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Assessing the impacts of reservoir expansion using a population model for a threatened riverine fish

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ABSTRACT

Increasing demand for water and a desire for greater human water security has facilitated the global expansion of dams, with river regulation acknowledged as the leading cause of biodiversity decline in rivers. Native biota within these stressed systems are also impacted by reductions in habitat availability, decreased hydraulic diversity, increased sedimentation, movement barriers, invasive species and altered flows that may profoundly change the character and functioning of rivers. Construction or enlargement of reservoirs is continuing, and whilst downstream impacts are often considered, upstream impacts receive far less attention. We develop a population model to examine the impacts of reservoir expansion on a threatened riverine species in South Eastern Australia: the two-spined blackfish. We examined two processes, loss of breeding habitat and increased predation, directly linked to reservoir expansion as well as a broader threat of recruitment failure due to sedimentation. These threatening processes were assessed using the expected minimum population size as an indicator of risk. As is often the case for threatened species, limited data were used to parameterise the model and sensitivity analysis performed to assess the appropriateness of the model parameterisation. The outcomes indicate that the two-spined blackfish population is vulnerable to the loss of breeding habitat particularly if two-spined blackfish are unable to spawn in the larger dam, although this vulnerability is ameliorated if the whole river is accounted for. Including possible impacts from the resident trout population for the whole river, indicates the two-spined blackfish to be vulnerable to low level predation particularly if the trout population have a high growth rate. Population modelling has rarely been used to predict the consequences of dam construction on aquatic species/communities. The example here shows it to be a powerful tool to visualise and quantify potential biodiversity outcomes.

1. Introduction

The global biodiversity crisis is most pronounced in freshwater ecosystems (Dudgeon et al., 2006; Vorosmarty et al., 2010). Freshwater ecosystems sustain a disproportionately high percentage of the Earth's biodiversity and have suffered comparatively greater declines in biodiversity than marine or terrestrial systems (McAllister et al., 1997; Johnson et al., 2008). Whilst riverine environments make up a small component of freshwater ecosystems (Groombridge and Jenkins, 1998), they are subjected to the cumulative deleterious impacts of anthropogenic stresses driven by flow regulation, habitat degradation, land clearing, invasive species and consumptive abstraction, where such stressors have contributed to a reduction in system dynamism, central to the conservation of native species diversity (Poff et al., 1997; WWF, 2004; Thieme et al., 2008; Solans and Poff, 2013). Increasing demand for water, electricity and a desire for greater human water security has facilitated the global expansion of dams, with river regulation acknowledged as the leading cause of biodiversity decline in rivers (Poff et al., 1997; Nilsson et al., 2005; Dudgeon et al., 2006; Lintermans, 2013a; Zarfl et al., 2015; Winemiller et al., 2016). Native biota within these stressed systems are further impacted by reductions in habitat availability, hydraulic diversity, sedimentation, movement barriers, invasive species and altered flows that may profoundly change the character and functioning of rivers (Kondolf, 1997; Dyer and Thoms, 2006; Agostinho et al., 2008; Davies et al., 2010).

Historically the downstream impacts of dams on aquatic biota have been studied, as these impacts can extend for 100 s of kilometres when natural flow regimes are altered (Power et al., 1996; Poff et al., 1997;

Abbreviations: EMPS, expected minimum population size; S.D., standard deviation; C.V., coefficient of variation

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Wohl, 2012). The upstream consequences can be equally severe, but often escape detailed scrutiny and are only just starting to be considered. Reservoir construction has been shown to eliminate lotic native fish both within and above the newly-impounded waters through loss of lotic habitat (Baxter, 1977) and through blocking migratory movements from downstream source populations, with such effects especially pronounced in catchments with intense reservoir development (Lintermans, 2013b ; Perekin et al., 2016). Reservoirs are increasingly recognised as altered environments that allow invasive species to establish and then facilitate upstream invasions (Clavero et al., 2004; Johnson et al., 2008).

A common approach to assessing impacts on the life history of a species is to construct a population model and quantify how and where the life history is affected (Todd et al., 2004, 2008). In addition, matrix population models allow the exploration of all vital rates important to the species persistence to help develop effective management strategies, in anticipation of system change, for the recovery of threatened species (Johnson et al., 2010). There are a number of examples where population modelling has included the impact of dams on population outcomes (Todd et al., 2005; Ahrens and Pine, 2014; Crimmins et al., 2015; Nieland et al., 2015). However, population models have rarely been used, if at all, to predict the consequences of dam construction on aquatic species/communities, but represents a powerful tool to visualise and quantify potential biodiversity outcomes (e.g. Todd et al., 2005; Nieland et al., 2015).

In the Australian Capital Territory (ACT), south-eastern Australia, human population growth projections led to a desire for increased security of water supply and seeking additional long-term reliable water sources for future consumptive needs. Consequently, the decision was made to enlarge the existing Cotter Reservoir from 4 to 78 GL in capacity (Fig. 1). The 20-fold increase in storage was achieved through the construction of a new 80 m high dam wall, completed in 2013. The new reservoir raised water levels by 50 m and inundated an additional 240 Ha (from 40 to 280 Ha) of land and 4.5 km of the Cotter River, following filling completion in 2016.

