and decline in dissolved oxygen), however the data presented here generally do not support this. Zinc and copper were consistently detected over ANZECC & ARMCANZ (2000) guidelines in bottom waters, and both metals were present in sediments (zinc frequently exceeding high trigger values). However, it is not possible to determine whether these observations were due to the presence of salt water, low oxygen or simply proximity to the sediment. Further investigation would be required to disentangle these possibilities. It should be noted that both zinc and copper are ubiquitous in urban environments and were generally at levels typical of waterways across south-west Western Australia (Kilminster et al 2011). Two sites, KS8 and KS4, did show considerable spikes in concentrations for copper and zinc respectively. These spikes were markedly higher than the 90th percentile of data collected from a number of local waterways; considering both estuaries (0.001 mg L^{-1} copper and 0.012 mg L^{-1} zinc) and catchments (0.002 mg L^{-1} copper and 0.014 mg L^{-1} zinc) (Kilminster et al 2011). This is possibly indicative of a localised source and should be considered in future studies.

Lanthanum was not found above detection limits in the bottom waters (<0.001 mg L^{-1}) within the stretch of river treated with Phoslock^{TM}. There was concern that lanthanum may have been released from Phoslock^{TM} during the saltwater intrusions. It is important to note that salinity will render Phoslock^{TM} ineffective by releasing any unbound lanthanum however this will not result in a release of either the SRP or lanthanum which is already bound. It seems likely that the phosphorus-binding capacity of the Phoslock™ clay had been exhausted before the saline intrusion, and this would render all lanthanum insoluble within the clay matrix because it would be bound to phosphorus. There were two samples which showed concentrations of lanthanum at the detection limit (0.001 mg L^{-1}), but these were at sites that had not been recently treated with Phoslock™ (sites BAC and KS2). Nevertheless, future Phoslock™ applications should be avoided in reaches of the river likely to experience estuarine conditions within 6 months of Phoslock™ application.

Aquatic biota (community composition and viability)

The Canning River system around KSW is departed from its natural state given, *inter alia,* the distinct separation of estuarine and freshwater environments created by the weir and the associated effects on water level, water quality and biotic migration. Accordingly, it is difficult to ascertain 'natural' expectations of biotic assemblage. Given that management of the system centres on preserving fresh water above the KSW, the Canning River above the weir has been treated, for discussion purposes, as a permanent freshwater system; the need for migration of some estuarine species into freshwater environments is acknowledged (currently facilitated by periods when the boards are removed and via overtopping events).

A cursory examination of community composition based on salt tolerance suggests that species distribution is generally as expected, with estuarine species dominating below the KSW and a typical freshwater community upstream (including estuarine species capable of living in fresh water).

The environment downstream of the KSW was dominated by fish species known to move between saline and freshwater areas, particularly the Swan River goby, black bream and western hardyhead, and periodically the sea mullet (using the area in winter 2010 while freshwater conditions were maintained below the weir). Records of species known to enter freshwater environments rarely were generally limited to summer and autumn, when saline conditions below the KSW were the highest.

In the environment upstream of the KSW, significant spatial variability was observed in species richness (and relative abundance of native species), with less diversity within the weir pool (KSW through to ODELL) compared with GOS (upstream of the weir pool). The richness observed at GOS was consistent with previous studies conducted in the Canning River (see Section 3.1).

Comparison of Fish Health Index scores for sites assessed in this study against other south-west Western Australian waterways (as assessed by Storer et al. 2011a,b, Figure 42) demonstrated the GOS and ODELL sites were relatively healthy on a south-west scale, being largely unmodified to slightly modified, whereas the weir pool sites (KENUS, CIV, HEST) were slightly to moderately modified (due to the low diversity and abundance of natives and high proportion of exotics). For context, reduced scores in sites assessed across south-west Western Australia that fell within scoring bands similar to the CIV, HEST and KENUS sites (0.5–0.8) were generally due to the presence of exotic species (abundance and richness).

The change in physical characteristics between sites in this study (deep pool environment at KSW transitioning to a shallower, narrower environment towards GOS) must be considered when assessing community differences, however this is unlikely to explain all findings (see later discussion).

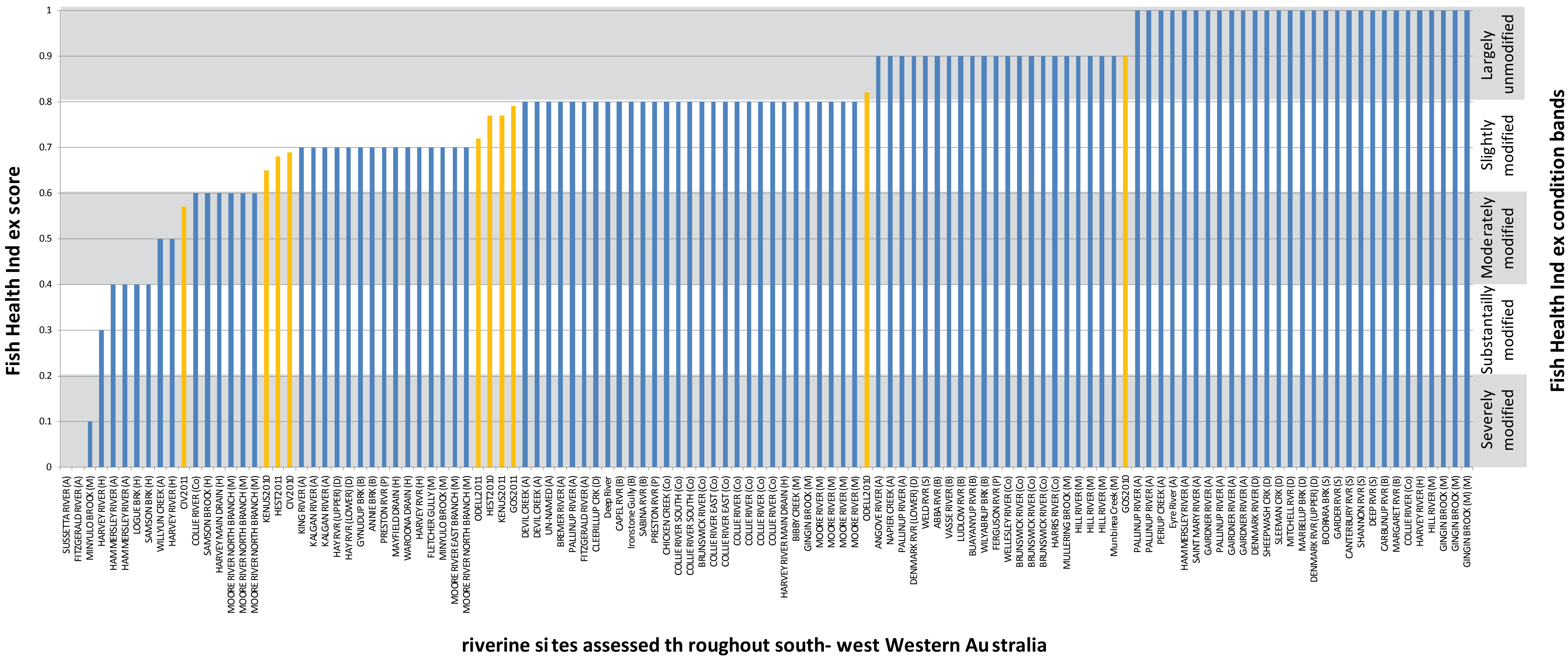

Figure 42 Fish Health Index scores for sites assessed in this study (yellow) compared with sites assessed across south-west Western Australia (from data collected for Storer et al. 2011a,b) (blue). Site ranked based on scores.

Note: sites used for comparison in Figure 42 to sites in this study were typically located above estuarine influence. The comparison reflects the management of the aquatic ecosystem above KSW as a permanent freshwater environment.

Communities within the weir pool were mostly comprised of exotics and species known to move readily between saline and freshwater environments (both groups being generally regarded as having a high tolerance to environmental changes). The environment was dominated primarily by Swan River goby, western hardyhead and mosquitofish, with the combined proportion of these species averaging over 90% of total abundance. Freshwater native species in this region were intermittent and depauperate (typically limited to western minnow, gilgie and more occasionally western pygmy perch). Black bream were present on only one occasion above the KSW (KENUS in summer 2011), with high numbers recorded (301 individuals), but none were recorded in the following sampling period.

Aquatic macroinvertebrate data support the spatial differentiation observed in the fish data. The weir pool environment (based on assessment at CIV and HEST) had lower species richness and comprised salt-tolerant species (predominantly crustaceans, molluscs and polychaetes), with the GOS site displaying a significantly greater proportion of freshwater species. Species richness and abundance were also higher at GOS in comparison. The data support previous findings by Storey and Rippingale (2000) that communities within the weir pool area are depauperate, dominated by oligochaeta and chironomid midge larvae.

Given the biological assemblages were relatively consistent in both 2010 and 2011 and drawing on previous studies (Table 1), it is more likely these results are related to long-term conditions associated with the weir pool environment rather than the increased salinity levels recorded in 2011. The conditions of the weir pool environment are likely a response to the water quality changes discussed in the previous section, however to some extent could be attributed to the weir pool's distinct form and its position in the catchment. For instance, the weir pool is deeper, wider and slower-flowing than the river type in the upper Canning River (upstream from ODELL). This altered form may be less attractive to the fish species recorded in this study due to reductions in their preferred habitat or given differences in prey composition associated with the distinct habitat characteristics (supported by altered invertebrate assemblages). The weir pool environment may also alter predator/prey dynamics where, for instance, predators such as the tortoise or larger estuarine fish species may be afforded a competitive advantage in the more open area. There are also reports of desnagging activities being carried out in the area (Malcolm Robb pers. comm.) which could further reduce prey fitness given the direct positive relationship between prey survival and habitat complexity (Storer 2005).

To elucidate the cause of compositional differences seen in fish and macroinvertebrate communities between sites examined in this study (distinguishing between physical characteristics and water/sediment quality perturbations), comparisons are made between sites in this study and other sites assessed across south-west Western Australia. The differences between the sites in this study are typically the absence of nightfish, freshwater cobbler and marron in the KSW pool (compared with ODELL and GOS). Assessment of other deep freshwater pool habitats in the state's south-west (10 deep pool sites analysed; data from DoF (2012) and Storer et al. 2011a) suggests these species are commonly found in deeper environments. Further, the same species are commonly present in sites occurring throughout the Swan Coastal Plain and in lowland (<50 m AHD) reaches in other areas (26 sites assessed). Accordingly, this supports the likelihood that these species would naturally occur in the KSW pool area if freshwater was maintained.

The reason for the suggested lack of variability between deeper pool environments and the shallow river runs[12] in south-west Western Australia may be due to a number of factors. For instance, the south-west has a low richness of fish species, has accordingly simple food chains with no dominant natural fish predators[13], and the species present are generalist and opportunistic in nature. As such, in the south-west, the presence of a deeper pool within a riverine system does not provide specific habitat features that promote fitness of one or more species (as all species are generalist) and does not sustain a more complex foodweb (as higher-order species do not exist). Further, with exception of greater depth, there is a relatively low disparity in habitat types between study sites.

Based on the discussion above, the reduced community within the weir pool is more likely a function of environmental degradation features (e.g. water quality and sedimentation), rather than due to the existence of a pool environment. This is further supported by a number of fish kills in the Canning River (four incidents between 2006 and 2009, with causes primarily linked to low dissolved oxygen) and the increased proportion of exotic species (reflective of organisms with invasive qualities tolerant of impact features such as poor water quality). Note: no fish kills in the Canning River above KSW were reported to the Department prior to 2006, although approximately nine incidents have been recorded below KSW.

The system's general departure from natural function is further emphasised by the observation of unnatural species cohabitation. For example, estuarine mussels *Fluviolanatus subtorta)* were discovered growing on marron (Figure 13). During a concurrent study, *F. subtorta* was also found attached to empty shells of freshwater mussels (*Westralunio carteri)* in the Yule Brook and Canning River below Royal Street Bridge (Klunzinger et al. 2011).

Phytoplankton characteristics were different over the whole Swan-Canning estuary between the periods June 2009 to May 2010 and June 2010 to May 2011, which is reflected in the phytoplankton data for the Canning River reported herein. The main difference of note above KSW is the presence of dinoflagellates and raphidophytes as a consequence of the saline intrusion. Should saline conditions become an annual phenomenon, the potentially toxic dinoflagellates may become more prevalent.

Fish migration

Finfish, decapods and other aquatic biota move within a system to gain access to habitat and food and complete lifecycles, and this movement is required for gene migration. Loss of surface water connectivity can result in isolation of populations, failed recruitment and local extinction of fish species (e.g. Pethebridge et al. 1998; Bunn & Arthington 2002; Fairfull & Witheridge 2003): this includes both longitudinal and lateral connection.

[12] Variability between these habitats may be more likely in systems outside of south-west Western Australia where diversity and niche occupation is more varied.

[13] Except tortoises, which given expected low predatory pressure on fish (comparably slow moving and low densities) are unlikely to produce significant top-down effects

Freshwater species

Upstream migration of most freshwater species within the Canning River was observed in spring, with increased catches recorded in the DS fyke (fish moving upstream). This coincided with a general spike in abundance across most freshwater species at this time (increased activity). Downstream migration (based on spikes in abundance in fykes opening upstream) was generally not recorded, suggesting this movement may be diffuse.

Marine species

Migration of marine species was not observed. Given the historic limit of saline conditions is not suggested to extend further upstream than the KSW (Brearley 2005), migration of marine species (found primarily below the weir in this study) through the area was not expected and accordingly is unlikely to be influenced by the KSW.

Estuarine species

Estuarine species were generally recorded moving into the KSW pool in summer/autumn, coinciding with increased salinity. Several species were shown to congregate below the weir, suggesting a desire by these species to migrate further upstream (restricted by the weir).

