Water quality and fish refugia in riverine waterholes in northern Queensland potentially subject to irrigation development

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Key Points

- Northern Australia has potential for additional agricultural and pastoral production, based on more intensive use of its land and water resources.
- Waterholes in northern Australia also provide critical refugia habitat for many aquatic animals, and changes to the timing, size and duration of flow owing to water extraction could lead to significant deleterious consequences on aquatic habitat quality, resilience and suitability.
- Turbid waterholes are more thermally stratified, by several degrees Celsius, due to the surface waters retaining heat, compared to clear waterholes which are well mixed.
- Thermal regime of waterholes is important driving primary production, which supports higher order waterhole biota.

Keywords

Freshwater ecology, irrigation development, fish, northern Australia, water resource planning

Introduction

River systems of northern Australia have extremely seasonal streamflow (Kennard *et al.,* 2010), with most of the total annual flow occurring during the wet season (November to April) and often during a short timescale (e.g. a few weeks; CSIRO 2009). Wet season flow is important in the longitudinal, lateral and vertical connection of rives and wetlands, especially on floodplains which provide important connection for fish to move to suitable areas for spawning and feeding (Balcombe *et al.,* 2007, Medeiros and Arthington 2008). The wet season flow also delivers productivity-boosting freshwater and nutrients to estuaries and coastal waters which support economic fisheries (Buckworth *et al.,* 2013). It also recharges groundwater aquifers, which supports riparian and floodplain vegetation, and aquatic fauna, but also delivers dry season baseflow to downstream waterholes long after the flow from floodwater has ceased (Butler *et al.,* 2009).

As part of the North Queensland Irrigated Agricultural Strategy, the Flinders and Gilbert Agricultural Resource Assessment (the Assessment; www.csiro.au/Organisation-Structure/Flagships/Water-for-a-Healthy-Country-Flagship/Sustainable-Yields-Projects/Flinders-and-Gilbert-Agricultural-Resource-Assessment-overview.aspx) was completed in 2013 led by CSIRO. The Assessment provided a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water resource development in the Flinders and Gilbert River catchments. The study included an investigation of the aquatic ecology of waterholes within these catchments.

Methods

Twenty waterholes were investigated, ten in each catchment (Figure 1) during six surveys, between October 2012 and May 2013. The sampling occurred over 2012/13 wet season, which was a below average rainfall season and therefore the data reflects an extended dry season (Waltham *et al.*, 2013). Waterholes were visited during each survey, though many dried completely during the study. A range of water quality measurements and samples were collected to examine the water quality dynamics and processes. Continuous water quality loggers were deployed to also measure diel and long term physic-chemical water quality in waterholes. Freshwater fish were also sampled using backpack electrofishing, bait traps, and nets (seine and gill). A full account of the data is presented in Waltham *et al.,* (2013).