The Cotter Reservoir expansion created uncertainty for the long-term sustainability of a remnant population of the threatened two-spined blackfish (*Gadopsis bispinosus*). Two-spined blackfish persisted in the 28 km of river from the upstream extent of the existing Cotter Reservoir to the base of Bendora Reservoir. The species does not occur in the existing Cotter Reservoir as a result of historic sedimentation that has smothered suitable spawning habitats (Lintermans, 2012). The major threats to the two-spined blackfish population from reservoir expansion include a reduction in preferred lotic habitat for spawning and survival, increased deleterious impacts of sedimentation on spawning and feeding and increased competition and predation by alien brown trout (*Salmo trutta*) and rainbow trout (*Onchorynchus mykiss*) (Gunkel et al., 2003; Lintermans, 2012).

The importance of natural flows is central in shaping evolutionary and ecological processes in aquatic ecosystems and adaptations of resident biota, with homogenisation of these systems a threat to continental and regional biodiversity (Poff et al., 2007; Solans and Poff, 2013). Damming rivers has a pervasive and protracted impact on spatial and temporal flow dynamics and compromises biota through restricted access to resources and dispersal. Manipulation of flows in the Cotter River (predominantly via abstraction) has resulted in a 50–80% reduction in the mean daily flow below Bendora Dam (~23 km upstream of Cotter Reservoir), with a consequent decline in flood magnitude, a contraction of the active channel cross-sectional area and reduced frequency of flows required to initiate movement of the streambed surface sediments (Nichols et al., 2006). Lower discharge rates and reduced water velocity will likely lead to increasing sediment levels within the river. Sedimentation poses a substantial threat to two-spined blackfish populations through the smothering of eggs and spawning sites, and the loss of invertebrate food sources (Lintermans 1998, 2012). While sediment loads in the Cotter River downstream of Bendora Dam are generally low, episodic events such as bushfire may release vast quantities of sediment into the system (Nichols et al., 2006; Lyon and O'Connor, 2008). which may have a catastrophic impact on the localised two-spined blackfish community.

Inundation of terrestrial habitats by dams often results in a trophic upsurge as nutrients are released, stimulating plankton production and increasing productivity in the system (Gunkel et al., 2003; Lintermans, 2012; Todd and Lintermans, 2015). The upsurge in productivity within the Cotter Reservoir is predicted to benefit alien goldfish (*Carassius auratus*) populations within the reservoir, with an expansion in this prey item likely to facilitate trout growth rates and population expansion (Lintermans, 2012). In addition, the increased depth of the Cotter Reservoir may provide thermal refuge to trout during warmer summer months (Tate et al., 2007; Lintermans, 2012). Additional trout are known to negatively impact native northern hemisphere fish species via predation and/or the introduction of pathogens and have been strongly linked with the decline of many native Australian fish species (Crowl et al., 1992; Cadwallader, 1996; McDowall, 2006; Lintermans, 2013a). Competition for food resources likely exists between riverine adult two-spined blackfish and immature rainbow trout as both species prey heavily on terrestrial and aquatic insects (Lintermans, 1998).

Trout are opportunistic predators and usually select the largest and most readily available prey (Tilzey, 1977; Allan, 1978). Piscivory in trout increases with size, likely due to increased energy requirements and the need for more energy dense prey (Ebner et al., 2010; Mangel and Abrahams 2001; Jensen et al., 2012). Increased trout growth rates produce larger, better conditioned fish that during their annual spawning migration (April to July) are capable of predating on adult two-spined blackfish leading to a reduction in spawning individuals in a given year. Migrating trout may also consume young-of-the-year two-spined blackfish (bred in the previous November to December), thus inhibiting recruitment (Cadwallader, 1996; Lintermans, 1998; Ebner et al., 2007). Predator avoidance behaviour may also indirectly impact two-spined blackfish populations through reduced fish condition as a result of fewer encounters with prey, the ability to locate mates and decreased parental care of eggs and larvae. In addition to the impacts of trout, impacts within the enlarged reservoir inundation zone include increased sedimentation of previously lotic blackfish spawning habitats, decreased water quality during reservoir filling, altered fish community structure, and invasion or proliferation of alien species (Lintermans, 2012).

All size classes of two-spined blackfish are vulnerable to trout predation (M. Lintermans, unpubl. data). However, the nocturnal habits of two-spined blackfish and their cryptic, cover-oriented behaviour enables them to survive in the presence of trout in habitats with complex substrates. Recent severe bushfires in south-eastern Australia (2003–2006) however have resulted in significant sedimentation of many upland rivers (Lyon and OConnor, 2008; Peat et al., 2005; Worthy and Wasson, 2004) with large quantities of silt filling pools and the interstices between cobbles that two-spined blackfish normally use as a refuge from predatory trout species. This is likely to lead to increased levels of trout predation on two-spined blackfish, and reduced recruitment from degraded spawning sites.

We constructed an age-based stochastic population model for two-spined blackfish to examine the major impacts of reservoir expansion. Specifically, 3 likely stressors were modelled for their potential impacts on the two-spined blackfish population:

- what is the impact of loss of lotic habitat (from inundation);
- what is the impact of predicted increases in trout predation; and
- what is the impact of recruitment failure resulting from stochastic increases in sedimentation. The population outcomes of multiple impacts were also modelled. All threatening processes were assessed using the expected minimum population size as an indicator of risk using the species life history to guide the model development.