METHODS

The current study is an extension of a previous larger study (Arthington *et al.* 2012) conducted to test the ELoHA framework (Poff *et al.* 2010), and to determine hydro-ecological relationships to inform environmental flow management in south-east Queensland. Field data was collected between 2008 – 2010; the trait dataset was assembled and analyses described here were performed in 2015. The report describing the original study provides extensive detail not included here (Arthington *et al.* 2012). Except where specified, all statistical analyses were performed using the R statistical programming environment (R Core Team 2013)

*Study area*

The study was conducted across seven catchments within coastal south-east Queensland, Australia. Sites were located between X and X degrees latitude and X and X degrees longitude (Table S1). The dominant land-use in the region is agriculture, with approximately 40 % of the area under grazing, and 4 % used for cropping. Urbanisation is also extensive, particularly along the coast. Native vegetation within conservation estate or state forest comprises 20 % of the study area, and additional native vegetation remnants are common in steep terrain. This study area has a subtropical climate, and is influenced by both tropical and temperate weather patterns. Little variation in temperature is present throughout the region, but a considerable longitudinal rainfall gradient exists: mean annual rainfall ranges from 800 mm in the west to 1400 mm in the eastern coastal catchments. The majority of rainfall is associated with summer thunderstorms between January and March, although southerly weather systems during autumn and winter are also responsible for a substantial amount of precipitation. Precipitation patterns are associated with high year-on-year variability, and river discharge regimes in the region are typically unpredictable, with high coefficients of variation in mean daily flow. This said, substantial hydrological variability is represented across coastal south-east Queensland. Four of the twelve hydrological classes identified on the Australian continent by Kennard et al. (2010) are present in the area: perennial, stable baseflow; perennial, unpredictable baseflow; intermittent, unpredictable; and highly intermittent, unpredictable summer dominated. Something about soils? Topography?

River flow regimes throughout the study region are modified by dams, weirs, intra- and inter-basin water transfer, and unsupplemented water extraction. The majority of the dams were constructed by the mid 1970s and have a maximum capacity of less than 50,000 ML. Two substantially larger dams (Wivenhoe Dam – 1,150,000 ML and Hinze Dam – 165,000 ML) in the area were constructed during the 1980s. Mackay *et al.* (2014) compared historic daily discharge data with modelled predevelopment discharge data and found that flow modification by structures and diversions in south-east Queensland is diverse and system specific. Reduced flow variability is prevalent, and while increased perenniality in drier systems and altered low spell duration are also common, few other generalisations can be made about the effects of regulation on streamflows in the region (Mackay *et al.* 2014).

*Site selection and vegetation sampling*

Riparian vegetation was surveyed between August and October in 2008, 2009 and 2010 at 44 sites. Twenty two river reaches were selected to sample the range of flow regime classes determined by a regional classification of flow regimes (see Mackay et al., 2014). Proximity to flow monitoring gauges with an associated recording history of >25 years was of primary importance. Duplicate surveys were made along each river reach as close as possible to the flow monitoring station, but separated by at least 2 km to ensure independence. Sampling sites required 100 continuous metres of relatively intact riparian vegetation, which was not subjected to regular burning and had not been cleared in at least 20 – 30 years. Ideally sites were not currently grazed, although this restriction was relaxed somewhat given the extensive pastoral land use throughout the region.

Three transects were randomly placed at each site, running perpendicular to the river. Additional transects were conducted at three sites (27, 31, 44), where low vegetation densities occurred. Transects extended from the water’s edge to the macrochannel bank, or a maximum of 50 m from the water’s edge. A standard sampling area was not used due to variability in vegetation structure, channel landforms and adjacent land uses. Site sampling areas were typically greater than 400 m2 (following Walker and Hopkins (1984), but ranged from 260 – 1013 m2. All trees, shrubs, ferns rushes, and sedges within a 5 m band centred on the transect line were identified and counted. Species identifications were confirmed by the Queensland Herbarium.

