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ANALYSING THE EFFECT OF ENVIRONMENTAL AND HYDROLOGICAL VARIABILITY ON FISH GROWTH RATES IN QUEENSLAND'S DRYLAND RIVERS

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# Abstract

TBA (to update as research progresses)

# Introduction

The complex interplay between spatial and temporal variability in physicochemical properties of the environment, and their influence on growth of various marine species has been the subject of extensive research (Canosa & Bertucci, 2023; Jobling, 2002). Concurrently, the growing evidence of shifting thermal and precipitation regimes, along with the intensification of extreme climate and weather events, (IPCC, 2022; Saintilan et al., 2013; Vousdoukas et al., 2018; Westra et al., 2014; S. Zhou et al., 2019), suggests increased potential for disruptions in ecosystem functions that are strongly linked to growth, such as spawning (Steel et al., 2019), nutrient cycling (D’Odorico et al., 2003) and overall ecosystem productivity (Gampe et al., 2021; Woodward et al., 2016). In lotic habitats such as dryland river systems, these influences are compounded by inherent environmental variability in key abiotic parameters such as turbidity, substrate composition, temperature and most notably, hydrology (Lapointe et al., 2014; Maestre et al., 2012). The distinctive hydrological characteristics of dryland rivers create cyclic conditions of “booms” in productivity due, in part, to episodic floods, followed by “bust” periods after the waters recede, leaving behind perennial and semi-perennial waterholes. During drought periods, these waterholes serve as refuges for many aquatic species (Arthington & Balcombe, 2011; Sheldon et al., 2010). Most of these dryland riverine ecosystems experience long periods of low to no-flow (Douglas et al., 2005; Kennard et al., 2010; Morón & Amos, 2018), and remain as disconnected refuges for most of the year, with some persisting over several years with no surface flow (Bunn, Balcombe, et al., 2006; Bunn, Thoms, et al., 2006). Though the term ‘refuge’ here is used to denote “places (or times) where the negative effects of disturbance are lower than in the surrounding area (or time)” (Lancaster & Belyea, 1997; Sheldon et al., 2010), the isolated, relatively small and densely populated nature of such refuges can introduce novel stressors and intensify existing ones. For instance, research conducted on similar remote habitats suggest that food web interactions, including predator prey interactions are heightened during such cases (Gido et al., 2015; Jackson et al., 2001; Magoulick & Kobza, 2003), particularly where species are present in high densities. These impacts have also been documented across a host of other biotic processes and interactions, such as predator-prey interactions, exposure to disease and parasites, competition, and migration. Sudden and often severe changes in these processes have been associated with fish mortality in such dryland refuges (S. R. Balcombe et al., 2005; Magoulick & Kobza, 2003; Turschwell et al., 2019; Wager & Unmack, 2000). Furthermore, the size and nature of such water bodies can also play a critical role in exacerbating abiotic stressors; the biogeographically insular nature of the refuges themselves can alter much of the physicochemical and biological properties of the habitat (Magoulick & Kobza, 2003). For example, not only are smaller water bodies known exhibit a higher degree of temporal variation in oxygen and temperature (Jackson et al., 2001), the increased evaporation and low-flow associated with such water bodies can cause increased sedimentation, salinity and turbidity (Pettit et al., 2012; Wager & Unmack, 2000), all of which can potentially contribute to low growth and survival.

Despite their highly variable hydrology and the consequential, often harsh, conditions, these are critically important and highly biodiverse ecosystems that have shaped (Macklin & Lewin, 2015; Moggridge & Thompson, 2021) and continue to shape not just land-use, sustenance, and livelihoods, but also the cultural values and heritage of the surrounding communities (Anderson et al., 2019). Furthermore, the ecosystem processes of these habitats are greatly influenced by this variability; from dispersal regimes (Petty & Grossman, 2004), to spawning (Franssen et al., 2007), to primary production (Stephen R. Balcombe et al., 2015). Hence, investigating the survival, growth, and reproductive success of different species within these habitats is paramount to understanding their response to the frequency and intensity of such disturbance events.

