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How do low magnitudes of hydrologic alteration impact riverine fish populations and assemblage characteristics?

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ABSTRACT

Water managers need quantitative information on the effects of hydrologic alteration on aquatic biota to guide ecologically sensitive water management strategies such as water releases from dams. A key gap in the global research literature is determining whether low levels of hydrologic alteration have significant effects on fish populations and assemblage characteristics. This study quantified patterns of fish response to flow regime alteration in a sub-tropical region where many rivers have regulated flow regimes but 57% of ecologically relevant flow metrics have changed by <20%. We tested for flow regulation effects on 17 (univariate and multivariate) response variables representing fish population abundance and assemblage characteristics using a field design based on the environmental flow assessment framework known as ELOHA (Ecological Limits of Hydrologic Alteration). Ecological response variables that are readily quantified and sensitive to variation and alteration in flow regimes are critical to the application of environmental flow frameworks such as ELOHA. In this study only three of 17 response variables representing fish population abundance and assemblage attributes showed significant differences between regulated and unregulated reaches (densities of both *Pseudomugil signifier* and *Melanotaenia duboulayi*, and fish assemblage composition). Effects associated with flow regulation were most evident where historically intermittent flow regimes have become more perennial as a consequence of managed water releases from dams. Our study provides positive evidence that dams and regulated flow regimes can be managed with sensitivity such that there are few significant changes in populations of most fish species, and little change in fish assemblage characteristics. However, it must be cautioned that the magnitude of flow regime alteration may interact with the duration of exposure (i.e. years to decades) such that other ecological impacts emerge over time as species and assemblages adjust to altered flow regimes.

1. Introduction

Human impacts on river flow regimes alter the magnitude, timing, frequency, duration and variability of flow events, with the specific changes depending on the nature and magnitude of flow regime manipulation (Poff et al., 1997; Magilligan and Nislow, 2005). Such changes to the natural flow regime contribute to altered habitat structure, impacts on life history processes, growth and ecosystem production, and the facilitation of non-native biota; these impacts contribute to changes in aquatic biodiversity (Bunn and Arthington, 2002; Naiman et al., 2008; Strayer, 2010). Different aquatic biota, such as fish, macroinvertebrates and riparian vegetation, respond in different ways to flow regime alteration, however fish have been identified as the only taxonomic group that consistently responds negatively (in terms of population abundance, demographics and species composition) to flow magnitude change (Poff and Zimmerman, 2010). Identifying the characteristics of the relationships between the flow regime and ecological patterns and processes is necessary to determine levels or thresholds where flow alteration is associated with ecological change (sensu Underwood et al., 2000; Downes, 2010). If clear relationships between types and degrees of flow alteration and ecological response can be found, then this information can make a significant contribution to defining environmental flow rules such as water releases from dams and/or appropriate levels of water extraction.

Knowledge of the environmental flow requirements of aquatic species and biological assemblages is derived from a range of approaches that relate flow regime alterations to ecological responses (Tharme, 2003; Acreman and Dunbar, 2004). The Ecological Limits of Hydrologic Alteration (ELOHA) framework is based on grouping (i.e. classifying) rivers at regional scales based on variation in flow regimes, and then testing for differences in ecological responses to flow regime alterations within those classes to produce flow alteration–ecological response relationships for each flow class (Poff et al., 2010). In theory, flow regime classes identified by classification may be regarded as management units that

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share ecological attributes and therefore could be managed in similar ways with regard to the design and allocation of environmental flows (Arthington et al., 2006; Kennard et al., 2010). However, for the ELOHA approach to be useful in the development of environmental flow rules/regimes, it is necessary to identify ecological variables that are both readily quantified and reflect population and assemblage level responses to different types of flow alteration.

Ecological evidence indicates that the effects of flow regime alteration on freshwater fish occur as a sequence of processes that are dependent on the magnitude and/or duration of exposure to flow alterations (Table 1). For example, lower population size in regulated versus unregulated (or less regulated) rivers (stage 1 in the sequence) has been attributed to the effect of flow regime alteration on population recruitment by modifying environmental conditions such as prey and habitat (e.g. Freeman et al., 2001; Humphries et al., 2002). Increasing flow regime change expressed as monthly and annual flow deviations from natural conditions has been associated with increasing abundance of non-native common carp, *Cyprinus carpio* (stage 2), and declining richness of native fish species in the Murray-Darling Basin, Australia, thereby altering fish assemblage composition (stage 3) (Gehrke et al., 1995). Reduced stream flow variability as a consequence of regulation has been linked with species extinction resulting in lower species diversity (stage 4, Table 1), and this is particularly evident for fish species with preferences for specific hydraulic habitats such as shallow, fast-velocity riffles (e.g. Meador and Carlisle, 2012). These examples provide evidence of patterns in fish populations and assemblage structure that reflect the effects of flow regime alteration on a sequence of ecological processes.