*Describing stream hydrology and quantifying flow regulation*

Daily discharge data for each reach were obtained from Queensland DERM (). Thirty five year time series spanning 1975 – 2009 were obtained where possible. Missing data were infilled using the Timer Series Manager module in River Analysis Package (Marsh, Stewardson & Kennard 2003), using linear interpolation for periods less than 15 days, or multiple regression using data from adjacent stream gauges. One site (Reynolds Creek) had substantial periods of missing data which could not be infilled by multiple regression, as the flow at this gauge is altered by Moogerah Dam. The record for this site was truncated to exclude the periods where data was missing. The shortest remaining period (34 days) was infilled by linear interpolation. Flow data for Obi Obi Creek at Kidaman (138104a) was obtained from Water Quality Accounting (Queensland DERM) as modelled gauge data derived from a calibration model for the Mary River catchment.

River Analysis Package was used to generate a set of X ecologically relevant hydrological metrics for each site, describing XXXXX. Table X provides definitions of these metrics and describes their ecological importance. As a number of these metrics exhibited collinearity, we have included a principal components analysis of this data in the Supporting Information (X). Metrics of flow magnitude which had units ML / day were standardised by mean daily flow to allow for comparison between different river cha­­nnel sizes. These metrics therefore represent ratios of flow magnitude to mean daily flow.

The extent of flow regulation at a given gauge site was characterised by the percentage deviation of each metric from the same metric generated using modelled pre-development flow data. These modelled pre-development daily discharge data were obtained using a generic integrated water quantity and quality simulation model (IQQM) developed for the region (Simons, Podger & Cooke 1996). IQQM data were available only for the period up to 1999, so data from the timeframe 1975-1999 were used for comparison.

*Other environmental variables*

Data on upstream land use were obtained via the Queensland Land Use Mapping Program (QLUMP) and dataset (Witte et al. 2006). This data was generated from surveys conducted in 1999 and 2006. Land use was categorised according to the Australian Land use and Management Classification version 6 (), which differentiates conservation and low impact land uses from intensive land uses. Percentages of upstream land use were calculated as: production from relatively natural environments (forestry, grazing natural vegetation), dryland agriculture and plantations (e.g. cropping, horticulture, grazing pasture), irrigated agriculture (e.g. irrigated cropping, horticulture), conservation and natural environments (e.g. national park) and intensive uses (e.g. residential and industrial uses). We then used inverse distance weighting to weight each land use according to its proximity to the stream, following Petersen et al. (2010).

Climate data were obtained from eMast/TERN, at a resolution of 0.01 degrees (Hutchinson, Kesteven & Tingbao 2014). Bioclimatic variables representing annual trends, seasonality and extremes were calculated following the BIOCLIM framework (Busby 1991). Soil data were taken from the CSIRO Soil and Landscape Grid of Australia, at a resolution of 3 arc seconds (~ 3 m) (Rossel *et al.* 2014 a b c d e f g h i j k; Wilford *et al.* 2014). Summary statistics for land use, climate and soil datasets are shown in the *Supporting Information (S1)*.

*Trait selection and dataset asssembly*

We assembled a dataset of functional traits (growth form, specific leaf area, leaf area, maximum canopy height, seed mass, wood density and flowering duration) with which to calculate functional diversity. These traits collectively integrate key trade-offs associated with ecological strategies of riparian plants (functional responses), as well as flow on effects of species on ecosystem functioning (functional effects).

Table X provides further description of the utility of each of these traits in describing the functional ecology of riparian vegetation communities.   
Data was taken from published literature, private and published trait datasets, and Australian flora texts. Where multiple records for a trait were found, values were removed if they were measured at sites with an environment substantially different from south east Queensland. With the exception of maximum height, for which the highest value was used, the remaining values were averaged to provide a single value for each species-trait combination. Not all species-trait combinations could be assigned data, so to reduce biases associated with analyses of incomplete trait datasets (Penone *et al.* 2014), only species with fewer than 3 missing trait values were retained for the analysis. The remaining missing values were imputed using a non-parametric random forests approach (missForest package for R, Stekhoven & Buhlmann, 2012). DATA DENSITY SUMMARY?? See Supporting Information SX for a full bibliography, data density information and imputation details.

