USING A POPULATION MODEL TO HELP MANAGE FLOWS AND CARP

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Environmental water allocation is considered an essential management tool for the rehabilitation of aquatic environments within the Murray-Darling Basin (MDB). Carp are a widespread and abundant alien pest fish species whose populations may expand rapidly following flooding. Hence, there is concern that environmental watering may lead to increases in Carp populations. This paper illustrates the utility of a carp population model to investigate carp population dynamics under a range of flow scenarios, with case studies presented for four habitat types in the lower MDB 1) terminal lakes, 2) floodplain redgum forest, 3) complex river channel system and 4) artificial floodplain inundation using a regulator. These case studies highlight the unique nature of outcomes, depending on site, time, location and management/flow regime. Recommendations from this work include ensuring that: environmental flow objectives for native biota remain paramount; carp are managed as a coincident risk in conjunction with water management; carp management plans are developed and implemented for each carp 'hotspot' and major watering site; and there is monitoring of the response of carp populations.

1 INTRODUCTION

Environmental flows are considered an essential management tool for the rehabilitation of aquatic environments [1], especially within the Murray-Darling Basin (MDB) in south-eastern Australia [2]. For the MDB, these will be largely delivered through implementation of The Basin Plan [3], which provides water allocations to restore wetland and river health. The primary ecological objectives of these allocations are related to achieving positive environmental outcomes for native biota (including fish) and the ecological processes that support their populations. There has also been an increase in the construction and use of regulators to inundate floodplains [3, 4] which pose considerable risks,, including potential for increased production of Carp *Cyprinus carpio* [5, 6].

Carp are a world-wide, pervasive alien fish species that has successfully invaded most of the MDB (1 million km^2) in less than 50 years [7] and is managed as a pest species [8]. Carp are highly visible, widespread and abundant, with many biological attributes (e.g. high fecundities and rates of movement) that allow their populations to expand rapidly. Given that Carp spawning and recruitment can be enhanced by flooding (especially onto floodplains), some types of environmental water management options may contribute to an increase in numbers. Any population responses would be intrinsically linked to their existing abundances, which are often much higher than those of current native fish populations. Given the poor public perception of Carp in Australia, this may be seen as an undesirable outcome relating to the use of environmental water.

This provides inherent challenges when managing flows to benefit native biotas as there may also be some unavoidable benefits to Carp. For example, the Carp spawning season (water temperatures >16°C) generally overlaps considerably with many native fish species and can also coincide with the timing of other watering requirements (e.g. watering for vegetation). Ecological objectives of environmental watering are based on the benefits for native species (fish, vegetation and birds), and the priority must remain for these to be maximized, but while simultaneously minimizing opportunities for Carp. One tool that can assist the flow management process is modelling, in particular the modelling of fish populations. The development of a Carp population model [9] allows a range of flow management scenarios to be compared against modelled population responses. The exploration of potential outcomes allows for comparison of different likely outcomes. These can then be used to inform decisions within risk management frameworks. This paper illustrates the utility of a carp population model to investigate carp population dynamics under a range of common flow scenarios, using four site-specific case studies. We then provide key recommendations for management.

2 METHODS

The population model was constructed utilizing expert workshops to collate the latest ecological knowledge on Carp, with modelling undertaken within a stochastic framework where flow data related to access by Carp to different habitat types at each defined life stage [see 9]. Access to these different habitats is likely to provide different population responses. For, example, while Carp are able to spawn in the river channel, larval survival and recruitment are likely to be much lower than under flooded conditions. As there are a wide range of sites and scenarios that involve the management of flows and Carp, these often become complicated and need to be modelled on an individual basis, with a need to consider local hydrology (flow volume, wetland inundation levels, height to fill thresholds, flow connections, etc.) and how Carp life stages are affected by them. Modelling of case studies, particularly priority areas/habitats in the southern MDB, demonstrates the applicability of the model with site-scale detail and to illustrate model outputs. We considered four case studies as representative examples of particular habitat types and common environmental watering scenarios: Lower Murray River downstream of Lock 1 (river and terminal lakes); Edward-Wakool river system (complex river channel system); Chowilla floodplain (artificial inundation); and the Barmah-Millewa floodplain (River Redgum forest).