Species found congregating below the weir included those species known to migrate into freshwater areas; these are the south-western goby, western hardyhead, black bream and Swan River goby, which in other more-connected systems across the south-west have an upstream range extending to, and in some cases past, the Darling Scarp (data from Storer et al. 2011a,b). The life history characteristics of these species suggest a need to migrate above the KSW, with black bream known to move into brackish waters during spring and summer to spawn (Norris et al. 2002) and south-western goby, western hardyhead and Swan River goby each being known to breed in freshwater environments (Morgan et al. 2007).

Yellowtail grunter were also shown to congregate below the KSW, particularly in freshwater drainage channels produced by downstream flow through the weir boards (February–April) and adult sea mullet were observed (not captured) schooling below the weir in high numbers during late spring and autumn (November–April). Upstream migration during summer (with saline conditions) is suggested to occur for many marine species (Gaughan et al. 1990; Shaw 1996), although cannot be confirmed for the species collected in this study (lack of species-specific evidence). Schools of juvenile finfish were also recorded around the KSW (predominately black bream in January and sea mullet in August), implying that the area around or above the KSW is used as a nursery. This is supported by Thomson (1963) reporting that sea mullet move upstream into brackish sections of rivers during winter to take advantage of protected nursery areas. Any disruption to migration of fish to nursery areas is likely to affect survivorship of the cohort.

Of the six estuarine species that show signs of migration interference due to the KSW in this study (south-western goby, western hardyhead, black bream, Swan River goby, sea mullet, yellowtail grunter), all were also found upstream of the weir. Each of these species was present in size-classes relative to young-of-year through to adult, suggesting viable populations (with exception of south-western goby where no individuals in the smallest size-class were observed above or below the weir). This finding can be explained by either the presence of separate self-sustaining populations of each species both above and below the KSW or that the species are able to move between environments – either while weir boards are out or during overtopping events.

Although these data suggest the weir's presence is not negating the viability of estuarine species, it is difficult to predict how species fitness would be affected if the weir boards remained in place over extended periods (given that 2010 was the first time they have not been removed). The ongoing viability of south-western goby, western hardyhead and Swan River goby species despite the KSW's influence is implied by Morgan et al. (2007), suggesting the presence of self-sustaining populations in the Canning River above the weir. Viability is further supported by data from Storer et al. 2011b, recording healthy populations of these species in freshwater systems across south-west Western Australia in areas where migration to estuarine environments is restricted.

Given a lack of understanding around the requirement for, and upstream extent of, migration of most estuarine species, it is difficult to determine the KSW's effect on the entire aquatic community. The results suggest the weir is affecting species migration, but not having a significant influence on the viability of species present within the system. However, an assessment of the six estuarine species identified above (in particular) would be warranted if the KSW became a more permanent barrier (weir boards in place over multiple years).

Fish barrier effects of the KSW can also be associated with forced cohabitation (and likely competition) of species that would otherwise occupy distinct ecological niches. Oval spider crab (estuarine) were found occupying the same environment as marron and gilgie (freshwater crayfish species), and estuarine mussels were observed growing on marron. These findings suggest the weir is representing a physical barrier to the return of some individuals to their preferred habitat. The localised effect of these novel interspecific interactions is unknown.

The observations described above appear largely inconsequential to the general survivorship of each specific species assessed in this study (in the short-term at least), as in each case the affected species demonstrated ongoing recruitment, was abundant within its range or was reported to be able to complete its lifecycle above and/or below the weir. This in part may be due to the historic period of weir board removal coinciding with migration of freshwater species and the Swan River goby. However, given that not removing the weir boards (seen for the first time in this study) is a novel situation in the Canning River (and likely to be more prevalent in future), the barrier effects described above could result in long-term effects for biodiversity (discussed in the next section).

Elucidating the specific impact of the KSW as a physical barrier to fish migration is confounded by the altered form of the environment upstream of the KSW (deeper, wider and slower-flowing than expected based on historical information). It is difficult to determine what effect the altered habitat would have on migrating species. For instance, black bream were temporarily observed above the KSW in large numbers in summer 2011, although they appeared to depart the area rapidly thereafter (no individuals caught in the subsequent sampling period above the weir). This may suggest they are responding to adverse water quality conditions (or other impact features) or, alternatively, that they are simply following flow and are not restricted from a preferred upstream habitat (at that time). This demonstrates that a better understanding of species biology is required to truly understand the impacts.

9.3 Prediction of ecosystem health under current management regime

South-west Western Australia is experiencing a drying climate: winter rainfall during the study period was significantly lower than the long-term average (DoW 2011; IOCL 2011a). The driest winter on record (since records began in 1900) was recorded in 2010 (BoM 2011a), resulting in insufficient flows to permit removal of the weir boards without allowing ingress of saltwater above the weir (as assessed by SRT, 2010). As discussed, this has produced significant changes, particularly in salinity. Based on climate modelling, the drying climate trend in the region is likely to continue (CSIRO 2009).

Although a significant departure from the typical conditions of the Canning River system was observed during 2011 (compared with 2010 and previous years) – particularly saltwater/freshwater dynamics, dissolved oxygen levels and bioconnectivity – there was a limited obvious biological signal of this departure with species distribution and abundance largely unchanged from 2010 data and based on expectations derived from previous studies.

Comparison of biotic assemblages between 2010 and 2011 did show an increased abundance of exotic species above the KSW in 2011 (mosquitofish and one-spot livebearer), an increase in western hardyhead and some species being seen for the first time: oval spider crab (at GOS), sea mullet (ODELL and GOS) and yellowtail grunter (KSW to HEST). Other species were absent in 2011 (western striped trumpeter and yellow-eye mullet) or abundance was significantly reduced (bridled goby). However, these changes were relatively minor and mostly related to movements associated with intruding salt water and quickly reverted back to the 2010 baseline.

The lack of significant biological change between 2010 and 2011 could be attributed to numerous factors such as: the weir pool being 'naturally' depauperate and thus having little capacity to change; species in the system not needing to migrate to complete their lifecycle; stress to biota from the 2011 conditions occurring but not detected because the environment was already significantly impacted (e.g. conditions were insufficient to elicit responses in the remnant, highly tolerant species); sampling effort was insufficient to detect change; and/or the study period was too brief to detect chronic responses and the changes described in the previous paragraph represented the start of a functional change in community composition. In respect to the latter point, it is likely that any potential effects to the population viability of migrating species due to the boards not being removed in 2010 would not be seen until the following season (e.g. through absence or reduction in juvenile species), or more likely would require multiple years with boards in place to elicit a detectable response.

The potential for degradation of system health (and associated values) is likely if reduced flows and storm surges become more prevalent, as is expected (CSIRO 2009). Threats from the predicted climate change for the Canning River system (if weir management doesn't change) include increased salinity in the weir pool (concentration and persistence) and increased intrusion upstream, potential drying or disconnection under declining freshwater flow (especially with boards removed), increasing contaminant concentrations in the weir pool, decreased dissolved oxygen and increased temperature range, reduced fish passage (with reduced removal of weir boards) and increased occurrence of algal blooms. The risk and magnitude of these threats is difficult to determine given the complex interplay of factors. For instance, reduced flows may result in a reduction in sediment deposition in the KSW pool given reduced upstream erosion (from stormwater), however, the capacity to flush sediment from the pool would also decline under these conditions. Understanding the likelihood and consequence of these threats requires a detailed risk assessment.

The effects of climate change on the system and its associated threats are complex and a function of many interacting factors. A risk analysis process factoring the likelihood and consequence of threats against the range of end-points in the system is required, including consideration of environmental, economic and social values. A preliminary risk-benefit analysis has been initiated to provide a starting point for this process (Section 10).

9.4 Status and sustainability of social values of the Canning River

Many of the social values associated with the Canning River system are linked with the protection of fresh water and depth upstream of the KSW, including provision of a certain quality and quantity of water for licensed abstractors and aesthetics. If historical conditions (experienced before 2010–11) continue, these values are unlikely to be in significant jeopardy (e.g. freshwater abstraction points are largely above the area affected by saltwater intrusion to date), however if climate trends continue these values could be at risk.

The current options for managing water levels and salinity in the Canning River above the KSW (i.e. weir board management and environmental water releases) are likely to have little effect if further reductions in rainfall occur. Management strategies will need to be reassessed under this scenario.

Recreational fishing value (primarily black bream and mullet) is at risk if the KSW becomes a more permanent fish barrier and/or water quality does not improve or deteriorates. There is a possible risk of bioaccumulation of contaminants in fish; although given the distribution and migratory behaviour of recreationally targeted species and the level of contaminants recorded in this study, the risks associated with how the KSW is managed are relatively low. Results of this study also show that recreational target species are largely confined downstream.

Aesthetics, human health and biota are also at risk due to potential increases in phytoplankton in the KSW pool under the reduced flushing scenario presented by leaving boards in place. Increased bloom events are potentially more likely, due to the lack of physical flushing of phytoplankton downstream as well as the accumulation of nutrients in the weir pool. Stagnation of the weir pool may also result in a thermocline that may further exacerbate conditions. The specific phytoplankton response to more saltwater transgressions is difficult to predict. As seen during the 2010–2011 salinity intrusion, saltwater tolerant species will be resident in the pool when the salinity allows and this includes dinoflagellates species which can migrate to the stratified bottom layer rich in nutrients released from re-mineralising organic matter. It is therefore possible that potentially toxic dinoflagellate blooms will become a feature of the weir pool under saline conditions.

It should be noted that artificial oxygenation of bottom waters has been in place for more than a decade to address low oxygen conditions in the KSW pool. This has been sufficiently successful in reducing frequency and duration of low oxygen events that a third plant is being established to treat the weir pool past Nicholson Road Bridge, as far as Hester Park. Increased periods of salinity stratification will in fact provide for more efficient oxygenation of the stratified bottom water since oxygen losses to the atmosphere are minimised by the density stratification. Notable, bioavailable nutrients such as ammonia, nitrate and phosphate are reduced in oxygenated bottom water compared to hypoxic or anoxic waters. This planned additional intervention may mitigate negative aesthetic, human health and biotic impacts of increased salinity stratification.

10 Conclusions

This study demonstrated that the Canning River aquatic ecosystem near the KSW holds significant environmental value. The river supports more than 30 species of finfish, decapods and tortoise and more than 30 aquatic macroinvertebrate species[14]. This community includes four freshwater finfish endemic to south-western Australia, four native estuarine finfish (two endemic) and two endemic freshwater crayfish species. The system also supports abstraction, recreation and visual amenity. All values are contingent on a healthy ecosystem.

These values of the Canning River system are currently exposed to stress from various sources including, *inter alia*, climate change, allochthonous inputs from the developed catchment (sediment, nutrients and other contaminants), invasion of exotic species and vegetation clearing. Stress to the system is likely to continue or worsen, particularly in response to reductions in rainfall predicted under even conservative climate scenarios (CSIRO 2009).

This report examined the effects of two separate but related stressor events: weir boards left in place during low winter flows and saltwater overtopping during the dry summer period. Both events were a symptom of climate changes and require consideration for ongoing management of the Canning River system.

Leaving weir boards in place had mostly a biological effect (being a barrier to movement of biota across the KSW), with few management options available to alleviate the effect on biota in the absence of flow. The extended saline intrusion into the weir pool was shown to result in persistent stratification and deoxygenation in areas not influenced by the oxygenation plants.

Successive years of saline intrusions of this magnitude would change the ecology from a summer freshwater system to a summer estuarine system with the potential for residual saline bottom water in low flow winters. The social and amenity impacts are difficult to predict but loss of fringing vegetation intolerant of salt and loss of freshwater aquatic plants are possibilities. The latter may result in increased phytoplankton activity leading to blooms, which may reduce social value.

In respect of the community of aquatic fauna of the Canning River above the KSW, there were a number of concerns raised by the results of this study. In particular, a depauperate assemblage both in terms of richness and abundance of native freshwater fauna within the weir pool (between KENDS and ODELL) and a dominance of exotic and euryhaline species[15]. The current community appears to be a function of long-term conditions in the system rather than a direct response to hydrological (and resulting water quality) changes occurring in 2011, as the weir pool community was depauperate before the 2011 changes.

The primary stressors on the system which may influence the nature of current aquatic community include reduced flushing (due to the KSW and reduced stream flows), accumulation of organic matter, sediment and contaminants in the weir pool and restricted

[14] Species richness is likely to be a significant underestimation given that only a single sampling event was conducted and only channel habitat was assessed.

[15] This considers the environment above the KSW being managed as a predominantly freshwater system

bioconnectivity. A conceptual diagram of the current status of the system is provided in Figure 43. Some degree of variability in species assemblages within the weir pool compared with upstream communities may be attributed to the variability in physical conditions associated with pools versus river-channel habitat; however this is unlikely to explain all differences reported.

The fish species inhabiting the weir pool environment were predominantly invasive (with inherent adaptive plasticity) or were species known to migrate between estuarine and freshwater areas: as such they are typically resilient to environmental fluctuations, particularly regarding salinity tolerance. This may explain why no significant community changes in response to the saltwater intrusions seen in 2011 were evident.

Based on the biotic assemblages analysed in this study, a permanent barrier to fish migration at the KSW (if boards were to remain in place permanently) is not likely to result in loss of species in the greater Swan-Canning system. Localised extinctions of some species in the Canning River may occur under a prolonged period of disconnection, particularly as an indirect response to the changing water quality, sediment quality and habitat availability. Accordingly, there is not a strong case for a fishway. If establishment of a mechanism for fish passage past the KSW was pursued, a better understanding of species biology (to determine benefit) and also an assessment of the potential consequences would be required.

In summary, if rainfall and storm surges of the scale recorded through 2010-11 continue, it is likely that the health of the Canning River aquatic ecosystem will deteriorate. Resulting conditions could include more frequent and extreme water quality perturbations (particularly low dissolved oxygen and high temperature ranges), increases in contaminants, further invasion of exotic species, increases in the prevalence and magnitude of phytoplankton blooms, fish kills, and further reductions in native species in an increasing area above the KSW. Impacts to social values are also likely to become greater and more conspicuous, such as water quality problems resulting in undesirable effects on aesthetics.