Approximate 83% of all 3.5 million kilometres of Australian low land rivers (when mapped at a scale of 1:250,000) have been classified as dryland rivers; that is to say, they are primarily found in arid to semi-arid regions (Sheldon et al., 2010; Thoms & Sheldon, 2000). The Murray-Darling Basin alone, where this research project is centred, supports agricultural production valued at AUD 30 billion per year (Murray–Darling Basin Authority, 2023). Given the high economic and ecological significance of these habitats, research on non-perennial and semi-perennial rivers in Australia has spanned a vast array of topics, demonstrating clear trends in evolving research focus over the past several decades (Shanafield et al., 2024). Much of the work focusses on the role of waterholes as refuges, and how various aspects of fluvial geomorphology contribute to their suitability as such. This includes research into factors that contribute to their persistence, such as groundwater discharge (Bourke et al., 2023; Davis et al., 2021), bank return flow (Rhodes et al., 2017; Z. Zhou & Cartwright, 2021) and drainage and evaporation rates (Brunner et al., 2009; Hamilton et al., 2005). Many papers also report on the response of various species to the hydrological and environmental variability, including the effect of these extreme conditions on various biological processes, such as migration (Marshall et al., 2016), dispersal regimes (Chester et al., 2015; Faulks et al., 2010; Razeng et al., 2017), reproduction and fecundity (Mooij et al., 2002). Works focussing on factors affecting growth of species in dryland river systems includes research on the interactions between growth and extreme high temperatures (Wallace et al., 2015), as well as comparative inter-species and inter-site analyses (Koehn, 2004; Mallen‐Cooper & Stuart, 2003). Reviews focussed on the Murray-Darling Basin note that much of the data requires updating and highlight the need for further research into factors that affect fish growth (Koehn et al., 2019, 2020). Amid this broad spectrum of research, this project aims to add to the current repository of knowledge by deepening our understanding of the impact of various environmental and hydrological factors on, growth rate of three species across 11 sites in rivers in the Northern Murray-Darling Basin; golden perch (*Macquaria ambigua*), Bony bream (*Nematalosa erebi*) and Common carp (*Cyprinus carpio*). This research not only models the impact of multiple environmental predictor variables on the growth rates of fish species, but also includes both native and non-native species, thus offering a robust dataset for comparative analysis, providing valuable insights into how different species respond to similar environmental pressures in dryland river systems.

Given the complex nature of interactions between environmental factors and species growth that are expected, reliable and quantifiable methods of measuring growth is required. Especially since monitoring growth and movement in fish populations can be particularly challenging when the species in question exhibit migratory behaviour (ref). Sclerochronological studies, which analyse incremental marks on calcified structures, are one method utilised to address this issue. In particular, otolith (ear bone) growth rings are widely researched and recognised as effective proxies for tracking fish growth, as well as the impact of pertinent environmental parameters such as temperature (Dunlop et al., 2023; Gillanders et al., 2012; Martino et al., 2019; Morrongiello et al., 2019). As such, otolith biochronology is used in this project as a proxy measure for examining the impact of various hydrological and environmental factors and their spatiotemporal variability, on incremental growth rates in the aforementioned three species. The data was obtained from a Power BI Solution database which was developed through a collaboration between La Trobe University and the Department of Environment and Science (DES), Queensland.

# Methods and Approach

## 2.1 Data Sources

A range of ecological and environmental datasets will be utilised for this project, including data on otolith-derived incremental growth rates, from age 1 to age 2 for the three fish species, river flow metrics, and annual average temperature readings. These datasets will be accessed and extracted via a Power BI Solution developed by La Trobe University, with input from the Department of Environment and Science (DES), Queensland. The streamflow data and temperature data contained therein will be sourced from stream gauges installed within the study area. The raw datasets will be collated and organized via R, to create a consolidated dataset that will be used for subsequent data analysis.