3 RESULTS

The case studies modelled highlighted the unique nature of outcomes, depending on site, time, location and management/flow regime; all providing different management recommendations.

3.1 Lower Murray downstream of Lock 1

The lower Murray case study includes the Lower terminal Lakes (Albert and Alexandrina), the lower wetlands (which are mostly inundated on a long-term basis), and the Murray River to Lock 1. This case study considers five habitat types: river channel with: base flow; ephemeral wetland; permanently connected wetland; natural floodplain inundation; and terminal lakes. Population modelling outputs show a system dominated by the dynamics of Carp in the Lower Lakes with all scenarios indicating the rapid development of a large lakes population. This population has sufficient breeding fish to have few limits on population growth. This population also produces large numbers of Carp available for dispersal to other parts of the river system as exhibited by congregations of Carp at Lock 1.

Key management outcome: The Lower Lakes remains a significant source Carp population regardless of flow; hence any environmental flows provided will have little impact.

3.2 Edward-Wakool River System

The Edward-Wakool River System provides a good example of a complicated water management site. It consists of a mosaic of rivers, wetlands and floodplains. Flows are supplemented by water from a number of secondary sources and the region is criss-crossed with a range of ephemeral creeks. This case study considered three habitat types: in-channel cover of benches; summer irrigation flows; and natural floodplain inundation. Historical flow sequences provided a broad spectrum of flow conditions (i.e. wetter and dryer periods) and were used to examine the response of Carp populations. Three scenarios were considered: 1) Wakool only; 2) Edward only; and 3) Edward and Wakool combined. In scenario 3 Carp can move freely within the system and Carp from the Wakool can access the floodplain in the Werai Forest. Modelling indicates that even moderate flows that inundate the Werai Forest will maintain Carp populations in the Edward-Wakool system.

Key management outcome: Any flooding of the Werai Forest is likely to increase Carp populations in the Edward-Wakool River System and any use of the Edward River for ‘down the river’ water transfers is likely to contribute to a higher Carp population in this system.

3.3 Chowilla

Chowilla is a large River Red Gum and Black Box floodplain in the lower Murray River where engineered artificial floodplain inundation is proposed using a regulator. The Chowilla case study is a simplified study of two habitat types: within channel flows and floodplain inundation through natural or artificial means. Artificial inundation or natural inundation of the Chowilla floodplain will similarly result in a large number of Carp being available for dispersal. The modelled inundations from the proposed regulator operational strategy shows large increases in the number of Carp available for export into the Murray River. If Carp access the Chowilla floodplain through the operation of the Chowilla regulator there will be significant recruitment and large numbers of Carp available for dispersal in 3 out of 5 years.

Key management outcome: Water managers have high levels of control over regulator operations and ultimately artificial floodplain inundation should be carefully considered, with frequent events minimized.

3.4 Barmah-Millewa floodplain

Barmah–Millewa (BM) Forest in the mid-Murray River has a large, complex floodplain wetland system that includes Barmah and Moria Lakes, which are used by Carp in the mid–upper Murray River as a preferred spawning site. Three habitat types were modelled: summer irrigation flow; river wetland; and natural floodplain inundation. The Carp population in the BM region maintains itself when only the summer irrigation flows are considered. When Carp have access to either Barmah–Moira Lakes (river wetland), or the BM floodplain, the average adult population size increases and the number of Carp available for dispersal significantly increases. The exploration of these scenarios indicates that interaction between the BM floodplain and Barmah–Moira Lakes makes managing Carp in the region very difficult. While it may be possible to limit access to Barmah–Moira Lakes, it would be nearly impossible to limit access to the broader BM floodplain. The outcomes from modelling this complex system indicate the BM floodplain and Barmah–Moira Lakes are capable of producing very large numbers of Carp for dispersal to other areas of the MDB. Annual irrigation flows that provide access to the adjacent wetlands may also be artificially supporting higher Carp numbers.

Key management outcome: Limiting access to Barmah–Moira Lakes during irrigation will help contain Carp numbers in years outside of natural floodplain access. When Carp have access to a natural floodplain or a river wetland, the population response can be large and provide large numbers of Carp for dispersal.