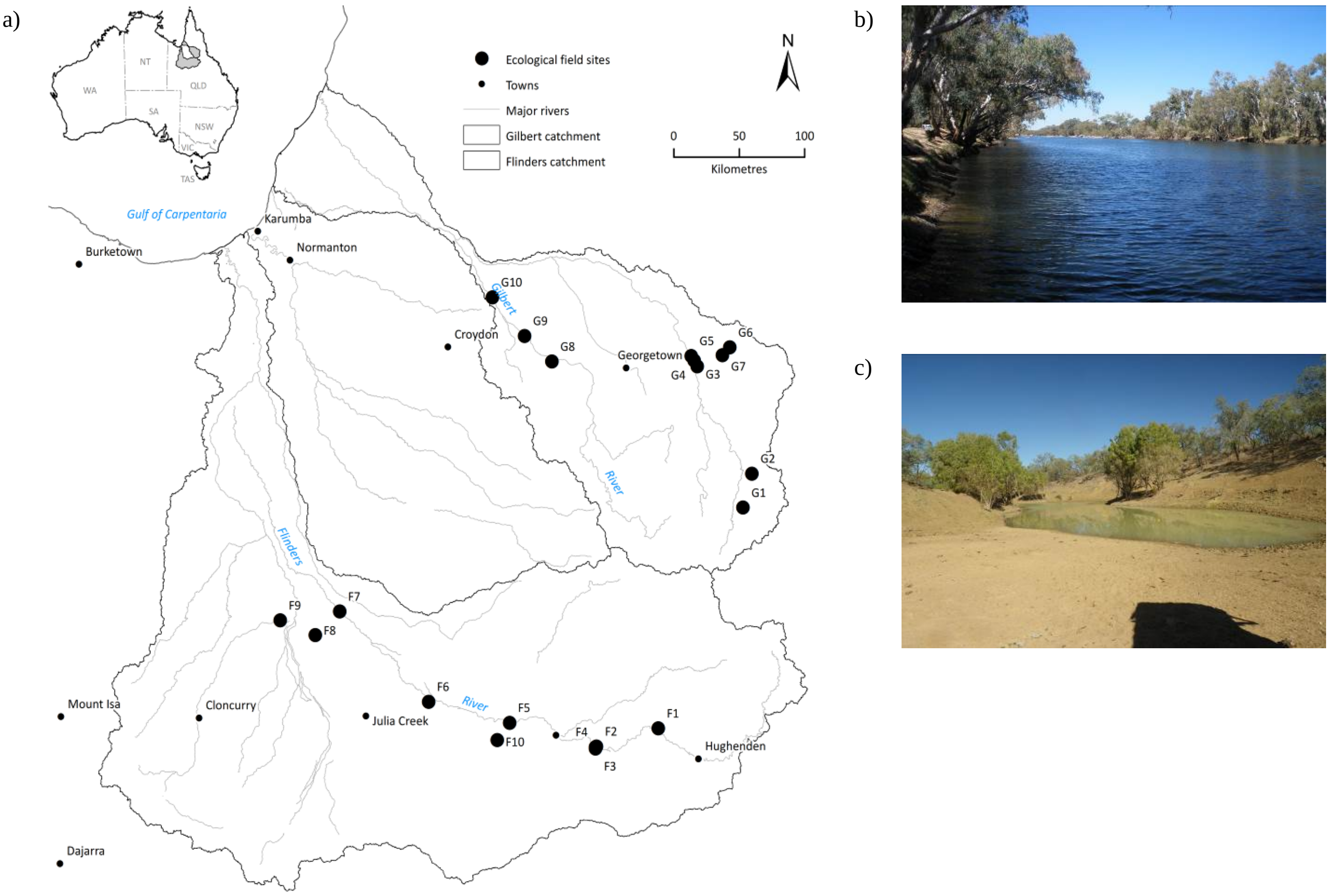

Figure 1. A) Location of waterholes investigated in the Flinders (F) and Gilbert (G) catchments; and example waterhole in b) Gilbert River (G05); and c) Flinders River catchment (F07).

Results

Summary of the key water quality findings during this investigation are provided below.

- Both catchments reported over 40 species of freshwater fish species, including declared vulnerable species such as the freshwater sawfish (*Pristis pristis*), and freshwater whipray (*Himantura dalyensis);*
- Waterholes in the Flinders catchment were more turbid than waterholes in the Gilbert catchment (Figure 2);
- The euphotic depth in Flinders catchment waterholes were low enough to support the hypothesis that most of the primary productivity occurs in the surface waters with little light and primary productivity occurring in benthic waters. Euphotic depth values in the Gilbert catchment waterholes generally exceeded the total water depth, suggesting that the light climate allows benthic primary production;
- Most waterholes in the Flinders catchment were thermally stratified, by several degrees celsius, due to the turbid surface waters retaining heat in the surface layer, compared to the Gilbert catchment waterholes which were well mixed (Figure 3);
- Diel dissolved oxygen cycling was prominent in all waterholes, with minimum concentrations falling to below 30% saturation on a number of occasions, particularly so in the stratified Flinders catchment waterholes where circulation was minimal. Following a small flow event, a single waterhole (F09) had dissolved oxygen concentrations that fell promptly to below conditions that would cause acute stress on fish and aquatic invertebrates: whether this same pattern occurs in other waterholes more broadly was not specifically able to be examined due to the low wet seasonal rainfall experienced;

- pH was quite high in most waterholes though this is likely in response to the time of day when profiling was completed. On several occasions the measured pH was approaching 9.0 which is the point where ammonia toxicity increases substantially;
- A significant proportion of nitrogen and phosphorus was in dissolved form which is typical for grazed catchments. The availability of dissolved nutrients, particularly in the Flinders catchment waterholes, allows for rapid uptake by primary producers; and
- Chlorophyll-*a* was higher in waterholes in the Flinders catchment than those in the Gilbert catchment. The small inflow in several sites was not large enough to flush waterholes, with concentrations increasing rapidly following flow. Lowest concentrations were recorded in waterholes with highest groundwater flow (i.e. Gilbert River sites; G06 and G07). A strong positive correlation was found between diel dissolved oxygen amplitude and chlorophyll-*a* indicating that much of the cycling is attributed exclusively to phytoplankton, at least under no flow conditions.