Under the scenario above, the ability to manage the system using the current KSW structure is limited. With this in mind, assessment of management options to address likely drying climate conditions and increased tidal surges should include either managing the KSW pool environment as a treatment area for low oxygen, nutrients and other contaminants, or to relocate the weir. Using the KSW pool as a treatment system, for example, could incorporate binding of certain contaminants (e.g. nutrients) to sediments through the application of Phoslock^{TM} (and maintaining conditions to prevent the re-release of such contaminants) and improving oxygen supply to the system through artificial oxygenation. Moving the weir upstream (or constructing a second weir structure above the KSW) aim at reducing the extent of saltwater intrusion upstream and in doing so creating a larger area of permanent freshwater and a more natural fresh water-estuarine water mixing zone. A conceptual diagram depicting the scenario of using the KSW pool as a treatment system has been provided in Figure 44.

Given the levels of contaminants recorded in water and sediment within the study reported here there appears to be little immediate risk to ecosystem or human health, and therefore little justification for active removal of sediment at this time; particularly given the risk associated with possible mobilisation of nutrients and other contaminants if sediment removal was attempted. Notably, additional oxygenation of the system (recommended in this report) has the secondary benefit of reducing bioavailability of any contaminants, which will further reduce any risk due to presence of contaminants.

Understanding the management needs of the Canning River is complex, in particular considering the:

- ecological variability associated with the position of the KSW at the interface between estuarine and freshwater ecosystems;
- potential and varied changes to the system under climate change scenarios;
- need to manage competing values (social, economic and environmental).

This complexity is compounded by potential synergistic and antagonistic effects from contaminants present in the system and also through intricate relationships between environmental variables which can result in both positive and negative effects to system health. For example, the existence of haloclines presents a risk to environmental and social values, yet has the potential to lower other risks given that high salt levels occurring in the benthic zone may mitigate phytoplankton blooms[16]. Similarly, increasing permanency of freshwater upstream of the KSW is preferable for freshwater species; however this includes creating favourable conditions for cyanobacteria, which may result in undesirable blooms. In this instance, sustaining existing macrophyte communities and maintaining oxygenation and application of Phoslock™ (to reduce available phosphorous) may be important.

Given the complexity described above, a thorough risk analysis is required to disentangle the likelihood and consequence of the threats and benefits associated with available management options. Accordingly, any future management action requires ecological monitoring given the complexities described.

Improvement of catchment management to reduce inputs of organic material, sediment and contaminants will benefit the ecosystem under any management scenario.

[16] increased salinity can inhibit cyanobacteria spores located in sediments and returning to system upstream of the KSW to a more permanent freshwater environment may result in blooms

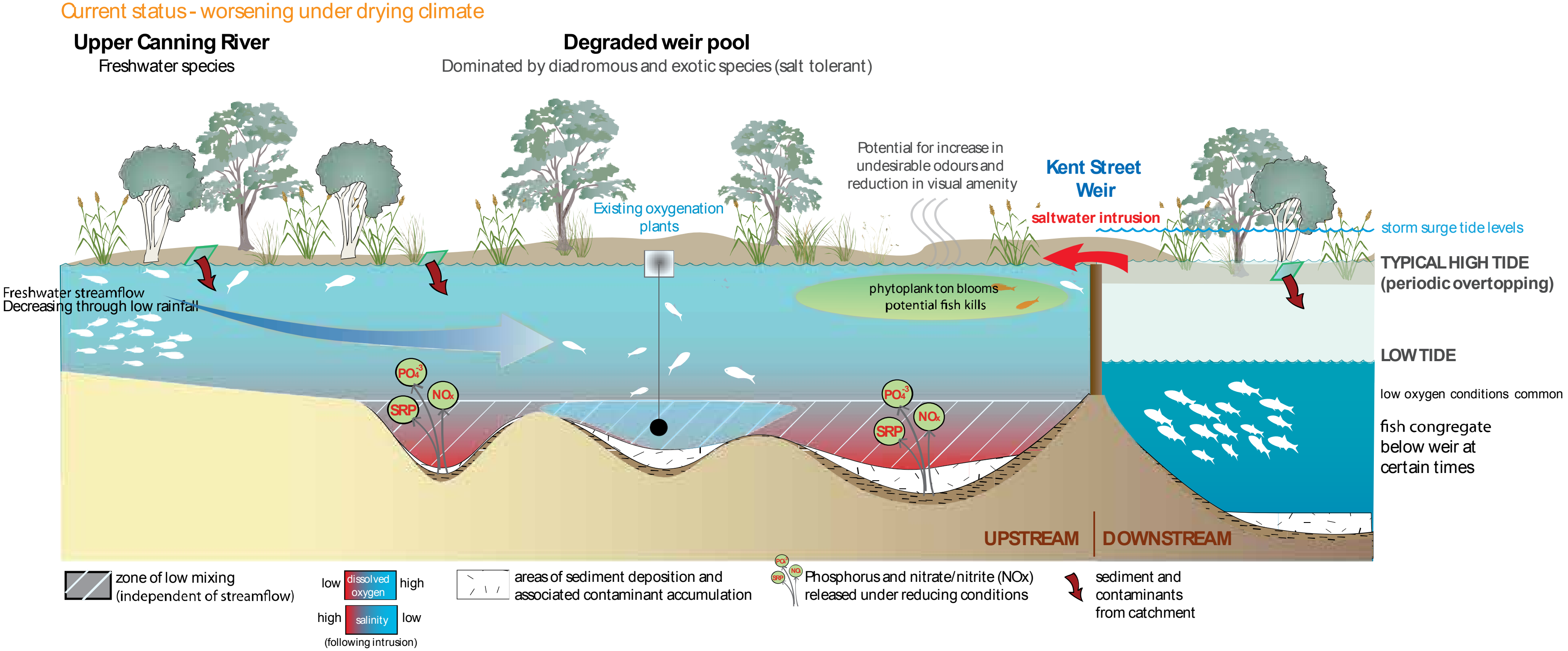

Figure 43 Conceptual diagram: KSW pool highlighting current water quality issues and impediments to flushing (existing oxygenation plant included).

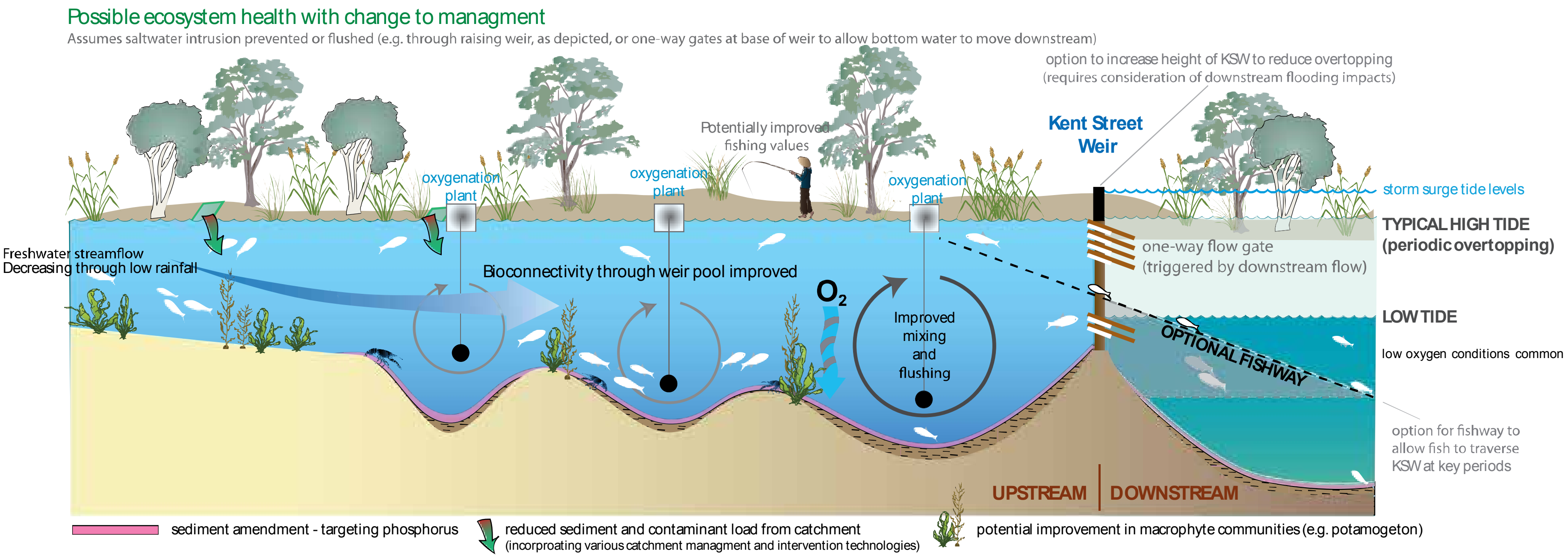

Figure 44 Conceptual diagram: KSW pool environment following implementation of management scenarios (assuming salt water upstream of KSW can be prevented or flushed quickly)

Note: rationale around restoration of bioconnectivity (fishway) at the KSW requires consideration of social, environmental and economic values and risks. The inclusion of a fishway in the diagram above is for conceptual purposes only and does not suggest this is a preferred option.

11 Recommendations

Maintain artificial oxygenation

Existing oxygenation activities in the Canning River above KSW have been shown to be effective in maintaining oxygenated water, reducing risk of release of some contaminants from sediment, and preventing build-up of ammonia in bottom waters. Maintenance of this management action and the addition of the new plants to mitigate some of the adverse water quality conditions described in this report (e.g. within the deeper section near Nicholson Road Bridge) are recommended.

Conduct a detailed risk analysis to determine best management practice for the KSW

Due to the current state of deterioration of the concrete structure of the KSW and given the environmental perturbations detailed in this study, it is clear that the KSW needs to be either repaired or replaced.

It is recommended that the appropriate strategy to remedy the issues surrounding the KSW and to manage the system into the future be determined through a detailed risk analysis involving a cross-section of relevant scientists and stakeholders. The risk analysis should include, but not be limited by, the scenarios and threats identified in this study and in the risk analysis in Appendix J.

A key component of the risk analysis is an Ecological Risk Assessment.

Appendices

Appendix A — Field sheets

Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
COVER SHEET

SITE CODE ________________

SWMA ________________

RIVER SYSTEM ________________

RIVER/STREAM NAME ________________

SITE NAME ________________

DATE ______________ COC __________ SAMPLE NUMBER ______________

NAME OF SAMPLERS ________________

NOT ASSESSED IN FIELD

ALTITUDE ______ (m) SLOPE ________ (m/km) DFS ________ (km) STREAM ORDER ______ (km)

NEAREST RAINFALL STATION ________ (name) DISTANCE AWAY _____ km AVERAGE ANNUAL RAINFALL ____ (mm)

FLOW PATTERN CATEGORY ________________ DISCHARGE CATEGORY ________ (mm)

ORDER OF SAMPLING – DAY 1

1. Take water quality samples: grab followed by in-situ
2. Collect macroinvertebrates
3. Deploy water quality loggers. *Note: after loggers have been deployed only enter river downstream.*
4. Process macroinvertebrate sample
5. Deploy fish/crayfish traps and fyke nets
6. Site photos (important to capture conditions on first day as factors such as water level and flow can change rapidly)
7. Field sheets (if time permits)

ORDER OF SAMPLING – DAY 2

1. Collect fish/crayfish traps and fyke nets
2. Collect water quality loggers: after 25 hours (144 logged measurements)
3. Complete field sheets
4. Complete site photos: fill-in checklist below.

Photo checklist

[ ] Upstream and downstream photos; taken at the top, middle and bottom of the 100m sampling site (6 photos total)
[ ] Representative site photos
[ ] Macroinvertebrate sampling area
[ ] Representative video taken
[ ] Canopy shots (taken from edge of stream of both sides – representative of density of canopy throughout site)

Acronyms
LB: Left Bank, **RB:** Right Bank

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS

GPS DATUM ______________

LONGITUDE (°E) or EASTING ______________

LATITUDE (°S) or NORTHING ______________

MAP NAME and YEAR OF PUBLICATION ______________ SCALE ______________

PAGE REFERENCE OR MAP NUMBER ______________

ACCESS DETAILS ______________

PROPERTY OWNER ______________

PHONE NUMBER ______________

ADDRESS ______________

NOTIFY BEFORE EACH VISIT [ ] Yes [ ] No PERMISSION REQUIRED [ ] Yes [ ] No

KEY REQUIRED [ ] Yes [ ] No KEY NUMBER / AVAILABLE FROM ______________

ACCESS MAP – SKETCH ROUTE BELOW OR ATTACH MAP TO BACK OF FIELD SHEET

Include flow direction, site location, roads, crossings, north arrow, distances and landmarks.

MAP ATTACHED ☐

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

Artists name ______________________

LONGITUDINAL DIAGRAM (AERIAL VIEW)

Essential features	Legend
Flow direction	→ → →
Loggers	(L)
Macroinvertebrate sample	(M)
Water quality sample	(W)
Fyke nets	► or ◄
North arrow	↑ N

Possible features	DIY legend	*Possible features*	DIY legend
Macrophyte habitat		Vegetation type A: ________	
Large trees		Vegetation type B: ________	
Woody debris		Vegetation type C: ________	
Riffles			
Sandbars/sediment deposits			
Significant erosion			
Natural or artificial barriers			

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

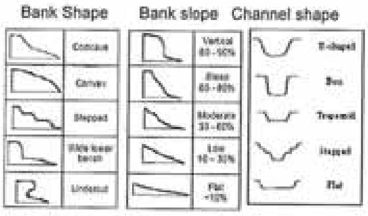
CROSS SECTION DIAGRAM

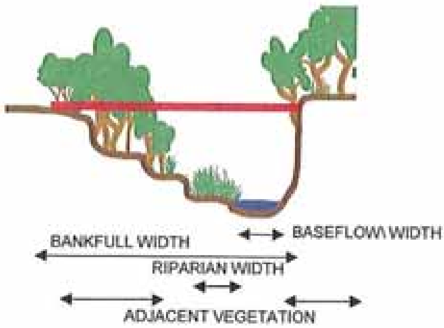
Representative of sampling region (where high variability exists draw two cross-sections).

