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Use of artificial habitats to detect spawning sites for the conservation of *Galaxias maculatus*, a riparian-spawning fish

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ABSTRACT

Galaxias maculatus is a diadromous riparian-spawning fish that supports an important fishery. Eggs develop terrestrially as with several other teleost fishes. Spawning habitat occurs in specific locations near rivermouths and its protection is a conservation priority. However, quantifying the areas involved is hampered by high egg mortality rates on degraded waterway margins. We hypothesised that temporary artificial habitat would detect spawning in these situations producing a useful indicator for riparian management. We installed arrays of straw bales as artificial habitat in two independent experiments over consecutive years and assessed their impact using pairwise Before-After-Control-Impact (BACI) experimental designs. We tested degraded gaps within the distribution of known spawning sites and also areas further upstream and downstream. Nine spawning occurrences were recorded on artificial habitats in 2015, 22 in 2016, and two on paired controls. Both experiments produced a significant effect for artificial habitats deployed in degraded gaps within the known spawning site distribution ($p = 0.0001$) providing evidence that these locations should be regarded as actual or potential spawning sites. In 2016 the technique also produced a significant effect downstream of known sites in one of the study catchments ($p = 0.0375$). We believe the use of artificial habitats as a detection tool could be useful in a variety of management contexts. These include identifying areas for protection, as confirmation of site suitability prior to making restoration investments, and in investigations to support the migration of habitats to new locations under climate change, since these may currently be degraded.

1. Introduction

Galaxias maculatus (Jenyns, 1842) is a diadromous fish species that is widely distributed in the Southern Hemisphere (Berra et al., 1996). The harvesting of juveniles during their upstream migration supports lucrative fisheries in several countries (Barbee et al., 2011). However, the species is in decline in New Zealand (Goodman et al., 2014) and South America (Encina-Montoya et al., 2011) prompting concern for the fishery and a range of conservation measures. A major contributing factor is the degradation of spawning habitat associated with land use change in lowland catchments (Hickford et al., 2010). Due to a specialised reproductive strategy the eggs develop in a terrestrial environment (McDowall and Charteris, 2006). This is associated with delayed hatching to coincide with favourable conditions for larval survival (Martin, 1999). Conversely, this increases vulnerability to anthropogenic threats (Hickford and Schiel, 2011a). Other examples of terrestrial egg development in teleost fishes include Mummichog (*Fundulus heteroclitus*), Diamond killifish (*Aidinia xenica*), California grunion (*Leuresthes tenuis*), Gulf grunion (*L. sardine*), and Giant kōkupu (*Galaxias argenteus*) (Franklin et al., 2015; Martin, 1999). Spawning occurs in riparian vegetation inundated during spring high tides and close to the upstream limit of salt water intrusion (Benzie, 1968). Spatiotemporal variance may result from interactions between salinity, water level, topography and the timing of fish movements and spawning events, making detection of the sites used more difficult (Orchard and Hickford, 2018a). This is a significant issue for management and is usually attempted by direct observations of adult fish during spawning events, or searches of riparian vegetation for eggs (Taylor, 2002). However, both of these approaches have conceptual and practical weaknesses.

For the detection of spawning sites, observations of adult fish have problems with precision unless spawning was actually observed. Adult *G. maculatus* spend several days shoaling in pre-spawning aggregations and devote considerable energy to searching riparian vegetation before selecting a spawning site (Benzie, 1968). There may be a large area in which an aggregation is observed prior to spawning that is relatively imprecise compared to the sites actually used. In comparison, direct searches for eggs provide indisputable evidence that spawning has

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occurred. However, egg mortality between the date of spawning and the field survey reduces the effectiveness of this approach. Recent research has found that spawning may occur irrespective of whether the habitat is favourable for egg survival (Hickford and Schiel, 2011a) and egg mortality can be extremely high (Hickford and Schiel, 2011b). This suggests that egg mortality is a major management issue rather than the absence of spawning *per se*, and the same issue makes the detection of spawning sites more difficult. Once dead, the tiny eggs (approximately 1.2 mm Ø) dehydrate and rapidly disappear (Harzmeyer, 2006). In degraded environments, surveys reliant on egg discovery may fail to detect spawning sites or underestimate the areas involved.

Further research has shown that artificial habitats such as installations of straw bales can provide favourable spawning sites and support high egg survival rates (Hickford and Schiel, 2013). We predicted that temporary installations of artificial habitats could also be used as a detection tool in degraded areas. In particular, we expected that experimental arrays might produce a useful indicator for management to help identify unknown spawning locations or establish the full extent of potential spawning habitat on degraded riparian margins. To test this, we hypothesised that artificial habitats would detect spawning at locations where eggs had not been detected in previous field surveys due to either the influence of egg mortality on survey findings or avoidance of those sites by adult fish, since it is difficult to distinguish directly between the two.

