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Artificial tidal lakes: Built for humans, home for fish

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ABSTRACT

The construction of artificial, residential waterways to increase the opportunities for coastal properties with waterfrontage is a common and widespread practice. We describe the fish community from the world's largest aggregation of artificial, estuarine lakes, the Burleigh Lake system that covers 280 ha on the Gold Coast in Queensland, Australia. Fish were collected from 30 sites in winter and spring of one year, and water salinity was measured 3-monthly for a 10 year period. Fish are not present in deep, bottom waters and the intensive sampling focussed on the shallow waters around lake margins. The fish fauna consisted of 33 species. All but three species are marine species that can tolerate some brackishness. The other three are freshwater species, normally found in rivers but also occurring in the upper reaches of estuaries. Fish communities differed among the lakes, reflecting a weak gradient in salinity in lakes at different distances from the single connection to the natural estuary and thus marine waters. Overall, the deeper (to 28 m), wider (700 m) characteristics of lake estates, and their incorporation of partial barriers to tidal exchange with natural reaches of estuaries, remove some of the hydrological concerns with very extensive canal estates. The shallow lake margins are habitat for a subset of fish species inhabiting adjacent natural wetlands. Where the lakes occupy space that was formerly land, this is novel habitat for fish. In place, however, where lakes have replaced natural wetlands, further comparisons of fish in lake and adjacent natural wetlands will be useful.

1. Introduction

To increase the extent of usable waterfrontage land in the coastal zone developers have been excavating large tracts of natural wetland (e.g. mangroves, saltmarsh) or digging out terrestrial habitat to create artificial, urban waterway developments (canal estates). A recent review highlighted the extent of canal proliferation for residential purposes (Waltham and Connolly, 2011). Globally, there are >4000 km of these created waterways (more than the length of the Mississippi River). They are particularly prevalent around the coast of North America, including Florida which has the largest single aggregation (1700 km), but now occur on every inhabited continent (Waltham and Connolly, 2011). They are an increasingly conspicuous component of our coastlines, and what are known as "transitional waters" (Elliott and Whitfield, 2011).

In Australia, construction of canals has proliferated since the first, built in 1956, with more and more canals joined directly to natural estuaries or to the end of existing artificial systems (Johnson and Williams, 1989). For example, artificial urban waterways on the Nerang River estuary in Queensland alone have increased the original linear length of the estuary from 20 km to over 150 km (Waltham and Connolly, 2011). One consequence of this ongoing construction activity has been major hydraulic and erosion problems to downstream residential properties and bridge foundations. In response, waterway property developers altered the engineering to lake developments by separating the new system from the downstream waterway via a tidal control device (e.g. locks, weirs, gates, pipes). The design shift has allowed property developments to extend even further landward with minimal consequences on the downstream tidal prism (Zigic et al., 2005). These urban lakes now occupy 1430 ha in Australia, and are also becoming a prominent feature of coastal developments elsewhere (Asia/Middle east 950 ha, North America 460 ha, Europe 138 ha). They now represent 5% of the total global extent of artificial urban waterways (Waltham and Connolly, 2011).

The engineering of these created waterways has taken two main designs: (1) open canal estates with direct tidal exchange with the downstream primary estuary, and (2) tidal lakes that are separated with the downstream estuary via a tidal control structure (e.g. weir, gate) (Waltham and Connolly, 2007). Despite these differences, both canals and lakes differ substantially from natural

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estuaries in that they generally lack aquatic vegetation (Connolly, 2003; Waltham and Connolly, 2006), have a depauperate benthic macroinvertebrate composition (Maxted et al., 1997), and have smooth, engineered, shorelines and unvegetated substrate (Morton, 1989). Water quality can be poor owing to the greater depth for navigation access, reduced circulation in highly ramified networks (many narrow branching arms) and high input loads of untreated urban stormwater (Maxted et al., 1997; Waltham, 2002). Preliminary evidence suggests that these impoverished conditions are more prevalent in lakes because of the imposed tidal restrictions compared to open, more connected canals (Waltham, 2002). We have previously shown that lakes support different fish assemblages than canals (Waltham and Connolly, 2007). The lakes surveyed in that study, however, were small (<5 ha) and generally well mixed, which prevented an adequate assessment of the factors underpinning fish distributions.

We surveyed the world's largest artificial, urban lake system (280 ha), the Burleigh Lakes system in southeast Queensland, Australia. The objectives were to: (1) describe the fish assemblage occupying the lake system; (2) examine the spatial arrangement of fish; and (3) determine whether the spatial pattern related to environmental factors considered important in natural estuaries. Our aims are to provide an overall description of fish assemblages occupying this increasingly prevalent form of built environment, and provide important data, where none currently exists, to assist managers balance engineering design with ecosystem function.