Suggested information to include on cross section diagram above
- Bank shape (see below)
- Bank slope (see below)
- Channel shape (see below)
- Base-flow and bank-full width (m)
- Streamside and adjacent vegetation width and structure
- Presence of bars, benches, toes

Circle diagrams below

Bank Shape Bank slope Channel shape





STREAM WIDTH MEASURMENTS

	Top	Middle	Bottom
Bankfull width (m)	______	______	______
Current water width (m)	______	______	______

Water width compared to base-flow (circle)				
No flow dry isolated	Low < low water mark	Moderate Equal to base-flow	High > high water mark	Flood

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
AQUATIC HABITAT ASSESSMENT – 100m sampling site

STREAM HABITAT DIVERSITY

Habitat area	%
Channel (includes woody debris)	
Macrophytes	
Riffle	
Pool	
Total	100

Macrophyte types	%
Emergent	
Submerged	
Floating	
Total	100

Large woody debris ☐ present ☐ absent (*Size relative to 'un-impacted' conditions for specific area*)	
Diversity (circle)	**Abundance** (circle) *
Wood of similar size	Sparse (few pieces)
2-3 different sizes	Moderate *
Variety of sizes	Dense (throughout most of site)

* A few sections of moderate density or low density across most of site

Bank vegetation draped in water ** (percentage of bank length)	

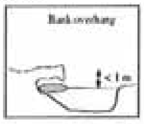
*Note: section relates to habitat (not shading) ** Dead vegetation not included*

Roots overhanging and draped in water			
None	Limited	Moderate	Extensive
Overhanging banks			
None	Limited	Moderate	Extensive

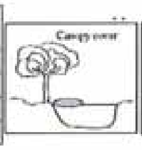
Limited = 1-10% of bank length, Moderate = 11-50%, Extensive >50% of bank.

Flow (circle)
Uniform flow (e.g. drain)
Moderately varied flow
Varied flow (eg eddies, backwaters, fast, slow)

Depth (circle)
Uniform depth (eg drain)
Moderately varied depth
Varied depths



Stream shading	Percentage of bank length		Average distance from bank (m) **Average stream width** ________ m	
	LB	RB	LB	RB
Tree cover #				
Shrub overhang				
Grass overhang (rushes/sedges)				



Note: density of canopy will be determined from canopy photographs; therefore only total area should be assessed.

Physical substrate DIVERSITY	Increasing complexity (circle one number)
Mainly bedrock or artificial substrate	1 2 3 4 5
Silt or sand or a mixture of silt and sand	6 7 8 9 10
Mainly sand with some pebbles &/or boulders	11 12 13 14 15
Mix of boulders, pebbles & sand etc	16 17 18 19 20

Note: increasing complexity or density are not a direct indication of health (i.e. boulders are not expected at all sites)

Biological substrate DENSITY *Tip: try breaking site into sub-sections (i.e. 10 x 10m sections for a 100m sampling site), to estimate cover*	Increasing density (circle one number)
<10% of substrate cover	0 1 2 3 4 5
11-30%	6 7 8 9 10
31-60%	11 12 13 4 15
>60%	16 17 18 19 20

Biological substrate DIVERSITY (circle)				
leaves	twigs	branches	detritus *	Epiphytes

* *Detritus relates to undifferentiated organic material*

Sediment deposition	None or minor	Not obvious	Obvious

Type (sand/silt): ______________________________

WATER AND SEDIMENT

Circle the appropriate description under each category.

Water odours	*Water Oils*	*Turbidity*	*Tannin staining* *		*Algae in water column*	*Algae on substrate*	*Plume***	*Sediment oils*	*Sediment odours*
Normal/None	None	Clear	Clear		0%	0%	Small	Absent	Normal/None
Anaerobic	Slick	Slight	Slight		1 to 10%	1 to 10%	Moderate	Light	Sewage
Sewage	Sheen	Turbid	Light tea		11 to 50%	11 to 50%	Large	Moderate	Petroleum
Petroleum	Globs	Opaque	Dark tea		51 to 75%	51 to 75%		Profuse	Chemical
Chemical	Flecks		Black		> 75%	> 75%			Anaerobic

* tannin staining can be confused when combined with systems containing fine suspended sediment (if problematic assess from filtered water sample)
** relates to amount of fine sediment generated and time take to settle (i.e. a large plume may extend for a meter diameter and remain suspended for 5 seconds or more)

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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
PHYSICAL FORM/CATCHMENT IMPACT ASSESSMENT – 100m sampling site

BANKS AND PHYSICAL FORM

AMOUNT of erosion *Length of bank affected (%)*		
0 to 5%	LB	RB
>5 to 20%	LB	RB
21 to 50%	LB	RB
> 50%	LB	RB

SEVERITY of erosion, and bank stability	Circle	
Severe: LITTLE TO NO STRUCTURAL INTEGRITY Banks are predominantly bare. Significant sections of erosion (undercutting/slumping) on both outside bends and straight stretches (sediment deposits in river). Exposed roots obvious (where applicable), with significant loss of vegetation in eroding areas. Channel shape, bank shape and depth likely to change in near future.	LB	RB
High: POOR STRUCTURAL INTEGRITY Evidence of bank instability (undercutting/slumping); with signs of soil loss from banks, and possibly areas of sedimentation (i.e. sandbars or toes) and scouring. Some exposed roots (where applicable), with loss of vegetation in eroding areas. Erosion typically around outside bends.	LB	RB
Low-Moderate: GOOD STRUCTURAL INTEGRITY Banks relatively stable – exposed and superficially eroding bank (erosion doesn't penetrate deeply into bank wall) or stabilised by only exotic grasses. Little likelihood of significant change to channel/bank shape, depth or loss of bank material in near future.	LB	RB
Minor: EXCELLENT STRUCTURAL INTEGRITY Banks stable and mostly intact (minor slumping, undercutting or bare banks expected naturally): stabilised by vegetation or bedrock.	LB	RB

Factors affecting bank stability	Circle	
Feral animals	LB	RB
Livestock access (if yes, compete table below)	LB	RB
Human access	LB	RB
Cleared vegetation	LB	RB
Runoff		
Irrigation draw-down		
Flow and waves		
Culvert, bridge, dam		
Drain pipes	LB	RB
Other (specify)		

Stabilisation works Yes ☐ No ☐		
Choose one or more	Circle	
Rock wall protection	LB	RB
Bank matting	LB	RB
Logs/planks strapped to bank	LB	RB
Concrete lining	LB	RB
Revegetation plantings	LB	RB
Fenced human access (deterrent)	LB	RB
Fenced livestock access	LB	RB
Fenced stock watering points	LB	RB
Other (specify)	LB	RB

Indicate livestock types ________________________________ & indicate their impact (major or minor) for each category below.

CATEGORY	MINOR	Tick box	MAJOR	Tick box
Vegetation damage	Only small patches of vegetation grazed		Most groundcover vegetation grazed.	
Bank damage	Isolated areas (1 or 2) of livestock damage		Near continuous livestock damage to stream	
Pugging	Isolated (1or 2) areas of pugging		Extensive pugging along the stream length	
Manure	≤2 significant manure deposits per site		>2 significant manure deposits per site	
Tracks	≤1 track per site		>1 track per site	

POLLUTION SOURCES

Local point source pollution		*None evident* ☐
Potential	Obvious	Indicate type/s:
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

Local non-point source pollution		*None evident* ☐
Potential	Obvious	Indicate type/s:
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

LANDUSE AT SITE - WITHIN 50m FROM EDGE OF STREAM

Circle all applicable for each bank

LB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban
RB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
VEGETATION ASSESSMENT - 100m sampling site

RIPARIAN VEGETATION

Riparian zone = a clear distinction in vegetation type between water dependant and non-water-dependent vegetation

Riparian zone ABSENT ☐ >>>> Due to: **human impact** ☐ **natural feature (eg bedrock)** ☐ **fire/flood...** ☐ **unknown** ☐

Riparian zone PRESENT ☐ [complete rest of box]

Indicate riparian layers PRESENT*?	circle			**Width of riparian zone** Left bank ______m Right bank ______m
Ground layer (i.e. sedges, rushes)	yes	no	reduced	**Dominant riparian species** (if unknown write: refer to photographs):
Shrub layer (woody)	yes	no	reduced	
Tree layer	yes	no	reduced	

* this refers to the presence of riparian species (intactness is incorporated below). Note: if only 1 or 2 shrubs remain (for example) circle 'no'.

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE AND EXOTIC VEGETATION

Percentage cover	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Bare ground (not bedrock)										
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

*Shrubs include Blackberry, Tea trees

STREAMSIDE ZONE VEGETATION (FIRST 10m) - EXOTIC VEGETATION

Proportion (%) of exotic vegetation in each vegetation layer	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE WOODY VEGETATION

Recruitment evidence	*Recruitment type*	*Extent of recruitment*	*Recruitment health*
None	Trees	Limited	Poor
Natural	Shrubs	Moderate	Moderate
Planted	Both	Abundant	Healthy

ADJACENT ZONE VEGETATION (10 to 100m)

Tick box for the DOMINANT feature in each zone	10 to 50m		50 to 100m		100m +	
	LB	RB	LB	RB	LB	RB
Minimal vegetation Typical of areas of urban development / industry / mining						
Weeds/Grasses May have a few scattered trees (typical of agriculture)						
Remnant vegetation Mostly native trees and/or shrubs (may have exotic understorey).						
Forest Native trees, shrubs and understorey. Few or no exotics.						
Plantations **Type:** ______________________________						
Other (describe)						

COMMENTS (VEGETATION IN ADJACENT ZONE): ____

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Date ________________ Site code ________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS

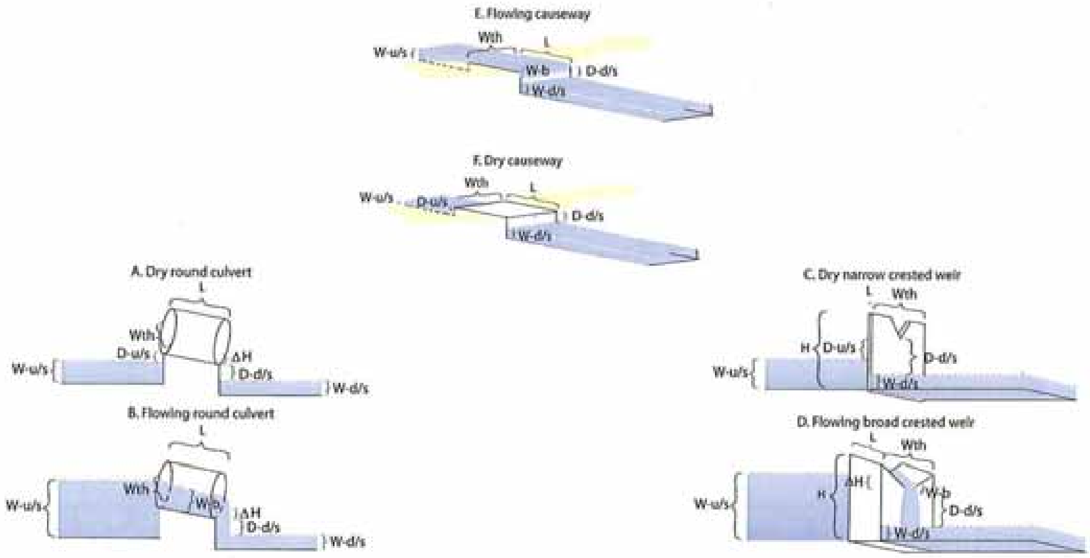
BARRIER ASSESSMENT - 100m sampling site

NATURAL AND ARTIFICIAL BARRIERS IN 100m SITE

No barriers ☐

Description		Barrier 1	Barrier 2	Barrier 3
	Type of Barrier – artificial (see bottom of page for types) or natural			
	Longitude or Northing			
	Latitude or Easting			
	Tick when photo taken			
L	Length (longitudinal) (m)			
ΔH	Height difference across barrier (m)			
Wth	Width or diameter (cross-section) (m)			
H	Height (m)			
W – b	Water depth across barrier (m)			
D – d/s	Downstream drop (bottom of barrier to water) (m)			
W – d/s	Water depth – downstream (m)			
D – u/s	Upstream drop (bottom of barrier to water) (m)			
W – u/s	Water depth – upstream (m)			
	Blockage – overgrowth or sedimentation % cross-sectional area			
	Flow over barrier (either measure or describe)			
	Structure material (e.g. concrete, timber, steel, plastic, loose rock)			
	If culvert, number or pipes or boxes			
	Barrier floods at flow condition (extremely high, high, medium, low flows)			

Note: Not all of the above measurements will apply to natural barriers.



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Date ______________ Site code ______________

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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
100m sampling site

NATURAL OR ARTIFICIAL BARRIERS OUTSIDE 100m SITE

Artificial barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

Natural barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

CHANNELISATION

Signs of channelisation	No ☐	Yes ☐ (describe below)

Note whether channelisation is due:

1. **Direct causes:** deepening and straightening by humans to increase water flow (e.g. to reduce flooding), or
2. **Indirect causes:** deepened systems with more vertical banks due to bank erosion and bed scouring; a result of increased flows from changes such as catchment clearing or hydrological modifications.

WATER VELOCITY (FLOW) ACROSS 100m SAMPLE SITE

Flow information is recorded on the Macroinvertebrate Sampling Sheet and WQ 2 Sheet, if neither is being used for this assessment use space provided below.

