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Entrapment of an estuarine fish associated with a coastal surge barrier can increase the risk of mass mortalities

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ABSTRACT

Estuarine storm surge barriers are designed to prevent the flooding of human-developed landscapes. While such barriers may have a range of ecological impacts, including the fragmentation of aquatic habitats and the alteration of water quality, their impact on obligate estuarine fishes is largely unknown. The sparid, *Acanthopagrus butcheri*, was used as a model species to determine how surge barriers may influence the movements of solely estuarine species and fish kill events. Individual *A. butcheri* were monitored for one year using passive acoustic telemetry in the Vasse-Wonnerup Estuary (south-western Australia), in which fish kills occur regularly during summer and autumn. Hydrological data and surge barrier operational information were used to make inferences on the movements and habitat use of *A. butcheri*. Individuals were largely restricted to the waters downstream of the surge barriers. The fish tended to occupy deeper sites in proximity to complex structure with the distribution also influenced by changes in salinity during the spawning period. A strong seasonal trend existed in the daily distance travelled by the fish and this was positively associated with the annual flow period. The majority of fish that successfully passed upstream through one of the surge barriers did so through a fishgate that operated outside of the spawning period. All those fish were then likely trapped with no downstream fish passage occurring in summer and autumn at a time when water quality was characterised by low dissolved oxygen and cyanobacterial blooms. The surge barrier therefore acts as a seasonal trap and increases the risk of mass mortalities. Given a projected increased need to combat flooding and storm surges associated with climate change in low-lying coastal areas, the study highlights the necessity of ensuring that the life-cycles and movement requirements of estuarine fishes are considered in the design and operation of coastal flood mitigation structures.

1. Introduction

Estuaries and associated habitats including coastal deltas and tidal wetlands are of great ecological value (Hoellein et al., 2013; Sheaves et al., 2014; Tweedley et al., 2016a). Owing to their high productivity and location at the interface of freshwater and marine ecosystems, these systems are also often the centres of urban, industrial and agricultural development, which has resulted in estuaries being the most degraded of all marine ecosystems (Jackson et al., 2001; Gedan et al., 2009; Potter et al., 2015a). One of the major anthropogenic impacts on coastal and estuarine ecosystems has been the construction of flood mitigation barriers (or 'surge barriers') that can severely alter the hydrology (Lotze et al., 2006; Du et al., 2017) and may have wide-ranging ecological impacts (Pollard and Hannan, 1994; Poff et al., 1997; Lotze et al., 2006; Arthington, 2012; Boys et al., 2012).

Estuarine surge barriers prevent upstream inflow while enabling downstream movement of freshwater; thus mitigating the risk of flooding from tidal and storm surges. However, they are known to fragment and cause degradation of habitats (Pollard and Hannan, 1994), alter water quality (Gordon et al., 2015) and may impede the movement of aquatic fauna, which may reduce species diversity and abundance (Boys and Pease, 2017). Despite this, few studies have assessed the impact of estuarine barriers on non-diadromous estuarine fish species, such as how they may effect migration patterns or population viabilities. Such an understanding is particularly important for fishes that complete their life-cycle within estuaries and thus their populations are generally not able to be readily replenished from stocks outside of the estuary (Potter et al., 2015b).

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Microtidal estuaries (tidal range < 2 m) with highly seasonal freshwater discharge can have a long hydrological residence time (e.g. months to years; Tweedley et al., 2016a) in comparison to macrotidal systems. These characteristics make microtidal estuaries particularly susceptible to environmental perturbations, including toxic phytoplankton blooms and/or hypoxia (Tweedley et al., 2016b; Warwick et al., 2018). Microtidal estuaries thus represent ideal systems to model and investigate the effects of anthropogenic stressors on estuarine fishes (Tweedley et al., 2017b).

The sparid *Acanthopagrus butcheri* (Black Bream) is a solely estuarine species that attains a maximum total length (TL) of 600 mm and can live for up to 30 years (Morison et al., 1998). It is an important target for recreational anglers in the estuaries of southern Australia and, in some estuaries, also contributes to commercial fisheries (Jenkins et al., 2010; Smith et al., 2014). *Acanthopagrus butcheri* may be highly mobile, with some individuals recorded moving > 1000 cumulative km per year; regularly travelling the length of estuaries (Williams et al., 2017). However, the life-cycle is generally completed within its natal estuary, with individuals thus exposed to environmental perturbations within estuaries should they arise (Cottingham et al., 2014, 2016). *Acanthopagrus butcheri* is thus an appropriate model species to investigate how the movement and distribution of an obligate estuarine fish species may be impacted by surge barriers.

In recent decades, hypoxia and toxic algal bloom events have increased in estuaries in southern Australia due to eutrophication, reduced rainfall and the subsequent reduction in freshwater discharge (Valesini et al., 2017). These events often develop in the upper regions of estuaries during summer and autumn; directly overlapping with the known habitats of *A. butcheri* (Hoeksema et al., 2006; Hallett et al., 2016). The presence of anthropogenic barriers may prevent mobile species, such as *A. butcheri*, avoiding those adverse conditions. While there have been several acoustic tracking studies on this species to determine its habitat use (Hindell et al., 2008; Sakabe and Lyle, 2010; Williams et al., 2017), as with many other species globally, none of those have specifically examined how the presence of surge barriers may exacerbate the impacts of environmental degradation on the species.