2. Methods

2.1. Study area

The Burleigh Lake system is located at the end of the Nerang River canal system (28.083883°S, 153.418017°E; Fig. 1). The system has been progressively extended over the past 35 years and now exists as a single system consisting of 8 interconnecting lakes joined by narrow canals but with tidal exchange limited by shallow sand or concrete sills. Initially the lake creation replaced estuarine wetlands, but subsequently they were extended into terrestrial habitat. A tidal weir separates the entire system from the downstream Nerang River canals. The weir consists of 4 concrete gates (each 3 m long × 2 m high) programmed to open and close, allowing tidal exchange; 6 h flood and 6 h ebb flow, over two cycles per day. The opening of the weir is calculated to be 2 h after the high and low tide recorded at the nearest passageway to the open ocean. The delayed opening minimizes tidal currents through the gates and therefore erosion and damage to the infrastructure (Zigic et al., 2005). The lakes all have homogeneous shorelines of sand/mud substrate devoid of macrophytes. Lakes have maximum depths between 7 and 28 m and widths from 100 to 700 m.

2.2. Fish survey

Fish were collected during the day in austral winter (July) and spring (October) of 2002, mid-way through the long-term water quality monitoring period, at 30 randomly chosen sites across the system. Each site was located at a different distance from the weir and measured using GIS software, taken as the shortest route by water. The intention was to examine fish abundance with environmental conditions at sites located at different distances from the weir (regression model), including dead-end lakes. Each site was also considered as a replicate within a lake (see Table 1 for number of samples per lake), and we could therefore analyze differences in fish assemblages among lakes (categorical). Initial sampling, using pop up ring nets and underway video cameras, in deep parts of lakes determined that no fish occurred on lake beds (Brickhill, 2009). We therefore subsequently limited fish surveys to the shallow margins of the lakes. Fish were caught, identified and counted using the pooled catch from two seine hauls per site (large seine: 70 × 4 m, 18 mm stretch mesh; small seine: 5 × 1 m, 1 mm stretch mesh). Fish data at nine of the sites (from Heron, Miami and Swan Lakes) were reported previously as part of a less intensive study comparing temporal differences among canals and lakes in southeast Queensland (Waltham and Connolly, 2007). At the same time, salinity, temperature, and dissolved oxygen (YSI 600) were measured at all sites immediately following fish sampling, 0.5 m below the surface. In natural estuaries, turbidity has been an important determinant of fish assemblages (e.g. Blaber and Blaber, 1980; Thiel et al., 1995), but it was low (2–25 NTU) here, and was therefore not considered further (Table 2).

Non-metric multidimensional scaling (NMDS) was used to ordinate lakes (Lake Orr and Silvabank Lake were removed from analysis because of too few data points) from biotic similarity matrices using the Bray–Curtis index, on 4th root transformed data. Fish assemblages were compared across lakes and season (both fixed) by PERMANOVA using the Bray–Curtis dissimilarity measure (Anderson, 2001). Similarity Percentages (SIMPER) identified which species contributed most to the difference (i.e. high mean/SD ratio; Clarke, 1993). BIOENV was used to assess relationships for single or combinations of environmental factors (recorded at the time of fish sampling) with the fish composition using the weighted Spearman coefficient (ρ_w) (Clarke and Ainsworth, 1993). Fish counts (for species observed at >5 sites), total abundance and species richness were $\log_{10}(x+1)$ transformed because examination of raw fish data and environmental factors using scatter plots revealed an over emphasis in the distribution of counts at some sites and not others. Following transformation, scatter plots of residuals against predicted values revealed no clear relationship, consistent with the assumption of linearity. Also, the normal plot of regression standardized residuals for fish counts indicated a relatively normal distribution, indicating that this transformation was a suitable model for the dataset. Seasons were analyzed separately. Distance from the tidal gate was excluded from analysis because it was collinear with salinity (winter $R^2 = 0.73$, $P = 0.001$; spring $R^2 = 0.53$, $P = 0.006$).

2.3. Long term water quality monitoring

Surface (0.5 m) water quality was measured for temperature, dissolved oxygen and salinity with a calibrated multiprobe (YSI 600) in 7 of the 9 lakes every 3 months for 10 years, May 1999 to November 2009, with sites located towards the centre of each lake (Fig. 1). These data are included here to provide context for the period in which fish were sampled.

3. Results

3.1. Fish species composition

In all, 10 686 fish were caught, about half at each season, comprising 33 species from 19 families (Table 1). All but three of the species are also recorded from adjacent, natural estuarine wetlands. Fourteen species of economic importance in the region accounted for 35% of the total catch. The five species contributing >5% of total combined catch by number were *Favonigobius exquisitus* (22%), *Gobiopterus semivestitus* (17%), *Herklotsichthys castelnaui* (14%), *Ambassis jacksoniensis* (11%) and *Pandaka lidwilli* (9%). The family Gobiidae dominated the catch, accounting for 73% and 38% in winter and spring respectively.