Meter or Method used ______________________ units ________ Velocity__________

WEATHER CONDITIONS

Rain in past week	Tick box
Yes	
No	
If known, mm	

Cloud cover	%
Day 1	
Day 2	

Rain	Tick box
Day 1	Yes ☐ No ☐
Day 2	Yes ☐ No ☐

Weather comments ______________________________

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Date ______________ Site code ______________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
WATER QUALITY 1: GRAB AND IN-SITU SAMPLES

Recorders name ______________________

PRE - INSTRUMENT CALIBRATION

Instrument Type ______________________ Instrument Number ______________________

Pre – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature
Pre reading						
Post reading						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Circle:

Conductivity units	uncomp	comp (25°C)	
Conductivity setting	fresh	salt	none
Salinity setting	2311	Other (indicate):	
Electrical conductivity calibration solution used	1.413 mS/cm	Other (indicate):	
Dissolves oxygen calibrated to	100% sat. in air	Other (indicate):	

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

________ hPa ______ mmHg
(mmHg = hPa x 0.7502)

GRAB WATER QUALITY

Water quality samples taken

Date ______________ Time ______________

Sample number ______________ COC ______________

IN-SUTU WATER QUALITY

	Date	Time (24 hrs)	Salinity (ppt)	pH	Dissolved oxygen (mg/L)	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)	Add any others here	
Surface										
Bottom										

Note: Usually only surface water samples are taken.

POST - INSTRUMENT CALIBRATION

Post – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature (°C)
Pre reading						
Post reading						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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Date ________________ Site code ________________

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SW-WA FARWH – FIELD SHEETS
WATER QUALITY 2: DIEL DISSOLVED OXYGEN AND TEMPERATURE

Recorders name ____________________________

PRE-DEPLOYMENT MEASUREMENTS

Deployment date ______________ Deployment time ______________

Probe Letter	Pump Number	Field air calibration			Water readings (mg/L)	Pump running (yes or no)	Water depth to first inlet hole (cm)	Actual water depth (m)
		Pre-cal (mg/L)	Span (%)	Post-cal (mg/L)				

LOCATION OF LOGGERS

Circle one each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ____________	m upstream

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ____________________ units ________ Velocity__________

POST DEPLOYMENT MEASUREMENTS

Retrieval date ____________ Retrieval time ____________

Probe Letter	Pump running	Condition of HOUSING	Condition of MEMBRANE		Water reading (mg/L)	Air reading (mg/L)
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ______________________
____
____

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Date ________________ Site code ________________

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SW-WA FARWH – FIELD SHEETS
WATER QUALITY 3: MULTI PARAMETER LOGGING

Recorders name ____________________________

PRE-DEPLOYMENT INSTRUMENT CALIBRATION

Instrument Type ____________________ Logger Number ______________ Handpiece Number ______________

Pre – field Calibration	Salinity	pH 7	pH 10	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

_______ hPa _______ mmHg
(mmHg = hPa x 0.7502)

LOGGING INFORMATION

Deployment date ______________ Deployment time ______________

Parameters set to log (tick)
[ ] Dissolved Oxygen [ ] Temperature [ ] Electrical conductivity
[ ] pH [ ] Turbidity [ ] Other ______________

Loggers set to record every ________________ mins for ________________ days / hours (circle)

LOCATION OF LOGGERS

Circle one option for each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ____________ m upstream	

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ____________________ units ________ Velocity ____________

LOGGER REMOVAL

Logger removal date ____________ Logger removal time ____________

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ______________________________
____

Post – field Calibration	Salinity	pH 7	pH 10	DO%	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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Date ________________ Site code ________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ______________________ Date traps deployed ______________________

☐ (tick) Local Fisheries WA officer called (1800 815 507) up to one day prior (need permit number, car registration and samplers names)

TRAP SETTING – BOX TRAPS

Trap #	Small trap (S) or Large trap (L)	Left bank (LB) Right bank (RB) or Centre (C)	Water Depth (cm)	Describe location of trap e.g. in woody debris, under log, amongst emergent macrophytes, in full sun, % shaded, under overhanging vegetation, amongst tree roots.

TRAP SETTING – FYKE NETS

TYPE		Water Depth (cm)	% stream width *	Comments e.g. fyke in eddy, gaps between wings and bank or river bottom
Dome (D) or Rectangle (R)	Upstream (US) or Downstream DS)			

*If both wings are fully extended to edge of bank this would be 100%. If spaces exist between wings and bank or between wings and surface of water (due to depth), estimate coverage and provide explanation of set-up.

LIST FISH/CRAYFISH SPECIES OBSERVED BUT NOT CAUGHT

____

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Date ________________ Site code ________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ________________________ Date traps collected ________________________

TRAP COLLECTION

Trap #		Size class (mm)					Evidence of Reproduction*	Comments (for example)
	Fish	0-20	20 - 50	50 - 100	100 +	Other	none	• staining, parasites, disease, injury
	Crayfish	0-20	20 - 50	50 - 76	76 - 100	100+	✓ (few)	• smallest size gravid individual • size of largest individual
	Large fish	0-100	100-200	200-400	400+	Other	✓✓ (many)	***Note size of marron over 76mm***

**Evidence of reproductive condition includes gravid females &/or characteristic colours*

Legend
WM = Western Minnow, **TM** = Trout Minnow, **BSM** = Black-stripe Minnow, **NF** = Nightfish, **WPP** = Western Pygmy Perch, **BPP** = Balstons Pygmy Perch, **SWG** = South West Goby, **SRG** = Swan River Goby, **COB** = Cobbler, **JOL** = Jollytail, **GAM** = Gambusia, **1SPOT** = One spot live bearer, **WH** = Western Hardy Head, **ELONG** = Elongata, **BB** = Black Bream, **RP** = Redfin Perch, **RT** = Rainbow Trout, **BT** = Brown Trout, **MM** = Mud Minnow, **GIL** = Gilgie, **GH** = Hybrid Gilgie, **MAR** = Marron, **HMAR** = Hairy Marron, **K** = Koonac, **KX** = Koonac sp X, **Y** = Yabbie, **FS** = Freshwater Shrimp.

Large fish include: cobbler, trout, redfin, lamprey.

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[additional sheets are provided in field kit; explaining disparity in page numbers]

Date ______________ Site code ______________

Government of Western Australia
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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
MACROINVERTEBRATES: AUSRIVAS FIELD SHEET

Recorders name ______________________

DATE SAMPLE TAKEN ______________________ TIME SAMPLE TAKEN ______________________

COLLECTED BY ______________________ PICKED BY ______________ AND ______________

HABITAT ______________________ % OF 100 m reach ______________________

SAMPLE NUMBER ______________________ COC NUMBER ______________________

SAMPLING CONDITIONS [ ] good [ ] average [ ] poor

PICKING CONDITIONS [ ] good [ ] average [ ] poor

BREAKDOWN OF 10m SAMPLING AREA

Mineral Substrate	%	**Habitat surface area**	%	*Density (circle) (1= sparse, 5 = dense)*
Bedrock		Mineral substrate		
Boulders (>256mm or scorer ball)		Emergent macrophyte		1 2 3 4 5
Cobble (64 to 256mm or cricket to soccer ball		Submerged macrophyte		1 2 3 4 5
Pebble (16 to 64mm or 5c piece to cricket ball)		Floating macrophyte		1 2 3 4 5
Gravel (4 to 16mm or raw sugar to 5c piece)		Detritus		1 2 3 4 5
Sand (1 to 4mm)		Algal Cover		1 2 3 4 5
Silt (<1mm)		Riparian veg draped in water		
Clay		Other (e.g. woody debris)		
Total	100%	Total (may be > 100%)		

DEPTH

Depth macroinvertebrate sample taken (circle) <25cm <50cm <100cm < 200cm > 200cm

WATER VELOCITY (FLOW) AT MACROINVERTEBRATE SITE

Meter or Method used ______________ units ________ Max velocity ____________ Min velocity____________

BOX SUB-SAMPLER TALLY

Number of cells picked ____________

Number of cells in box ____________

Total number of macroinvertebrates picked ____________

Comments (if any)

____

____

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Appendix B — Coordinates of aquatic biota assessment sites

Site code	Easting	Northing
KENDS	398064.1	6456686.2
KENUS	398205.1	6456607.0
CIV	398922.0	6456796.2
HEST	400353.6	6455675.8
ODELL	401389.0	6454306.2
GOS	405094.0	6452359.3

Appendix C — History of weir boards management at KSW (2000–11)

Year	Period open (weeks)	Boards removed	Boards installed
2000	20.0	24 May	11 October
2001	17.0	23 May	19 September
2002	24.0	1 May	16 October
2003	22.0	21 May	22 October
2004	18.1	2 June	7 October
2005	25.0	11 May	2 November
2006	19.4	29 May	12 October
2007	21.3	12 June	8 November
2008	17.9	19 June	22 October
2009	15.0	9 July	22 October
2010	0	Closed	Closed
2011	11.0	7 July	22 September

Appendix D — Size-class categories for fish

Size-classes			
Small finfish (TL mm)	**Large finfish (TL mm)**	**Crayfish (CL mm)**	**Not measured**
0–20	0–100	0–20	
20–50	100–200	20–50	
50–100	200–400	50–76	
+100	+400	76–100	
		+100	
Western pygmy perch Western minnow Nightfish Swan River goby Western hardyhead South-western goby Bridled goby Western striped trumpeter Gobbleguts Blowfish Silver biddy Australian anchovy Mosquitofish One-spot livebearer Goldfish Western king prawn Western school prawn	Freshwater cobbler Black bream Yellowtail grunter Sea mullet Yellow-eye mullet Koi Spangled perch Western long-necked tortoise *Blue swimmer crab*[*]	Gilgie Marron Yabbie	Freshwater mussel Freshwater shrimp Oval spider crab Frog/tadpole Water boatman/backswimmer Dragon/mayfly larvae Beetle adult /larvae Diptera larvae Leech Water scorpion Jellyfish Bivalve

TL refers to total length and CL to carapace length.

[*] *Blue swimmer crab size-classes: 0–100, 100–126, 126–150, +150; based around the 126 mm minimum legal size*

Appendix E — Aquatic macroinvertebrate data

				CIV 30 Mar 2011	HEST 30 Mar 2011	GOS 10 Mar 2010	GOS 10 Apr 2010
Oligochaeta			spp.	1			134
ANNELIDA Polychaeta	Syllidae		sp.	88	7		1
CRUSTACEA Cladocera		Cladocera	sp.		1		3
CRUSTACEA Copepoda	Calanoida		sp.	14	3		
CRUSTACEA Copepoda	Cyclopoida		sp.	1			1
CRUSTACEA Decapoda	Palaemonidae	Palaemonetes	australis	36	2		
	Parastacidae	Cherax	cainii			2	
	Parastacidae	Cherax	preissii				1
	Parastacidae	Cherax	quinquecarinatus			2	
CRUSTACEA Isopoda	Sphaeromatidae	Syncassidina	aesturia	2			
CRUSTACEA Ostracoda							7
INSECTA Coleoptera	Hydrochidae	Hydrochus	sp.		1		
INSECTA Diptera	Ceratopogidae	Ceratopoginae	sp.			1	22
	Chironomidae Chironominae	Chironomus	alternans		2		
	Chironomidae Chironominae	Cladopelma	cutivalva			6	202
	Chironomidae Chironominae	Cryptochironomus	griseidorsum			3	
	Chironomidae Chironominae	Stenochironomus	nr anomolus			3	
	Chironomidae Chironominae	Tanytarsus	barbitarsus	10	4		
	Chironomidae Chironominae	Tanytarsus	fuscithorax			17	
	Chironomidae Orthocladiinae	Botryocladius	freemani			1	
	Chironomidae Orthocladiinae	Thienemanniella	sp.				1
	Chironomidae Tanypodinae	Procladius	paludicola	12	1		
	Chironomidae Tanypodinae	Procladius	villosimanus				4
	Empididae	Hemerodroma	sp.			1	
	Simulidae	Simulium	ornatipes			1	

				CIV 30 Mar 2011	HEST 30 Mar 2011	GOS 10 Mar 2010	GOS 10 Apr 2010
INSECTA Ephemoptera	Caenidae	Tasmanocoenis	sp.				1
INSECTA Odonata	Coenagrionidae	Ischnura	heterosticta		2		
	Hemicorduliidae	Hemicordulia	tau			2	
	Gomphidae	Austrogomphus	collaris				2
	Libellulidae	Nannophya	occidentalis				1
	Libellulidae	Orthetrum	caledonicum				1
INSECTA Trichoptera	Hydroptilidae	Hellythira	malleoforma			1	
	Leptoceridae	Triplectides	australis			2	
MOLLUSCA	Ancylidae	Ferrissia	sp.			3	6
	Hyriidae	Westralunio	carteri			2	
	Sphaeriidae	Musculium	kendricki				1
	Thiaridae	Brotia affin		1			
	Pomatiopsidae	Coxiella	striatula affin	4			
	Trapezidae	fluviolantes	subtorta	17	4		
NEMERTIA affin	Unknown non-segmented worm			17	1		
PORIFERA	Unknown sessile attached to material		sp.	many	several		

**GOS data from March 2010 was based on a degraded sample; as such April data has been used for comparison*

Appendix F — Water quality data

Water quality data is summarised by data range and medians by site in Table 25 and median seasonal values by surface and bottom waters in Table 10.

Table 25 Site water quality profile data – median and range.