Many environmental flow methods are based on the idea/assumption that the magnitude of ecological response to flow regulation is proportional to the magnitude of hydrologic alteration from pre-impact conditions. Evidence from studies in rivers with high levels of flow regime change support this prediction. For example, measures of fish abundance, demographic parameters and diversity decrease by at least 50% in response to both decreased (−50% to −100%) and increased (+50% to 100%) flow magnitude (Poff and Zimmerman, 2010). Likewise it might be expected that if hydrologic alterations are kept to low levels there will be very small or no detectable ecological impact. Unfortunately, the lack of published ecological response data for low to moderate levels of hydrologic alteration leaves a gap in understanding of potential subtle impacts of flow regime change on fish populations and assemblages (Poff and Zimmerman, 2010). This knowledge gap is important from a management perspective, for example, in defining thresholds of ecological response to assist in establishing limits to water abstraction, or setting particular release volumes from dams.

This study was designed to quantify the effects of relatively low levels of hydrologic alteration on fish population size and assemblage characteristics within an ELOHA framework. Firstly, we tested for differences in fish response variables between currently regulated and unregulated (i.e. sampling control, sensu Downes, 2010) reaches in rivers of different natural (pre-development) flow regime type (i.e. reference flow classes). By testing for ecological differences between regulated versus unregulated reference reaches, we can test the hypothesis that flow regulation initiates the impact sequence described above (Table 1), and determine if such ecological changes differ across a range of reference flow regime classes. Secondly, we applied a modified survey design that tested for differences in fish response variables across flow regime classes that incorporate different types and magnitudes of flow alteration based on recent gauged flow records (i.e. current flow classes), thereby testing the hypothesis that fish respond to hydrologic differences and regime shifts brought about by water release patterns from dams. By testing for differences using two different experimental designs we can strengthen our inference of relationships between the magnitude and type of flow regime alteration and associated ecological changes in rivers of contrasting hydrological character.

2. Methods

2.1. Study area and flow regimes

This study was conducted between the South Coast and Mary River catchments of South East Queensland (SEQ), Australia (see Arthington et al., 2012). Briefly, the climate is subtropical and influenced by both tropical and temperate weather patterns. Rainfall predominantly occurs during the summer period of December–March, and has a distinct increasing gradient from west to east (inland to the coast) of 800–1400 mm average per annum. SEQ is inhabited by ~2.8 million people, predominantly in the Gold Coast, Brisbane and the Sunshine Coast regions.

Rivers in the study region generally have late summer–early autumn high discharge regimes, with periods of low discharge occurring from August to November (Pusey et al., 2004). However, temperate weather systems that produce winter rain in southern Australia may also produce significant rainfall in the study area from autumn to mid-winter. As the occurrence and intensity of summer and autumn–winter rainfall is irregular, discharge regimes of rivers and streams in the region vary considerably. The flow regimes of many rivers have been altered by the construction and operation of dams and weirs, unsupplemented extraction (extraction of water from natural river flows, as opposed to supplemented extraction, where explicit releases are made from storages for extraction downstream), inter- and intra-basin water transfers, and land use changes. Twenty-four dams >15 m wall height now exist in SEQ, with total storage capacity of 38% of the total natural mean annual runoff for the study region.

Two regional hydrological classifications have been undertaken to explore patterns of flow regime variability and the effects of flow regulation in the study area (Arthington et al., 2012; Mackay et al., in press). Each classification was based on 35 minimally redundant hydrologic metrics describing the major facets of the natural flow regime (magnitude, frequency, timing and duration of discharge events, and discharge variability/predictability; sensu Poff et al., 1997). The metrics analysed are known to be ecologically relevant, sensitive to hydrologic alterations due to human activities, and potentially amenable to management through ecologically sensitive dam operations and water abstraction rules. The purpose of undertaking a classification based on modelled pre-development flow data (i.e. the reference classification) was to represent variation in flow regimes under near natural conditions (i.e. without the effect of human alterations to hydrology caused by stream flow manipulation, extraction and land use change). The aim of undertaking a separate classification based on gauged flow records (i.e. current conditions) was to quantify differences in flow regimes that incorporate the influence of human alterations. Classification was undertaken using model-based hierarchical agglomerative clustering based on Gaussian finite mixture models, as implemented in the Mclust package for R (Fraley and Raftery, 2008; R Core Development Team, 2010). Cluster analysis distinguished six reference classes (based on modelled pre-development flow data) and five current classes based on stream gauge data (Table 2). The sixth reference flow class was removed from further analysis because it contained very few replicate river reaches. Specific details of the methods and results of the flow classifications are presented in Arthington et al. (2012), Mackay et al. (in press) and Supplementary material S1. Briefly, six flow metrics discriminated between reference flow classes (mean annual 1-day minimum, mean annual