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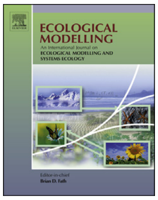

Who do you move? A stochastic population model to guide translocation strategies for an endangered freshwater fish in south-eastern Australia

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ABSTRACT

The number of threatened species continues to increase due to a range of anthropogenic disturbances, and many species continue to decline increasing their risk of extinction. Translocation is a widely used management technique to establish new populations to reduce the risk of extinction. There are, however, a range of issues to be considered. For example, for some species the donor population may be impacted by translocation, for other species it must be decided whether to translocate adults or juveniles to establish new populations. The question then becomes who do you move? The endangered Macquarie perch in south-eastern Australia is continuing to decline, with the recent Millennium Drought (1997–2010) and associated events (e.g., bushfires) contributing to dramatic local declines and the need for emergency responses. Successful historic translocations of this species involved adult fish, however the removal of significant numbers of adult fish may now impact source populations and alternative translocation approaches needed investigating. The use of sub-adult or juvenile fish, that would be expected to experience higher mortality, may be an approach to establishing new populations which would have less severe impacts on source populations. However, the number of fish required, frequency of translocation and likelihood of population establishment are unknown. This study outlines the development of a population model to assist in trialling translocation scenarios for establishing new populations of Macquarie perch. The model predicts that translocations of young-of-year fish (age 0+) is unlikely to be successful unless ~600 females are released annually for five years. If translocating yearling (age 1+) fish, annual translocations of >100 females is required to achieve success, with stocking for at least five consecutive years required. If the frequency of recruitment failure or magnitude of Allee effects increases, then translocations of increased numbers of yearlings or prolonged stocking (10 years) is required to achieve success. The addition of small numbers of adult fish in combination with yearlings decreases the number of yearlings required, and increases the chance of success under more stressful scenarios.

1. Introduction

We are currently in a biodiversity crisis and globally the number of threatened species continues to grow through anthropogenic impacts (Gaston, 2005; Hoffmann et al., 2010). The translocation of animals to establish new populations or reinforce existing populations is often performed as part of recovery activities for threatened species (IUCN/SSC, 2013; Koehn et al., 2013; Lintermans, 2013b; Lintermans et al., 2015); to mitigate catastrophic events (e.g., Hammer et al., 2013; Ellis et al., 2013; Lintermans, 2013a); or manage genetic impacts of small population size (Weeks et al., 2011). In recent decades, reintroductions have been increasingly used across all vertebrate groups as a major tool in the restoration and management of threatened species (Griffith et al., 1989; Minckley, 1995; Fischer and Lindenmayer, 2000; Seddon et al., 2007). There are two major sources of animals used for reintroductions; captive-bred and translocated wild individuals. While the potential limitations of captive-bred stock are well documented (e.g., restricted genetic diversity, behavioural deficits see Philippart, 1995; Brown and Laland, 2001; Jule et al., 2008), an advantage is that for highly fecund groups such as some fishes, large numbers of individuals may be available for reintroductions. In contrast,

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reintroduction efforts based on wild-caught animals are often hampered by low availability of individuals. Furthermore, the impacts on the donor population of harvesting individuals for reintroductions elsewhere are a significant consideration (e.g., Saltz, 1998; Todd et al., 2002; Dimond and Armstrong, 2007). The question of who do you move when there is limited donor fish available is an important issue for translocation programs, and is one of the 10 key questions for reintroduction biology (Armstrong and Seddon, 2008). One way of minimising impacts on donor populations, and maximising the number of individuals available for reintroductions is to use juveniles. For fish, large numbers of offspring may be produced annually, with most not expected to survive (King et al., 2013). In freshwater environments, relatively large numbers of juveniles can often be readily collected and transported to release sites but natural mortality would still be expected to be high. Consequently the trade-offs between increased mortality, increased availability and impacts on donor populations need to be considered.

Natural populations live in environments that are continuously changing. In the management of wildlife it is not possible to predict the exact consequences of management options for any population, and for threatened species it is usually not prudent to do post hoc impact analysis. Often the best that can be done is to estimate the likelihood of particular outcomes based on observed variation in the past and any mechanistic understanding of the processes that control change in the population (Burgman and Lindenmayer, 1998). Stochastic population models are useful tools for assessing the conservation status, and the ranking of management options for rare and/or endangered species, particularly in circumstances of incomplete data or lack of full ecological knowledge, and for guiding future research (Burgman et al., 1993; Burgman and Possingham, 2000; Todd et al., 2002, 2005, 2008; Koehn and Todd, 2012). The development of models for species reintroductions (including translocations) is recommended by IUCN/SSC (2013): “Information from the candidate or closely-related species can be used to construct models of alternative translocation scenarios and outcomes”.