	Salinity	Dissolved oxygen		Temperature	pH	Depth
	(ppt)	(% saturation)	(mg/L)	(°C)		(m)
KENDS (n= 102)						
min	0.4	0.0	0.0	13.9	6.7	0.2
max	39.4	214.2	15.0	33.0	8.2	2.7
median	26.6	29.5	2.0	22.9	7.2	
KENUS (n=155)						
min	0.3	2.1	0.1	13.3	6.5	0.2
max	35.9	160.2	12.2	31.0	7.8	3.4
median	1.0	68.1	6.2	21.8	7.2	
CIV (n= 118)						
min	0.4	4.5	0.3	13.5	6.6	0.2
max	31.7	209.4	14.0	31.7	8.2	4.5
median	0.7	79.7	7.0	22.9	7.2	
HEST (n= 181)						
min	0.4	1.8	0.2	12.7	6.4	0.2
max	33.0	276.9	19.2	32.4	7.7	4.5
median	0.6	32.9	2.8	20.3	7.0	
ODELL (n= 68)						
min	0.3	4.2	0.4	14.0	6.6	0.2
max	14.9	92.8	9.4	29.3	7.7	2.8
median	0.5	55.5	4.7	20.7	7.1	
GOS (n= 18**)**						
min	0.2	34.3	2.9	11.3	6.7	0.1
max	0.7	102.0	10.7	26.4	7.8	0.2
median	0.4	74.0	6.5	20.3	7.0	

Table 26 Seasonal median salinity (ppt) for surface and bottom waters.

	Surface water (0.2 m)						**Bottom water (depth variable)**					
	KENDS	KENUS	CIV	HEST	ODELL	GOS	KENTDS	KENTUS	CIV	HEST	ODELL	GOS
Summer	18.0	1.1	1.0	0.7	0.6	0.5	29.4	14.3	5.7	0.9	0.6	na
Autumn	22.0	2.4	1.3	1.0	0.5	0.4	34.0	16.9	8.3	14.7	0.6	na
Winter	1.4	0.4	0.5	0.4	0.4	0.4	18.0	0.5	0.5	0.5	0.4	na
Spring	1.1	0.6	0.7	0.7	0.7	0.7	20.9	0.7	0.7	0.9	0.7	na

Table 27 Salinity and oxygen classification thresholds

Salinity classification	Salinity concentration (ppt)	Conductivity (mS/cm)	Dissolved oxygen	Saturation (%)
Fresh	<5	<9	Super saturation	>100
Brackish	5–25	9–40	Well oxygenated	80–100
Saline	25–35	40–53	Moderately oxygenated	60–80
Hypersaline	>35	>53	Poorly oxygenated	40–60
			Hypoxic	10–40
			Near-anoxic	<10

Appendix G — Analysis for sediment in study 1

Parameter	Description	Analysis method	Laboratory	Limit of reporting
Particle size analysis	Determination of the particle size distribution of sediment. Particles to be grouped into the following size-classes according to the Wentworth scale: <4 um (clay) <62 um (silt) <250 um (fine sand) <500 um (medium sand) <2000 um (coarse sand) <10 000 um (gravel)	Sieving followed by laser diffraction.	CSIRO	n/a
Moisture content	Determination of the percentage of water present in the sediment sample Units: %	Water content in sediment samples determined by evaporation at 105°C and gravimetric measurement.	NMI	n/a
Total metals	Measurement of total metals suite: Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn (14 metals) Units: mg kg^{-1} as a dry weight		NMI	Lowest available
Polycyclic aromatic hydrocarbons (PAHs)	Measurement of PAH suite: Naphthalene Acenaphthylene Acenaphthene Fluorene Phenanthrene Anthracene Fluoranthene Pyrene Benz[a]anthracene Chrysene Benzo[b]and[k]fluoranthene Benzo[a]pyrene Indeno[1_2_3-cd]pyrene Dibenz[ah]anthracene Benzo[ghi]perylene Units: mg kg^{-1} as a dry weight	GC-MS, GC-ECD analysis (USEPA 8080/8140; 1983, 1996e; APHA, 1998).	NMI	Lowest available
Polychlorinated biphenyls	NR19 Congeners			0.01 mg/kg
Organochlorine (OC) pesticides	Measurement of OC pesticide suite: HCB	GC-MS, GC-ECD analysis (USEPA 8080/8140; 1983,	NMI	Lowest available

Parameter	Description	Analysis method	Laboratory	Limit of reporting
	HCH(BHC) Tot alpha,beta,delta Lindane (gamma-BHC) Heptachlor Heptachlor Epoxide Heptachlor Epoxide Chlordane Alpha Endosulphan Beta Endosulphan Endosulphan Sulfate Aldrin Dieldrin Endrin p,p-DDE p,p-DDD p,p-DDT Methoxychlor Total OC's Units: mg kg^{-1} as a dry weight	1996e; APHA, 1998).		
Total organic carbon (TOC) **% TOC**	Measurement of total organically bound carbon (TOC) within the sediments. This is required for normalisation of organic compound data to 1% organic carbon in accordance with guidelines ANZECC and ARMCANZ (2000a). Units: mg C kg^{-1} as a dry weight		NMI	n/a
Acid volatile sulfur (AVS, %S)	Measures that determine the reduced sulfur within sediments that is soluble in acid (cold 9 M HCl, 18 hr). These are typically considered to be metastable monosulfides.		NMI	
Total sulfur (%S)	Measures the total sulfur in the sample		NMI	
Chromium reducible sulfur (CRS, %S)	Chromium reducible sulfur provides a measure of reduced sulfur that includes pyrite (FeS2(s)), elemental sulfur, and the more stable monosulfide fractions (some FeS and H2S are likely to be lost on drying of sediment before analysis).		NMI	

Appendix H — Coordinates and description for sediment monitoring sites in study 2

#	Site code	Type	Easting	Northing
1	CANDR001	Channel	398408	6456255
2	CANDR002	Closed pipe	398482	6456253
3	CANDR003	Closed pipe	398554	6456280
4	CANDR004	Closed pipe	398556	6456696
5	CANDR005	Revegetated drain	398588	6456766
6	CANDR006	Closed pipe	398680	6456841
7	CANDR007	Closed pipe	398813	6456857
8	CANDR008	Channel	399308	6456495
9	CANDR009	Channel	399245	6456566
10	CANDR010	Waterway	399364	6456391
11	CANDR011	Channel	399704	6456190
12	CANDR012	Closed pipe	400028	6455816
13	CANDR013	Waterway	400341	6455796
14	CANDR014	Closed pipe	400353	6455678
15	CANDR015	Channel	400479	6455535
16	CANDR016	Waterway	400867	6455303

Appendix I — Analysis for sediment in study 2

Parameter	Description	Analysis method	Laboratory	Limit of reporting
Particle size analysis	Determination of the particle size distribution of sediment. Particles to be grouped into the following size-classes according to the Wentworth scale: <4 um (clay) <62 um (silt) <250 um (fine sand) <500 um (medium sand) <2000 um (coarse sand) <10 000 um (gravel)	Sieving followed by laser diffraction.	CSIRO	n/a
Moisture content	Determination of the percentage of water present in the sediment sample Units: %	Water content in sediment samples determined by evaporation at 105°C and gravimetric measurement.	NMI	n/a
Bioavailable metals	Measurement of bioavailable metals suite: Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, Zn (13 metals) Units: mg kg^{-1} as a dry weight	Analysis of dried sediment sample for a range of metals using a cold dilute acid extraction (0.5–1.0 M hydrochloric acid in a sediment : acid ratio of 1:50 for one hour.	NMI	0.2 mg/kg for Hg; 0.5 mg/kg for other metals
Polycyclic aromatic hydrocarbons (PAHs)	Measurement of PAH suite: Naphthalene Acenaphthylene Acenaphthene Fluorene Phenanthrene Anthracene Fluoranthene Pyrene Benz[a]anthracene Chrysene Benzo[b]and[k]fluoranthene Benzo[a]pyrene Indeno[1_2_3-cd]pyrene Dibenz[ah]anthracene Benzo[ghi]perylene Units: mg kg^{-1} as a dry weight	GC-MS, GC-ECD analysis (USEPA 8080/8140; 1983, 1996e; APHA, 1998).	NMI	0.01 mg/kg
Organochlorine	Measurement of OC pesticide	GC-MS, GC-ECD	NMI	0.01 mg/kg

Parameter	Description	Analysis method	Laboratory	Limit of reporting
(OC) pesticides	suite: HCB HCH(BHC) Tot alpha,beta,delta Lindane (gamma-BHC) Heptachlor Heptachlor Epoxide Chlordane Alpha Endosulphan Beta Endosulphan Endosulphan Sulfate Aldrin Dieldrin Endrin p,p-DDE p,p-DDD p,p-DDT Methoxychlor Total OC's Units: mg kg^{-1} as a dry weight	analysis (USEPA 8080/8140; 1983, 1996e; APHA, 1998).		
Total organic carbon (TOC) **% TOC**	Measurement of total organically bound carbon (TOC) within the sediments. This is required for normalisation of organic compound data to 1% organic carbon in accordance with guidelines ANZECC and ARMCANZ (2000a). Units: mg C kg^{-1} as a dry weight		NMI	n/a
Total nitrogen			NMI	<50 mg/kg
Total phosphorus			NMI	<1 mg/kg

Appendix J — Management scenarios

A preliminary evaluation of several management scenarios for improving the health and longevity of the Canning River aquatic ecosystem was conducted as part of this study. These scenarios are discussed below in respect to likelihood and consequence of possible negative outcomes if these management options were employed.

This investigation was designed to highlight some key issues for more detailed assessment. Results can only be considered indicative, requiring a significant increase in the number of contributors and input from a broader cross-section of stakeholders and scientists. Additional threats, scenarios and end-points would also be expected in future assessments.

This analysis was conducted by Dr Tim Storer (aquatic ecologist) and Dr Tarren Reitsema (ecotoxicologist) from the Department of Water.

The scenarios assessed below are in addition to the current intervention strategies of :

- Nutrient reduction from inflows through local Water Quality Improvement Plan activities
- Constructed wetland and other drainage interventions
- Oxygenation of bottom waters which is being extended upstream as far as Hester Park
- Periodic Phoslock™ or other P binding clay applications to reduce P release from sediment.
- Provision of environmental flow through release of scheme water
- Replacement/rehabilitation of the weir

Scenarios

In response to the likely threats facing ecosystem health in the Canning River around the KSW, and the associated threats to social and economic values, the following management scenarios were proposed for assessment purposes:

- **No change to current management**: boards removed annually in spring to maintain some degree of flushing and bioconnectivity in the system (as per current operating strategy).
- **Boards remain in place continuously over short-term periods (few years maximum)**: to prevent intrusion and maintain water level above the KSW (likely if conditions in 2010–11 persist).
- **Boards remain in place continuously over a long-term period**: to prevent intrusion and maintain water level above KSW (likely in drying climate scenario).
- **KSW is removed**: restoring bioconnectivity permanently.
- **KSW is raised**: to improve ability to prevent intrusion.

- **Fishway installed at KSW**: restore bioconnectivity while preserving fresh water and water level upstream of weir.
- **Improved flushing of KSW pool** (various intervention options): reduction in stratification and accumulating materials in weir pool (including flushing of salt water following intrusions) while preserving fresh water and water level upstream of weir.
- **Dredging of KSW pool:** removal of accumulated sediment and organic material in weir pool (and associated contaminants).
- **Remedy contaminant and sediment sources**: reduce accumulation in weir pool through reduction of inputs.

These scenarios were assessed assuming climatic conditions were similar or more extreme than recorded in 2011.

Risk Analysis

Analysis of each scenario was achieved through calculating risk based on the likelihood and consequence of each identified threat following scoring protocols outlined below. Note: in the tables below the term 'system' relates to the KSW pool (KENDS-ODELL) unless otherwise specified.

Confidence limits were included to highlight knowledge gaps in understanding the threat response.

Likelihood was scored based on the following scoring protocol:

Likelihood	Description
1 Rare	Occurs only in exceptional circumstances
2 Unlikely	Could occur but not expected
3 Moderate	Could occur anywhere in system
4 Likely	Will probably occur in most circumstances (high probability anywhere in system)
5 Almost certain	Is expected to occur in most circumstances (will occur anywhere in system)

Consequence regarding environmental effect was scored based on the following scoring protocol:

Consequence	Description
1 Insignificant	Negligible/undetectable ecosystem response
2 Minor	Detectable but not of concern – i.e. minor reduction in abundance, change in food resource availability
3 Moderate	Obvious and of concern – i.e. change in community structure (loss of sensitive species), moderate habitat disturbance
4 Major	Functional change in the ecosystem – i.e. including loss of functional groups, major changes in food resources and foodwebs
5 Catastrophic	System-scale loss of species, dramatic changes to communities, dramatic changes to functions, replacement with generalists and exotics

Note: definitions for likelihood and consequence were adapted from assessments conducted for the Stream and Estuary Assessment Program Lake Eyre and Bulloo Province Stressor Prioritisation Workshop.

Consequences regarding social end-points (human health, aesthetics and abstraction) were assessed based on a gradient from undetectable or negligible (1) through to catastrophic (5) resulting in serious illness or potential loss of human life or an inability to abstract either due to quantity or quality effects. This component of the assessment in particular requires increased consultation. As stated, the assessment reported here is designed as a trigger for a more substantial analysis of threats and consequences in the future and should not be used directly for management.

Confidence was scored based on the following scoring protocol:

Confidence	Description
1 Low confidence	Not confident with the score due to a lack of scientific information and other evidence available and /or little expertise on the area of concern
2 Medium confidence	Have some confidence in the score but knowledge may not be across the system or entire scope of problem and the collected information and other evidence to support this is not complete
3 High confidence	Very confident of the score and can support this with collected information and anecdotal evidence

Risk was calculated as an unweighted multiplication of likelihood and consequence (out of 25). Results are provided in Table 28, with confidence limits provided in Appendix K.

Table 28 Analysis of risks to environment and social end-points in the Canning River around KSW under a number of scenarios relating to management of the weir.