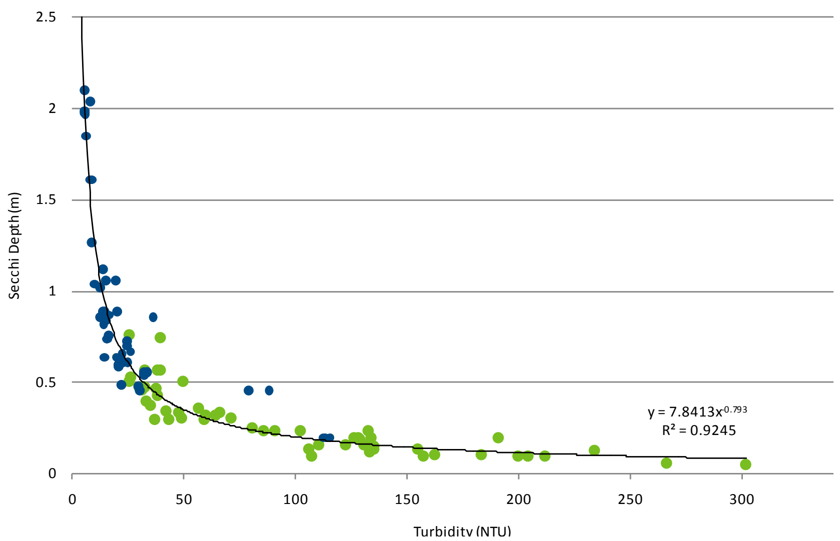

Figure 2. Relationship between turbidity (NTU) and secchi depth (m), by pooling all data across both catchments, is strong with a distinct separation of the two catchments along the relationship curve

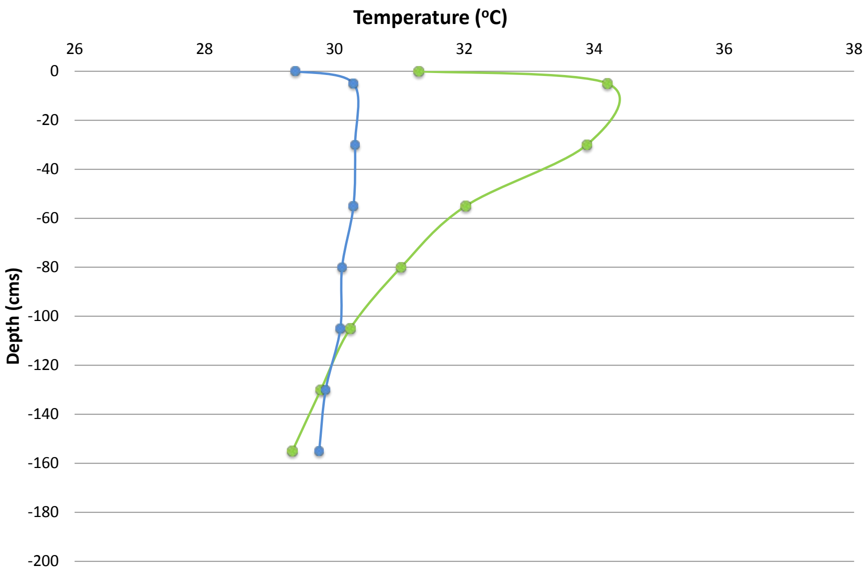

Figure 3. Gradients in river waterhole water temperature with depth at 15:00 in: a) the Flinders catchment waterhole F05 on 3 November 2012 (green line); and b) the Gilbert catchment waterhole G05 on 11 November 2012 (blue line)

Discussion

Water quality

The data here provides evidence that there was no stage during the 2012/13 hydrological year when water could be extracted from either river system without incurring significant risk of adverse impacts on the water quality and ecology of waterholes. Despite a small rain event occurring in part of the Gilbert catchment in December 2012, flow was not sufficient to replenish downstream waterholes, with water quality conditions (particularly dissolved oxygen) rapidly reaching critically low concentrations as flow ceased again.