In addition, a test of this hypothesis needed to account for the inability to provide a true control – a conundrum that is typical of before-after experiments (Stewart-Oaten et al., 1986). To address this we assessed the effect of installing straw bales on riverbanks using replicate treatment-control pairs in a modified Before-After-Control-Impact (BACI) experimental design (Underwood, 1992). In this terminology, the experimental approach tests whether an intervention (e.g., the introduction of artificial habitats) has a statistically significant impact on a response variable of interest, such as the occurrence of eggs (Stewart-Oaten and Murtaugh, 2003). We also considered the application of artificial habitats to two different management questions: whether spawning could be detected at previously unrecorded but currently degraded locations within the distribution of known spawning sites, and whether spawning could also be detected outside of the distribution of known sites where these areas also happened to be degraded. We use the term 'spawning sites' to refer to the geospatial position of eggs in the environment. The term 'spawning habitat' refers to the locations and physical conditions that support spawning. In this paper our objectives are to i) demonstrate the use of artificial habitats to overcome egg detection issues at degraded locations, and ii) discuss applications of this approach to support conservation planning in the wider management context.

2. Materials and methods

2.1. Study areas and context

The study areas are located in the Avon-Heathcote Estuary/Ihutai catchment in the city of Christchurch on the east coast of New Zealand's South Island (Fig. 1). This is a barrier-enclosed tidal lagoon system associated with a dynamic sand spit at the southern end of Pegasus Bay (Kirk, 1979). The Avon and Heathcote rivers are spring-fed lowland waterways with average base flows of approximately 2 and 1 $m^3 s^{-1}$ respectively (White et al., 2007). Anzac Creek and an area of interconnected swamps and small lakes are tributaries of the Avon (Fig. 1). The total study area included a reach of 3.5 km in the Heathcote mainstem, 3.5 km in the Avon mainstem, and an additional 0.7 km in the Anzac sub-catchment (Fig. 1).

Although many aspects of the main waterways are similar (White et al., 2007), the Heathcote catchment is modified by a tidal barrage that limits the upstream progression of the tide (Christchurch City Council, 2016). In comparison to the Avon, this reduces salinity in the

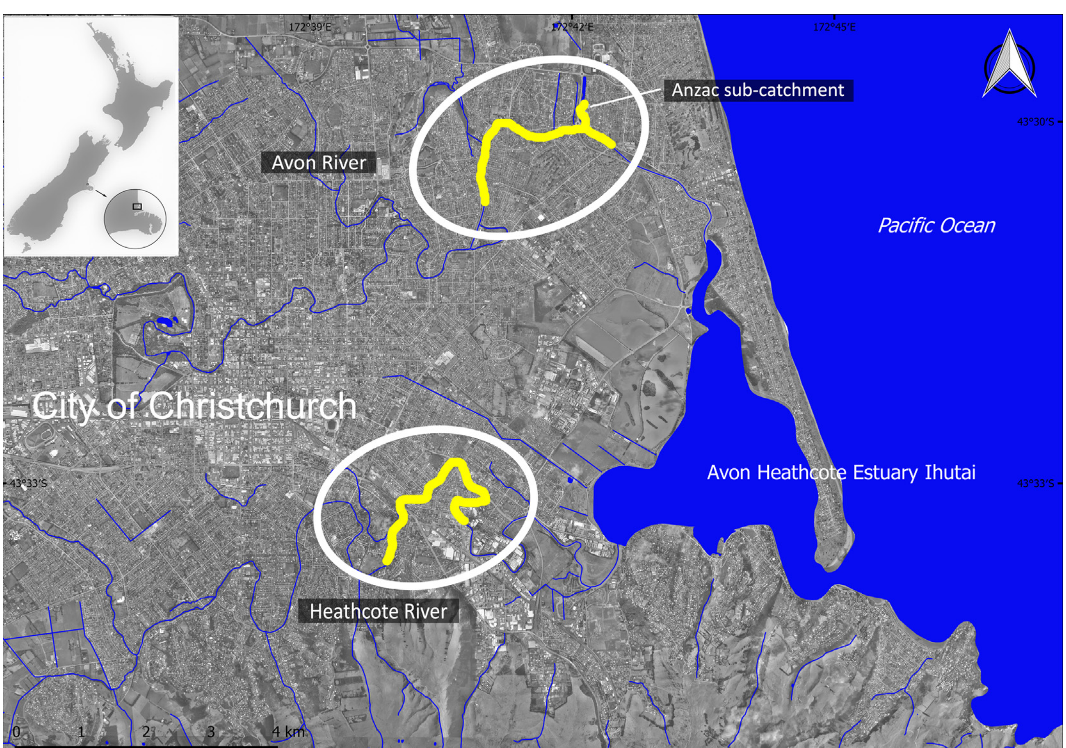

Fig. 1. Location of the city of Christchurch and Avon Heathcote Estuary/Ihutai on the east coast of the South Island, New Zealand, showing the study areas in the Avon and Heathcote River catchments. Yellow lines indicate reaches that were searched for *G. maculatus* spawning sites after the 2010–11 Canterbury earthquakes. The results of these surveys informed the artificial habitat experiment design. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)