RISK SCENARIOS	End-points	THREATS: Increased salinity in KSW pool (to HEST)	Increased salinity upstream of HEST	Drying or significant disconnection	Increased flooding D/S of KSW	Increased contaminant accumulation in weir pool	Increased exposure to existing sediment contaminants (short-term)	Increased exposure to existing sediment contaminants (long-term)	Increased anoxia or near-anoxic conditions (independent of phytoplankton)	Increased thermal stratification	Increased exotic invasion (aquatic fauna)	Reduced fish passage	Increased predation at stop point (weir)	Increased sediment in weir pool	Increased algal blooms	Release of low quality water D/S of KSW (short-term)	Release of low quality water D/S of KSW (long-term)
DO NOTHING – boards removed seasonally	aquatic biota	12	16	16	3	3	12	12	15	9	6	3	6	8	12	6	6
	riparian veg.	12	16	16	4	1	3	4	6	3	2	1	2	2	9	2	2
	human health	4	4	12	1	4	12	16	3	3	2	1	2	2	9	6	4
	aesthetics	8	12	16	3	1	3	4	9	3	2	1	2	2	9	4	4
	abstraction	4	20	16	1	4	12	16	6	6	2	1	2	2	9	2	2
	fishing	12	16	16	2	3	12	12	15	9	4	3	6	8	9	6	6
Boards in place permanently: short-term	aquatic biota	12	12	5	6	9	4	Not applicable	20	12	6	12	12	9	16	6	Not applicable
	riparian veg.	12	12	4	8	3	1		8	4	2	4	4	3	12	2	
	human health	4	3	3	2	12	5		4	4	2	4	4	3	12	6	
	aesthetics	8	9	5	6	3	1		16	4	2	4	4	3	12	4	
	abstraction	4	15	5	2	12	5		8	8	2	4	4	3	12	2	
	fishing	12	12	4	4	9	4		20	12	4	12	12	9	12	6	
Boards in place permanently: long-term	aquatic biota	15	20	15	6	15	Not applicable	9	25	15	9	15	15	15	20	Not applicable	6
	riparian veg.	15	20	12	8	5		3	10	5	3	5	5	5	15		2
	human health	5	5	9	2	20		15	5	5	3	5	5	5	15		4
	aesthetics	10	15	15	6	5		3	15	5	3	5	5	5	15		4
	abstraction	5	25	15	2	20		15	10	10	3	5	5	5	15		2
	fishing	15	20	12	4	15		9	25	15	6	15	15	15	15		6
KSW removed	aquatic biota	15	20	16	3	3	20	6	5	3	9	3	3	4	8	15	6
	riparian veg.	15	20	16	4	1	5	2	2	1	3	1	1	1	6	5	2
	human health	5	5	12	1	4	25	10	1	1	3	1	1	1	6	15	4
	aesthetics	10	15	16	3	1	5	2	3	1	3	1	1	1	6	10	4
	abstraction	5	25	20	1	4	25	10	2	2	3	1	1	1	6	5	2
	fishing	15	20	12	2	3	20	6	5	3	6	3	3	4	6	15	6
Height of KSW raised	aquatic biota	6	8	5	15	15	8	12	25	15	3	15	15	15	16	9	12
	riparian veg.	6	8	4	15	5	2	3	10	5	1	5	5	5	12	3	4
	human health	2	2	3	5	20	10	15	5	5	1	5	5	5	12	9	8
	aesthetics	4	6	5	15	5	2	3	15	5	1	5	5	5	12	6	8
	abstraction	2	10	5	5	20	10	15	10	10	1	5	5	5	12	3	4
	fishing	6	8	4	10	15	8	12	25	15	2	15	15	15	12	9	12
Fishway installed at KSW	aquatic biota	6	8	10	3	3	4	3	5	3	9	3	6	4	12	9	6
	riparian veg.	6	8	8	4	1	1	1	2	1	3	1	2	1	9	3	2
	human health	2	2	6	1	4	5	5	1	1	3	1	2	1	9	9	4
	aesthetics	4	6	10	3	1	1	1	3	1	3	1	2	1	9	6	4
	abstraction	2	10	10	1	4	5	5	2	2	3	1	2	1	9	3	2
	fishing	6	8	8	2	3	4	3	5	3	6	3	6	4	9	9	6
Flushing within weir pool improved	aquatic biota	3	4	10	3	3	16	3	5	3	3	3	6	4	4	12	6
	riparian veg.	3	4	8	4	1	4	1	2	1	1	1	2	1	3	4	2
	human health	1	1	6	1	4	20	5	1	1	1	1	2	1	3	12	4
	aesthetics	2	3	10	3	1	4	1	3	1	1	1	2	1	3	8	4
	abstraction	1	5	10	1	4	20	5	2	2	1	1	2	1	3	4	2
	fishing	3	4	8	2	3	16	3	5	3	2	3	6	4	3	12	6
Dredging of sediments in weir pool	aquatic biota	3	4	10	3	3	20	3	5	3	3	3	3	4	4	12	6
	riparian veg.	3	4	8	4	1	5	1	2	1	1	1	1	1	3	4	2
	human health	1	1	6	1	4	25	5	1	1	1	1	1	1	3	12	4
	aesthetics	2	3	10	3	1	5	1	3	1	1	1	1	1	3	8	4
	abstraction	1	5	10	1	4	25	5	2	2	1	1	1	1	3	4	2
	fishing	3	4	8	2	3	20	3	5	3	2	3	3	4	3	12	6
Remediation of sediment and contaminant source	aquatic biota	3	4	5	3	3	4	3	5	3	3	3	3	4	4	3	3
	riparian veg.	3	4	4	4	1	1	1	2	1	1	1	1	1	3	1	1
	human health	1	1	3	1	4	5	5	1	1	1	1	1	1	3	3	2
	aesthetics	2	3	5	3	1	1	1	3	1	1	1	1	1	3	2	2
	abstraction	1	5	5	1	4	5	5	2	2	1	1	1	1	3	1	1
	fishing	3	4	4	2	3	4	3	5	3	2	3	3	4	3	3	3

Colour key (RISK) score	1–11 (low)	12–14 (moderate)	15–19 (high)	20+ (very high)

As shown in Table 28, there are risks associated with all of the major management scenarios assessed, particularly relating to the current capacity to manage the KSW (first three scenarios).

It is clear that the risks associated with the various management scenarios are complex and characterising the likely outcomes whilst also considering the spatial and temporal variability in environmental parameters (e.g. flow, tides and associated water quality) requires considerable discussion; beyond the capabilities of this study.

Considering the current management options (manipulating weir boards) under the current climatic conditions we can make the following observations:

1. In low flow years weir boards would typically be left in place in order to maintain water depths in the weir pool, maintain freshwater upstream and promote the growth of aquatic plants such as *Potamageton*. Risks under this scenario relate to stagnation and the potential for cyanobacteria in still waters. The current weir construction does not allow for periodic dropping of water level to create surface flow that might be used to manage cyanobacteria. Since oxygenation and Phoslock™ application commenced cyanobacterial blooms have been infrequent.
2. Considering the risks of saline water overtopping into the weir pool with the boards in place; in the short term there is not likely to be a discernible biological effect, however if boards remain in over successive years significant effects to fish (particularly migration) will be affected. It is recognized that if flushing flows occur the KSW will be opened so leaving the weir boards in place does not affect the flushing per se. Overtopping of saline water during storm surges will reduce the freshwater character of the KSW to favour estuarine species of phytoplankton and fish and increase extent and duration of stratification. The density stratification from the added salt is much harder to break down through wind mixing than the weaker temperature stratification in the freshwater weir pool.

Ultimately, the Kent Street Weir structure is deteriorating and the manual removal and placement of weir boards is not compatible with modern occupational health and safety practices. Accordingly, replacement/rehabilitation of the weir is a very real possibility. There is a case in any redesign of the weir to have the weir height more easily adjustable which in turn provides for more flexible management of water level in the pool and flow over the weir.

Improved flushing and remediation of contaminant sources appear to be a requirement if ecosystem health is to be maintained into the future. However, significant work is obviously required to characterise what these management actions will entail. For instance, reduction of salinity upstream may result in cyanobacteria blooms. Potential current risk could be assessed by analysis of akinetes (resistant asexual spores) in surficial sediments.

The potential for inclusion of a fishway (sixth scenario) also requires significant investigation before the viability of this option can be assessed. An appropriate fishway design would need to maximise the movement of species at required times while reducing possible predation at choke points or the potential encroachment of salinity under reduced weir height. A fishway at the KSW would also result in conditions where migrating fish may be moving directly from fresh water to marine-level salinities – the potential for deleterious effects to occur due to this rapid change in conditions requires consideration.

Based on the assessment above increased flushing appears to be the most beneficial management scenario. However, this is not a simple response given the current flushing dynamics of the system – see conceptual diagrams at Figure 43 and Figure 44. That is, the system's flushing capacity is relatively poor even with the periodic removal of weir boards. Further, potential for mobilisation of sediment (from improved flushing or through disturbance from dredging) should be carefully considered as this would present a risk to the downstream environment (sediment impacts not considered as part of risk analysis) .

If the aquatic environment within the KSW pool can be significantly improved through the proposed management scenarios, consideration could be given to treating the weir pool as a treatment cell for the greater aquatic environment. That is, using the pool to assimilate nutrients, improve oxygen, and lock-up excess sediment and contaminants. This would benefit the downstream receiving environments and is unlikely to have significant impacts to current weir pool ecology. Obviously factors such as connectivity for dispersal and migration of fauna would still need to be considered.

Appendix K — Confidence limits for risk analysis

CONFIDENCE	Threat>>>	Increased salinity (conc./extent) U/S		Increased salinity (conc./extent) U/S		Drying or significnat disconnection		Increased floodign D/S of KSW		Increased contaminant accumualtion in weir pool		Increased exposure to existing sediment contaminants (short-term)		Increased exposure to existing sediment contaminants (long-term)		Increased anoxia or near anoxic conditions		Increased thermal stratification		Increased exotic invasion (aquatic biota)		Reduced fish passage		Increased predation at stop point (weir)		Increased sediment in weir pool		Increased algal blooms		Release of low quality water DS of KSW (short-term)		Release of low quality water DS of KSW (long-term)	
Scenario	end-points	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C	L	C
DO NOTHING - boards removed seasonally for flushing/bioconnectivity	aquatic biota		2		3		3		3		3		1		1		2		2		3		2		2		2		2		1		1
	riparian veg.		2		3		3		3		3		2		1		2		2		3		3		3		3		3		1		1
	human health		2		3		3		3		3		1		1		1		1		3		3		3		3		2		1		1
	aesthetics		2		3		3		3		3		1		1		2		2		3		3		3		3		2		1		1
	abstraction		1		3		3		3		3		1		1		3		3		3		3		3		3		1		1		1
	fishing	**3**	2	**3**	3	**2**	3	**3**	3	**3**	3	**1**	1	**1**	1	**3**	2	**3**	2	**2**	3	**2**	2	**2**	2	**2**	2	**2**	2	**1**	1	**1**	1
Boards in place permanently: short-term	aquatic biota		2		3		3		3		2		1				2		2		3		2		2		2		2		1		
	riparian veg.		2		3		3		2		2		1				2		2		3		3		3		3		3		1		
	human health		2		3		3		3		2		1				1		1		3		3		3		3		2		1		
	aesthetics		2		3		3		3		2		1				2		2		3		3		3		3		2		1		
	abstraction		1		3		3		3		2		1				3		3		3		3		3		3		1		1		
	fishing	**3**	2	**3**	3	**3**	3	**3**	3	**3**	2	**3**	1			**3**	2	**3**	2	**2**	3	**3**	2	**2**	2	**3**	2	**2**	2	**1**	1		
Boards in place permanently: long-term (likely overtopping)	aquatic biota		2		3		1		3		2				1		2		2		2		2		2		1		1				1
	riparian veg.		2		3		1		2		2				2		2		2		3		3		3		3		3				1
	human health		1		3		1		3		2				1		2		2		3		3		3		3		1				1
	aesthetics		1		3		1		3		2				1		2		2		3		3		3		3		3				1
	abstraction		1		3		1		3		2				1		2		2		3		3		3		3		1				1
	fishing	**3**	1	**3**	3	**1**	1	**3**	3	**3**	2			**1**	1	**3**	2	**3**	2	**2**	2	**3**	2	**3**	2	**3**	1	**2**	1			**1**	1
REMOVE WEIR	aquatic biota		3		3		3		3		3		1		1		2		2		2		3		3		2		1		1		1
	riparian veg.		3		3		3		3		3		1		1		3		3		3		3		3		3		1		3		3
	human health		3		3		3		3		3		1		1		3		3		3		3		3		3		1		1		1
	aesthetics		3		3		3		3		3		1		1		3		3		3		3		3		3		1		1		1
	abstraction		3		3		3		3		3		1		1		3		3		3		3		3		3		1		2		2
	fishing	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	1	**3**	1	**2**	2	**2**	2	**2**	2	**3**	3	**3**	3	**3**	2	**1**	1	**3**	1	**3**	1
RAISE WEIR	aquatic biota		3		3		L		1		1		2		2		3		3		3		2		2		2		1		1		1
	riparian veg.		3		3		L		2		1		2		2		3		3		3		3		3		3		2		1		1
	human health		3		3		L		3		1		2		2		3		3		3		3		3		3		1		1		1
	aesthetics		3		3		L		2		1		2		2		3		3		3		3		3		3		1		1		1
	abstraction		3		3		L		3		1		2		2		3		3		3		3		3		3		1		1		1
	fishing	**3**	3		3	**2**	L	**3**	1	**3**	1	**3**	2	**3**	2	**3**	3	**3**	3	**3**	3	**3**	2	**3**	2	**3**	2	**2**	1	**1**	1	**1**	1
FISHWAY	aquatic biota		3		3		3		3		3		2		2		3		3		1		3		2		3		3		1		1
	riparian veg.		3		3		3		3		3		3		3		3		3		3		3		3		3		3		2		2
	human health		3		3		3		3		3		3		3		3		3		3		3		3		3		3		2		2
	aesthetics		3		3		3		3		3		3		3		3		3		3		3		3		3		3		2		2
	abstraction		3		3		3		3		3		3		3		3		3		3		3		3		3		3		2		2
	fishing	**3**	3		3	**2**	3	**3**	3	**3**	3	**2**	2	**2**	2	**3**	3	**3**	3	**2**	1	**3**	3	**2**	2	**3**	3	**3**	3	**1**	1	**1**	1
IMPROVE FLUSHING	aquatic biota		3		3		3		3		3		2		2		3		3		3		3		3		3		1		2		2
	riparian veg.		3		3		3		3		3		3		2		3		3		3		3		3		3		3		3		3
	human health		3		3		3		3		3		2		2		3		3		3		3		3		3		L		2		3
	aesthetics		3		3		3		3		3		3		2		3		3		3		3		3		3		L		3		3
	abstraction		3		3		3		3		3		2		2		3		3		3		3		3		3		2		3		3
	fishing	**3**	3		3	**3**	3	**3**	3	**3**	3	**2**	2	**2**	2	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**1**	L	**2**	2	**2**	2
DREDGE	aquatic biota		3		3		3		3		3		2		2		3		3		3		3		3		3		1		2		2
	riparian veg.		3		3		3		3		3		3		2		3		3		3		3		3		3		1		3		3
	human health		3		3		3		3		3		2		2		3		3		3		3		3		3		1		2		3
	aesthetics		3		3		3		3		3		3		2		3		3		3		3		3		3		1		3		3
	abstraction		3		3		3		3		3		2		2		3		3		3		3		3		3		1		3		3
	fishing	**3**	3		3	**3**	3	**3**	3	**3**	3	**2**	2	**2**	2	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**1**	1	**2**	2	**2**	2
REMEDY CONTAM. AND SEDIMENT SOURCE	aquatic biota		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	riparian veg.		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	human health		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	aesthetics		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	abstraction		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3		3
	fishing	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3	**3**	3

Appendix L — Salinity tolerances of freshwater species

Table taken from Storer et al. 2011b – refer to report for reference list.