Waterhole clarity appears to be a dominant driver separating the ecology and biotic community composition of waterholes between both catchments. At least one species; fly-specked hardyhead (*Craterocephalus stercusmuscarum*), known to rely on aquatic macrophytes for breeding, has historically been absent from studies in the Flinders River compared to the Gilbert River (see Waltham *et al.,* 2013). The phototrophic community is particularly vulnerable to changes in turbidity and light availability. Algae are known to drive primary production in many rivers and evidence from northern Australia suggests that benthic algae production provides an important source of energy to higher trophic groups (Jardine *et al.,* 2012; Warfe *et al.,* 2013). Waterholes that currently have relatively clear waters (e.g. Gilbert River catchment) are particularly vulnerable to changes in turbidity resulting from development as even minor variations will cause large changes in the depth of light penetration (Figure 2) and thus waterhole metabolism (production and consumption of oxygen) among many other effects. Conversely, in the turbid waterholes of the Flinders catchment, variations in turbidity will likely have little effect upon the depth of light penetration through the water column and the associated ecosystem processes that follow.

Water temperature

Waterhole temperature stratification was an important characteristic of waterholes in this study. The development of thermal stratification prevents circulation of the whole water body such that the bottom and surface layers may have very different water quality characteristics. Under these conditions, bottom waters, isolated from gas exchange contact with the atmosphere and often receiving less sunlight, are prone to becoming hypoxic. Stratification was most pronounced in the lentic waterholes of the Flinders catchment, where the turbidity retained heat within the surface layers, strengthening stratification. Several lentic waterholes in the Gilbert study area developed less severe temperature gradients because the water was clear enough to allow sunlight to penetrate deeper into the water column; nevertheless, most sites were still thermally stratified for significant periods during this study; with thermal frequency cures revealing that waterholes regularly exceeding critical threshold temperatures determined for fish (Burrows and Butler, 2009). In contrast, perennially flowing sites in the Gilbert River catchment (G06, G07) only became stratified for brief periods during daylight hours and the water column generally became mixed each night, indicating that there was sufficient flow to prevent the development of stable stratification. As a result of the overnight mixing of surface and bottom waters, and the increased aeration capacity provided by the flowing water, these waterholes maintained consistently higher dissolved oxygen concentrations than the lentic sites and accordingly were far less susceptible to the development of hypoxia-related problems.

Waterhole ecology

The biological implications for changes in waterhole persistence and habitat quality depend on numerous factors and it is difficult to predict the effect of altered conditions as it is contingent on the type of development and how it is operated, the nature of hydrological and limnological alterations, species composition and interactions (and their responses to the changes). However, reduced flushing and longer periods of stagnation in waterholes of the Assessment area, and associated deterioration in water quality are likely to have significant consequences for the health, growth and reproduction success of biota that use them. Reduced flow and longer periods between flows are also likely to change the spatial and temporal distribution of waterholes.

Coastal fisheries

Near shore regions and their fisheries are highly vulnerable to changes in freshwater flows to estuaries (Burford *et al.*, 2011). Reduced freshwater flows have implications for salinity gradients, nutrients and the physical characteristics of estuarine environments. The Gulf of Carpentaria prawn fishery is well known for the strong link between river flow and fishery production, with higher prawn landings following a high wet season flow (Staples and Vance, 1985). In fact, more recently this relationship has been successfully used to develop sophisticated modelling tools to determine the effort combinations of allowable prawn catch across the stock regions each year in an attempt to ensure ongoing sustainable management of this highly valued fishery (Buckworth *et al.,* 2013). The recruitment of other species including barramundi and king threadfin salmon have been linked to characteristics of wet season flows (Halliday *et al.,* 2008; Staunton-Smith *et al.,* 2004). The body of research from temperate and tropical estuaries clearly demonstrates that the positive relationship between river flow and fishery catches is a common theme and should be seriously considered when assessing the economic merits and environmental impacts of water resource developments.

Conclusions

Effective management and planning to assess the associated risks and minimise the ecological consequences of water resource development is essential. The list of potential environmental impacts is long, but the options for management to redress many of these also exist, if managers are willing to implement them. The importance of providing sufficient river flows alongside good land management practices (i.e. best practices) cannot be understated. It not only benefits river ecosystem health but also ensures longer term benefits of natural resources to human users.

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