4 DISCUSSION

Environmental water management is a relatively new science and water managers and scientists are all continuing to learn and build knowledge from environmental watering applications and scenarios. This study illustrates the utility of a population model to estimate changes to Carp populations from a range of flow scenarios, including environmental water management. Such tools can greatly assist management by allowing exploration of the relative outcomes of various options. Current knowledge indicates that planning for environmental flow and Carp management is best conducted over longer time frames (e.g. 10 years), which can easily be accommodated with the use of modelling.

Modelling also indicates that the greatest responses by Carp populations are likely to relate to floodplain inundation (natural flooding and inundations using regulators), which results in a spike in Carp populations. While some scenarios such as natural flooding are infrequent and in most cases managers have little control over them, managed scenarios such as the use of regulators to artificially inundate floodplains allow high levels of control. The sequencing of managed floodplain inundations is also important, especially given the relatively short time for Carp to reach sexual maturity (2-3 years), and that abundance in Carp populations can be greatly increased by frequent, sequential floodplain inundation. The proposed high frequency use of floodplain regulators clearly poses the greatest risk of increasing Carp populations. Inundation of ephemeral and regulated wetlands, wetlands that adjoin weir pools and terminal and off-channel lakes also promote high population growth rates. The impact of changes to Carp populations on the river meta-population will depend on the return of newly recruited Carp from these off-channel habitats, and Carp populations are likely to increase even more if these additions are cumulative; either from multiple sites or across consecutive years.

Potential increases in carp populations can be viewed as an inherent risk of environmental water management. Becoming too risk averse to Carp responses, however, is likely to diminish desired outcomes. Prioritizing benefits and hydrological scenarios for native fish provides more beneficial ecological outcomes than simply managing flows to disadvantage Carp. Hence, Carp management should be a secondary objective in most instances and any potential increases in Carp must be balanced against other environmental benefits.

The need to manage the risk of an increase in Carp populations highlights the necessity to develop and implement adequate Carp management plans for all high risk sites. Regional level plans and management should consider local attributes such as: hydrology; flow volume; wetland inundation levels; height to fill thresholds; flow (and fish) connections; and how Carp life history and developmental stages (eggs, larvae, fry, fingerlings, etc.) are affected by them. While Carp management plans are required at a site scale, these could be assisted by an overarching MDB Carp management plan, better collaboration between water and Carp managers, and a clarification of agency responsibilities in relation to Carp management. There is also a need to quantify benefits of Carp management actions as this has largely been missing from Carp management to date and clearly defined management goals (e.g. aquatic plant values) are a key to this evaluation.

4.1 Key messages

Workshop discussions during model development and the modelling of generic flow scenarios allowed for general management recommendations, with more detailed, site-specific recommendations from the case studies.

1. The priority objectives for environmental water to benefit native biotas in the MDB must be maintained.
2. Carp are in high abundances and can readily respond to flows, especially overbank flooding. The potential season for Carp overlaps with that of many native fishes and also with likely watering times for other biotas.
3. There is a need to evaluate the benefits of flow management actions to native species so that these can be balanced against any unintended benefits for Carp.
4. Natural flooding also promotes Carp population growth but managers have little control over these flows.
5. Carp are now a major component of MDB fish fauna. In-channel environmental flows will have minimal impacts on Carp populations, and existing large Carp populations in the Lower Lakes of the Murray River mean that environmental flows will have limited additional impacts on Carp numbers in that location.
6. Artificial floodplain inundations using regulators are likely to pose substantial risks to increasing Carp populations and may export Carp to the river meta-population. Frequent, sequential inundations of the floodplain and the cumulative impacts from multiple large-scale sites constitute the greatest risk to increased Carp populations. Nevertheless, water managers have high levels of control over this type of management action and hence have the ability to manage such inundations carefully.
7. Watering for biotic outcomes other than fish could be considered during winter (water temperatures < 16ºC) to minimise Carp recruitment. This may, however, mean compromised outcomes for native fish.
8. There is a need for Carp to be managed in conjunction with watering through the development and implementation of adequate Carp management plans for all high risk watering activities and sites.
9. In order to quantify the responses of Carp to flows and to manage populations, monitoring is needed.

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