Salinity levels (mg/L TDS)	Reported tolerance levels for aquatic species	Reference
62 to 156	Recommended trigger value for upland and lowland rivers in south-west Western Australia.	ANZECC & ARMCANZ 2000a (trigger values)
800	Aquatic macroinvertebrates: adverse effects for the most sensitive species starts to occur.	Bailey & James 2000
1000	Aquatic macroinvertebrates: adverse effects (e.g. osmoregulatory function starting to fail). Insects are usually quite tolerant, however stoneflies, mayflies and caddisflies are more sensitive.	Hart et al. 1991; Hart et al. 1989
> 1000	Direct adverse effects become apparent in Australian river and wetland ecosystems. Below this salinity freshwater ecosystems are subject to little stress.	Mayer et al. 2005; Hart et al. 1991; Nielsen et al. 2003
1000–2000	Submerged macrophytes: sensitivity and some lethal effects (e.g. a decline in growth and suppressed reproduction) (Victorian study).	Hart et al. 1991; Hart et al. 1989; James & Hart 1993
2000	Aquatic macroinvertebrates: lethal effects (Victorian study).	Bacher & Garnham 1992
< 2000	Microinvertebrates: lethal effects (NSW wetlands).	Nielsen et al. 2003
3000	Riparian vegetation, e.g. adverse effects for species such as *Eucalyptus, Melaleuca* and *Casuarina* (e.g. seed germination decreases).	Hart et al. 1991; Hart et al. 1989
> 3000	Species reduction in freshwater algae, plants and aquatic macroinvertebrates.	Hart et al. 1991; Hart et al. 1989
4000	Freshwater aquatic plants: upper tolerance level.	Nielsen et al. 2003; Brock 1981
5000	Gastropods – majority only occurred at salinities below this concentration. Oligochaeta – majority only occurred below this concentration.	Rutherford & Kefford 2005*
8800	Adult finfish: most tolerate to this level.	James et al. 2003
10 000	Freshwater finfish: tolerate salinity to this concentration. Larval finfish are more sensitive than adults and eggs more tolerant than larvae: e.g. some juvenile finfish in the Murray-Darling Basin only tolerate a maximum 5000 mg/L. Examination of 491 freshwater WA Wheatbelt invertebrates showed that 76% of freshwater species were collected at salinities below this level.	Hart et al. 1991; Hart et al. 1989; James et al. 2003 Pinder et al. 2005; unpublished data in Halse et al. 2003
5000–10 000	Trichoptera: majority only occurred below this concentration.	Rutherford & Kefford 2005*
7000–13 000	General tolerance limits for freshwater finfish species (Southern Victoria and Murray-Darling river system).	James et al. 2003; Bacher & Garnham 1992

10 000	Few Dipteran species found above this level (WA Wheatbelt). Diversity of aquatic macroinvertebrates in saline lakes decreased rapidly above this level (Western Victoria). Waterbirds – species richness increased below this level (WA Wheatbelt).	Pinder et al. 2005; Williams et al. 1990
~15 000	Acute tolerance level for western minnows and pygmy perch from Blackwood River (WA). **	Beatty et al. 2008
15 000	Odonata – majority only occurred below this concentration.	Rutherford & Kefford 2005*
15 300	Most WA species of waterbirds are found below this level.	Goodsell 1990

***   Rutherford & Kefford (2005) re-examined a large field monitoring dataset from Victoria and South Australia that estimated the maximum field distributions of aquatic macroinvertebrates. Data given may not include all species from that order.***

***** New data (collected immediately after the FARWH trials) from the two sites on the Avon River (Western Australia) in June 2010 found western minnows in salinities up to ~25 000 mg/L TDS. The FARWH sampling also collected one individual western minnow in a river in the Albany Coast SWMA with 28 000 mg/L TDS, however they were mostly found below 20 000 mg/L TDS.***

Shortened forms

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARL	Aquatic Research Laboratories
AVS	acid volatile sulfur
BoM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CRS	chromium reducible sulfur
DEC	Department of Environment and Conservation
DoF	Department of Fisheries
DON	dissolved organic nitrogen
DoT	Department of Transport
DoW	Department of Water
FRP	filterable reactive phosphorus
HCWA	Heritage Council of Western Australia
IOCI	Indian Ocean Climate Initiative
ISQG	interim sediment quality guidelines
KSW	Kent Street Weir
LOR	limits of reporting
PAHs	polycyclic aromatic hydrocarbons
SCEMR	Swan-Canning Environmental Monitoring and Reporting program
SERCUL	South East Regional Centre for Urban Landcare
SRT	Swan River Trust
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TS	total sulfur
USEPA	United States Environmental Protection Agency

Glossary

Allocthonous	Material that is formed or introduced from an alternate area to where found.
Bioconnectivity	System connectivity as related to passage of fish and other aquatic fauna.
Ecosystem services	Benefits to humans stemming from environmental conditions, e.g. mosquito control, climate regulation, aesthetics, pollination, fishing and waste treatment (nutrient reduction – preventing algal blooms).
Euryhaline	Capable of tolerating a wide range of salt water concentrations. Used of an aquatic organism.
Halocline	A relatively sharp discontinuity in salinity at a particular depth in water column. In general, water with a higher concentration of salinity sinks below water that is less saline (exceptions exist).
Hypolimnion	The colder layer of water in a thermally stratified lake that lies below the thermocline.
Plastron-spiracle	Physical gills are a type of structural adaptation common among some types of aquatic insects, which holds atmospheric oxygen in an area with small openings called spiracles. The structure (often called a plastron) typically consists of dense patches of hydrophobic setae on the body, which prevent water entry into the spiracles.
Pneumostone (breathing pore)	A small opening in the mantle of a gastropod through which air passes.
Stratification	Formation of layers in a body of water
Thermocline	The region in a thermally stratified body of water which separates warmer surface water from cold deep water
Voltinism	Potential number of breeding cycles capable of being performed per year.

Data sources

The maps in this publication were produced by the Department of Water with the intent that they be used in this report only. While the department has made all reasonable efforts to ensure the accuracy of these data, it accepts no responsibility for any inaccuracies, and people relying on them do so at their own risk.

The department acknowledges the following datasets and their custodians in the analysis of data and production of the maps:

Dataset name	Custodian	Metadata year	Period covered	Comments
Expected distribution of freshwater finfish and crayfish in SWWA	DoW, Water Science Branch	Unpublished, contact Water Science Branch	1988–present	Spreadsheet of location of known occurrence of freshwater fish species based on Department of Water sampling (RHAS and SWWA-FARWH projects) and a literature review, created as part of the SWWA-FARWH project. Used to determine expected fish species in the study area and to define reference condition for *Fish Health Index*.
Swan Coastal Plain East 10cm 2010	Landgate	2010	22/02/2010 to 30/05/2010	Aerial photograph, 10cm resolution. Used for illustrative purposes.
Swan Coast Plain Central 2009 20cm	Landgate	2009	12/06/2008 to 17/12/2008	Aerial photograph; 20cm resolution. Used for illustrative purposes.
Hydrography, Linear (Hierarchy)	DoW	2007	1995 to 2007	Vector data derived from topographic mapping at 1:25 000 and 1:100 000 scale. Mapped streamlines with attributes for hierarchy (main stream, tributary etc.). Used for illustrative purposes.
Hydrography, Linear	DoW	2006	Unknown to 2004	Vector data derived from topographic mapping at 1:25 000 and 1:100 000 scale. Used for illustrative purposes.
Hydrography theme from GEODATA TOPO 250K	GA	2006	2001 to 2006	Vector dataset, national topographic mapping at 1:250 000 scale. Used for illustrative purposes.
Drains	DoW	Unpublished, contact Water Science Branch	Unknown	Network of the streams/drains that show the linkages between catchments. Used for illustrative purposes.

Upper Canning – derived bathymetric contours	DoW	Unpublished, contact Water Science Branch	2008–09	Derived from survey data provided by DoT (2008) and DoW's Swan Coastal Plain LiDAR dataset (2009). Used for illustrative purposes.

The maps have been produced using the following data and projection information:

Vertical Datum: AHD (Australian Height Datum)

Horizontal Datum: GDA 94 (Geocentric Datum of Australia 1994)

Projection System: Map Grid of Australia (MGA) 1994 Zone 50

Original ArcMap documents (*.mxd):

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List of species reported in this study

Latin name (fish lifecycle category)	Common name	Salinity preference	Native or exotic	Organism type
***Nannoperca vittata** (F)**	Western pygmy perch	Fresh	Native	Finfish
***Galaxias occidentalis* (F)**	Western minnow	Fresh	Native	Finfish
***Bostockia porosa* (F)**	Nightfish	Fresh	Native	Finfish
***Tandanus bostocki* (F)**	Freshwater cobbler	Fresh	Native	Finfish
Cherax cainii (F)**	Smooth marron	Fresh	Native	Crayfish
***Cherax quinquecarinatus* (F)**	Gilgie	Fresh	Native	Crayfish
***Palaemontes australis* (F)**	Freshwater shrimp	Fresh	Native	Shrimp
***Chelodina oblonga* (F)**	Western long-necked tortoise	Fresh	Native	Tortoise
***Gambusia holbrooki* (F)**	Mosquitofish	Fresh	Exotic	Finfish
***Phalloceros caudimaculatus* (F)**	One-spot livebearer	Fresh	Exotic	Finfish
***Carassius auratus* (F)**	Goldfish	Fresh	Exotic	Finfish
***Cyprinus carpio* (F)**	Koi	Fresh	Exotic	Finfish
***Leiopotherapon unicolour* (F)**	Spangled perch	Fresh	Exotic	Finfish
Cherax sp. (yabbie)* (F)**	Yabbie	Fresh	Exotic	Crayfish
***Emydura macquarii* (F)**	Murray River tortoise	Fresh	Exotic	Tortoise
Psuedogobius olorum (E)	Swan River goby	Fresh-Marine	Native	Finfish
Afurcagobius suppositus (E)	South-western goby	Fresh-Marine	Native	Finfish
Leptatherina wallacei (E)	Western hardyhead	Fresh-Marine	Native	Finfish
Acanthopagrus butcheri (E)	Black bream	Fresh-Marine	Native	Finfish
Mugil cephalus (O)	Sea (white-eye) mullet	Fresh-Marine	Native	Finfish
Amniataba caudavittata (E)	Yellowtail grunter	Marine	Native	Finfish
Pelates octolineatus ** (O)***	Western striped trumpeter	Marine	Native	Finfish
Aldrichetta forsteri (O)	Yellow-eye mullet	Marine	Native	Finfish
Torquigener pleurogramma (O)	Common blowfish	Marine	Native	Finfish
Arenigobius bifrenatus (E&M)	Bridled goby	Marine	Native	Finfish
Apogon reuppelii (E&M)	Gobbleguts	Marine	Native	Finfish
Engraulis australis (E&M)	Australian anchovy	Marine	Native	Finfish
Gerres subfasciatus (O)	Silverbiddy or roach	Marine	Native	Finfish
Portunus pelagicus (E)	Blue swimmer crab	Marine	Native	Crab
Halicarcinus ovatus* (O)***	Oval spider crab	Marine	Native	Crab
Melicertus latisulcatus (E)	Western king prawn	Marine	Native	Prawn
Metapenaeus dalli (E)	Western school prawn	Marine	Native	Prawn

*O – marine-estuarine opportunists, E&M – separate estuarine and marine populations, E – species completing lifecycle within estuaries, F – fresh water (lifecycle categories for finfish from Loneragan et al. 1989). * previously Edelia vittata, ** previously C. tenuimanus (for species occurring in Canning River, Austin & Ryan 2002), *** conjecture over nomenclature – species collected could be C. albidus or C. destructor (specimen descriptions recorded for future identification), **** reported as marine but found in freshwater environments in this study, ***** previously Pelates sexlineatus.*

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