1.1. *Study species*

Macquarie perch, *Macquaria australasica*, is a moderately-sized deep-bodied percichthyid of south-eastern Australia, attaining a maximum weight of 3.5 kg and 550 mm total length (TL) (Lintermans, 2007; Lintermans and Ebner, 2010). Macquarie perch has two morphologically distinct and geographically disjunct forms which are likely to be separate taxa (Faulks et al., 2010), with both forms listed as endangered under both national and state legislation and the Murray–Darling (western) taxon undergoing significant declines in the last 50 years (Lintermans, 2007). Major causes of decline include habitat loss and alteration, the impacts of alien species, and coldwater pollution (Koehn et al., 1995; Lintermans, 2012; ACT Government, 2007). During the recent Millennium Drought in Australia (1997–2010), several populations were severely impacted or extirpated (Lintermans et al., 2014) and the species is now restricted to a handful of populations in its native range, plus three populations outside its natural range as a result of historic translocations (Cadwallader, 1981; Lintermans, 2007, 2013b).

Continuing to simply manage existing populations is unlikely to result in recovery of the species, and the establishment of additional populations is a key recovery activity (ACT Government, 2007; Lintermans, 2012). Captive breeding of the species has proven problematic, with hatchery programs for the species discontinued in the 1990s (Gray et al., 2000; Ho and Ingram, 2012). Translocation is a viable alternative to hatchery production with historical translocations successful in establishing populations in several waterways in both Victoria (Yarra River, Seven Creeks) and New South Wales (Cataract Dam, Mongarlowe River, Queanbeyan River) (Cadwallader, 1981; Ho and Ingram, 2012, Lintermans, 2008, Lintermans et al., 2015).

The Cotter River system in the Australian Capital Territory (ACT) contains a significant population of Murray–Darling (western) taxon of Macquarie perch, with the Cotter Reservoir containing the last viable population of this species in the ACT where fish larger than 400 mm TL are rare. Cotter Reservoir has recently been enlarged with the new reservoir to be 50 m deeper and inundate an additional 4.5 km of river when at full supply level (Lintermans, 2012). As part of the mitigation actions for the enlargement of Cotter Reservoir a translocation program for Macquarie perch commenced with a view to establishing additional populations outside of the lower Cotter River catchment (Lintermans, 2012). The adult population size in the reservoir was suspected of being small, with subsequent estimates of mean effective population size ranging from 22 to 65 fish (Farrington et al., 2014). Consequently, the translocation program is structured around using juvenile fish, to minimise potential adverse effects on the adult donor population. The translocation program may be enhanced if a trophic upsurge were to occur as a result of enlarging the Cotter Dam and there may be an increase in the number of adults available for translocation (Lintermans, 2012). Macquarie perch can form significant populations in impoundments, but are truly a riverine fish that can only breed in flowing waters (Cadwallader and Rogan, 1977; Lintermans, 2007; Tonkin et al., 2014).

In this study, we develop an age-structured stochastic population model to examine translocation strategies of different age classes, the effects of under-population (Allee effects), the contribution of females to population growth, and frequency of recruitment failure on population persistence to develop strategies to establish new populations for the conservation management of Macquarie perch in the ACT.

2. Methods

2.1. *Model structure for Macquarie perch based on life history analysis*

Macquarie perch have an estimated life span of at least 25 years (Lintermans and Ebner, 2010; Tonkin et al., 2014), grow rapidly in the first few years of life and approach maximum size of around 420–450 mm after about 10 years, with a maximum recorded size of 550 mm (Lintermans and Ebner, 2010). Age at sexual maturity is thought to be 3–4 years for females and 2–3 years for males (Koehn and O’Connor, 1990; Lintermans, 2007). Macquarie perch are considered highly fecund although information on fecundity is quite variable with reports of 30,000 to 110,000 eggs per kg of fish (Koehn and O’Connor, 1990), and this most likely varies with both age/size relationship as well as fish condition. Macquarie perch lay demersal, adhesive eggs in pools that drift in to riffle areas to take hold on the gravel/rock substrates (Koehn and O’Connor, 1990; Lintermans, 2007; Tonkin et al., 2010). The eggs begin to hatch around ten days after spawning; however, in lower temperatures eggs may take longer to hatch, up to 18 days (Koehn and O’Connor, 1990). Macquarie perch larvae are well developed upon hatching and have the capacity to move almost immediately after hatching (Koehn and O’Connor, 1990). Macquarie perch have four identifiable life stages (eggs; larvae; juveniles and adults) and reach the juvenile stage within the first year of life (known as young-of-year, YOY) (Fig. 1).

Transforming the stage-based life history in to an age-based life history allows an age-based model to be constructed for Macquarie perch (Fig. 1). Having an age-based model fits more easily in to management time scales (annual time steps) and is analytically