|  |  |  |  |
| --- | --- | --- | --- |
| Trait | Definition | Functional responses & inherent trade-offs | Functional effects |
| Growth form | Categorical description of morphology: tree, shrub, woody climber, herbaceous climber, graminoid, herb | Differential responses to mechanical and biochemical stresses associated caused by flooding; different strategies for coping with drought and heat stress. | Differential biogeomorphic effects on fluvial landform cohesion and sediment deposition. |
| Specific leaf area (SLA) | Ratio of one-sided leaf area to oven dry mass (cm2 / g). | SLA is associated with leaf construction cost, photosynthetic rate and carbon : nitrogen economics. Indicator of ecological strategy under favourable vs. stressful conditions. | Affects ecosystem productivity and nutrient recycling. |
| Leaf area | One-sided leaf area (cm2) | Shade tolerance (larger leaves) vs. evaporative cooling ability in hot, dry conditions (smaller leaves). | May influence flow resistance of vegetation (and therefore fluvial erosion / deposition) when inundated. |
| Maximum canopy height | Height above ground of apical meristem (m). | Affects ability to tolerate mechanical disturbances such as flooding and maintain xylem integrity in dry conditions. | Determines coarse physical structure of plant community. Surrogate for competitive ability: taller plants receive more light but must construct and maintain support structures. |
| Seed mass | Combined mass of the seed coat, endosperm and embryo (g). Excludes dispersal structures. | Larger seed mass confers ability to establish in unfavourable conditions. Also related to seed buoyancy. | Seeds may be an important food source for animals. |
| Wood density | Oven dry mass divided by green volume (g/cm3) | Dense wood tissue confers mechanical strength, but is energetically expensive to construct. Wood density influences ability to tolerate drought stress and disturbance (Telewski 1995; Preston, Cornwell & Denoyer 2006; Lawson *et al*. 2015). | Regulates decomposition rate; this affects nutrient cycling and determines the residency time of woody debris in the fluvial system. |
| Flowering period length | Proportion of the year spent in flower (proportion, dimensionless) | Indicates species’ ability to respond reproductively to favourable conditions. | Flowers may be an important food source for animals. |

*Calculating functional diversity, species richness and proportional abundance of exotics*

We calculated abundance weighted functional richness, divergence and evenness of vegetation communities at each site, using the FD package for R (Laliberté & Legendre 2010). Gower’s method, which scales traits by their range, was used to generate the required dissimilarity matrix, and Cailliez’s correction was applied to render the matrix euclidean.

Where required, trait values were normalised by either log10 (SLA, seed mass) or square root (leaf area, flowering duration, maximum height) transformation prior to analysis. Wood density was not transformed. Summary statistics and correlation analysis of the trait dataset are available in the *Supporting Information* *(S2)*.

Species richness values were standardised by sampling area to account for differences in sampling effort. Abundance of exotic species was calculated as the number of exotic individuals divided by the total number of individuals counted at each site.

*Constructing variance partitioning models*

We used a variance partitioning approach to assess the individual contributions of river flow regime, flow modification, land use, climate and edaphic conditions to modelling variation in riparian plant species richness, functional diversity and exotic abundance. Exotic proportional abundance was also included as an explanatory variable for species richness and functional diversity metrics.

The following process was used to derive an optimal set of environment-diversity models for variance partitioning analysis (Legendre 2007):

1. We first generated minimal ordinary least-squares regression models for each set of environmental variables (i.e. descriptors of flow regime, flow modification, land use etc.).
2. For each dependent variable, the full set of explanatory variables was reduced to the subset which had statistically significant (p < 0.05) linear or quadratic relationships. Second order AIC was used to determine whether the linear or quadratic term better explained variation in the dependent variable (MuMIn package for R, Barton, 2012; Burnham & Anderson 2002).
3. For each set of environmental variables, variance explained by these univariate models was partitioned by partial regression using the *varpart* function in R (vegan package, Oksanen *et al.* 2013). Optimal multiple regression models were derived from the combinations of variables associated with the highest adjusted R2 values (Peres-Neto *et al.* 2006).
4. These multiple regression models were fed into a second variance partitioning analysis, and adjusted R2 was used to estimate the proportion of variation jointly and independently explained by each environmental model.

While we acknowledge that interactions between environmental conditions may be important drivers of diversity and exotic invasion, we did not attempt here to describe the multiplicity of plausible interactions between variables.

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