Overall, this study aimed to determine the key environmental factors that explain the movement patterns and distribution of *A. butcheri* within the lower portions of the Vasse-Wonnerup Estuary system in south-western Australia. The study also aimed to determine the hydrological and barrier operational conditions that explain the patterns of passage of fish through the Vasse and Wonnerup surge barriers. It was hypothesised that the surge barriers prevented freedom of fish passage, which would, in turn, increase the species' exposure to localised declines in water quality and therefore its susceptibility to fish kill events.

2. Materials and methods

2.1. Study site

The Vasse-Wonnerup Estuary is a shallow, intermittently-open system located near the town of Busselton, Western Australia (Brearley, 2005) (Fig. 1). The estuary is Ramsar Convention listed for its value to migratory birds, however, the estuary and its catchment have been extensively modified by anthropogenic activities (Tweedley et al., 2017a; Hart, 2014). The system experiences periods of gross eutrophication (Brearley, 2005) and fish kill events have occurred regularly, with at least nine such events occurring between 1984 and 2013 (Lane et al., 1997; Hart, 2014). Anoxia, high water temperatures, hypersalinity, macroalgal blooms and/or toxic phytoplankton have all been considered the causes of these events (Lane et al., 1997; Hart, 2014).

Permanent surge barriers were installed in 2004 at the junctions of both the Vasse and Wonnerup estuaries and the Wonnerup Inlet (current structures are each of the same design) to prevent seawater intrusion (Figs. 1 and 2). Fish kill events over the past two decades have predominantly occurred within the proximity of the Vasse surge barrier (Fig. 1) and consisting of the deaths of up to ~40,000 individuals of *A. butcheri* along with the mugilids *Mugil cephalus* and *Aldrichetta forsteri* (Tweedley et al., 2014). The surge barriers allow one-way downstream movement of water during the peak winter-spring flow period. During summer and autumn, the surge barriers close and slot boards are installed that block the connection between the Wonnerup Inlet and the Vasse Estuary upstream (to maintain upstream water levels to ensure habitat for wading birds), however, a fish-passage chute (4 m × 0.4 m (L × W), hereafter referred to as the 'fishgate') can be opened to an adjustable height with the aim of enabling upstream and downstream fish movement through the structure (Fig. 2).

2.2. Receiver deployment and fish tagging

Nine VR2W (VEMCO) acoustic receivers (69 kHz) were deployed in March 2014; five within the Wonnerup Inlet (downstream of the Vasse and Wonnerup surge barriers), two upstream of the Vasse surge barrier and two upstream of the Wonnerup surge barrier (Fig. 1). Receivers were fastened to 10 mm diameter nylon rope and suspended below a 200 mm diameter styrene float that was attached to 4.5 kg galvanised sand anchors. Range testing for detections at receivers was performed using a V9-2L range test tag (transmitted an acoustic signal every 12 s) that was suspended in the middle of the water column at progressive distances of 25 m from each receiver (starting at 0 m), up to a maximum distance of 100 m for a period of 5 min. To elucidate the detection range of each receiver, a comparison was made between the actual and the expected number (i.e. 25 detections) of detections recorded at each progressive distance.

Forty-one *A. butcheri* were captured for internal acoustic and external T-bar tagging from the Wonnerup Inlet using a combination of rod and line and a 21 m seine net. Mean size of the fish implanted with V9-2L VEMCO acoustic transmitters was 291 mm TL (± 5.95 S.E., TL range = 250–393 mm). Acoustic transmitters (weight = 4.7 g) were programmed to transmit at a random interval of between 60 and 120 s (estimated tag life = 382 days). The mean and maximum transmitter weight to fish weight ratio was ~1.1% and 2.2%, respectively. Prior to tagging, *A. butcheri* were placed into an aerated 110 L insulated holding tank and anaesthetised by emersion in 3 mg/L AQUI-S® anaesthetic-estuary water solution and monitored until loss of movement and equilibrium was observed. Each fish was then inverted and placed into a sponge cradle with its gills being constantly irrigated with the AQUI-S® solution and a transmitter implanted by making an incision in the abdominal wall and inserting it into the peritoneal cavity. The incision was closed with a single suture (gluconate monofilament size 4/0) and swabbed with an antibiotic solution (Betadine®). An external T-bar tag (Hallprint Australia®) was placed laterally to the dorsal fin to enable identification and release of tagged fish captured by recreational fishers. Tagged fish were then placed in an aerated 110 L recovery tank and monitored until full equilibrium and normal behaviour was observed at which time they were released at the site of capture (generally within 10–15 min post-surgery).

2.3. Environmental variables

In order to determine the drivers of the spatial and temporal changes in the residency and movement patterns of *A. butcheri* throughout the Vasse-Wonnerup Estuary, a suite of environmental and physical variables were collected over the study period. The variables that were measured included the known physicochemical drivers of the movement and habitat use of this species, or those that could indirectly influence them. They included; day of experiment (for seasonality of life history), flow regime (and operational status of the surge barrier, see below), habitat complexity, salinity (conductivity), water