## 2.2 Predictor Variables

The primary focus of the analysis will be to evaluate the impact of various environmental and hydrological factors on the annual growth rates (via otolith growth rings) of three lotic fish species. The predictor variables, derived from the data sourced through the Power BI dashboard, will include:

* Flow Volume: The mean, minimum, maximum water levels, to reflect the dynamics of water flow within the habitat.
* Flow Duration: The length of time for which water flow is sustained at various levels, affecting connectivity and movement.
* Bank full Flow Conditions: Indicates the maximum carrying capacity of the river, without overflowing, and consequently disrupting sediment transportation and habitat structure.
* Flow Days: The number of days with significant water flow, potentially affecting feeding opportunities and other interactions within the food web.
* Water Temperature (Annual Average): Indicating the thermal conditions experienced at the study sites annually.
* Temperature Accumulation (Degree Days): A cumulative measure of heat exposure over time, which influences fish metabolic rates and growth cycles.
* Drought and Flood Events: Instances of extreme low and high waterhole volume, affecting habitat quality and food availability.

Additional variables might be considered depending on their availability and relevance to the growth patterns observed in the otolith data. These could encompass environmental features such as habitat composition, water quality parameters, and anthropogenic influences. The inclusion of these variables will be adaptive and, contingent upon their statistical significance to the models, the insights they provide into the growth rates of the species being studied and the convergence properties of the models themselves.

## 2.3 Modeling

The primary final product will be a comprehensive analytical script prepared with the programming language R that tidies, prepares for analysis and thoroughly explores the dataset to examine the impact of the various environmental and hydrological factors outlined above, on the otolith growth patterns in Golden perch, Bony bream, and Common carp. The initial steps will involve data visualisation and generation of descriptive statistics to guide the modeling process. Following this, a methodologically iterative approach will be taken to explore the relationships between environmental factors and otolith growth patterns. This means starting with simpler models to understand basic relationships, then progressively incorporating more complex models to incorporate more nuance. This phased approach allows for a thorough exploration of the data, ensuring that the final model(s) provide insightful and reliable predictions about the impact of hydrological factors on fish growth rates. The aim is not only to identify significant environmental influences on individual fish growth but also to understand the magnitude of their effects, contributing to informed management strategies for riverine ecosystems. Some of the model types that will be considered include the following:

**Multiple Linear Regression:**

* Overview: A foundational method to quantify and model the relationship between fish growth and one or more of the independent variables.
* Implementation: The lm() function will be used to estimate model parameters, starting with a base model and iteratively adding potential predictors.
* Evaluation: Model diagnostics such as residual plots, QQ-plots, and the variance inflation factor (VIF) will be employed to check the assumptions and fit of the model. The R-squared value will be used to provide insight into the explanatory power of the model.

**Mixed Effects Models:**

* Overview: These models will consider both fixed and random effects of the predictor variables on otolith growth and are predicted to be especially useful where there is spatial or temporal nesting within the data.
* Implementation: Implementation will be using the lmer() function from the ‘lme4’ package in R, fixed effects of predictors will be analysed while accounting for the random variations across catchments and sites.
* Evaluation: Model fit will be evaluated using likelihood ratio tests, and AIC and BIC criteria. As with multiple linear regression, model assumptions will be checked via residual plots.

**Generalized Linear Models (GLMs):**

* Overview: These models will extend linear regression to allow for response variables that have error distributions other than a normal distribution.
* Implementation: The glm() function will be employed, and Gaussian GLMs will be the primary focus, but the project will explore variations, adjusting fixed and random effects, and trying different link functions based on data distribution.
* Evaluation: Deviance and residuals will be the key evaluation metrics. The goodness of fit will be evaluated using the AIC and BIC.

**Advanced Techniques (Tentative):**

Random Forest and Artificial Neural Networks (ANNs) may be explored for their ability to capture non-linear relationships and complex interactions within the data. The choice to use these techniques will depend on initial findings from simpler models and the complexity of the data.

## 2.4 Data Splitting and Model Validation

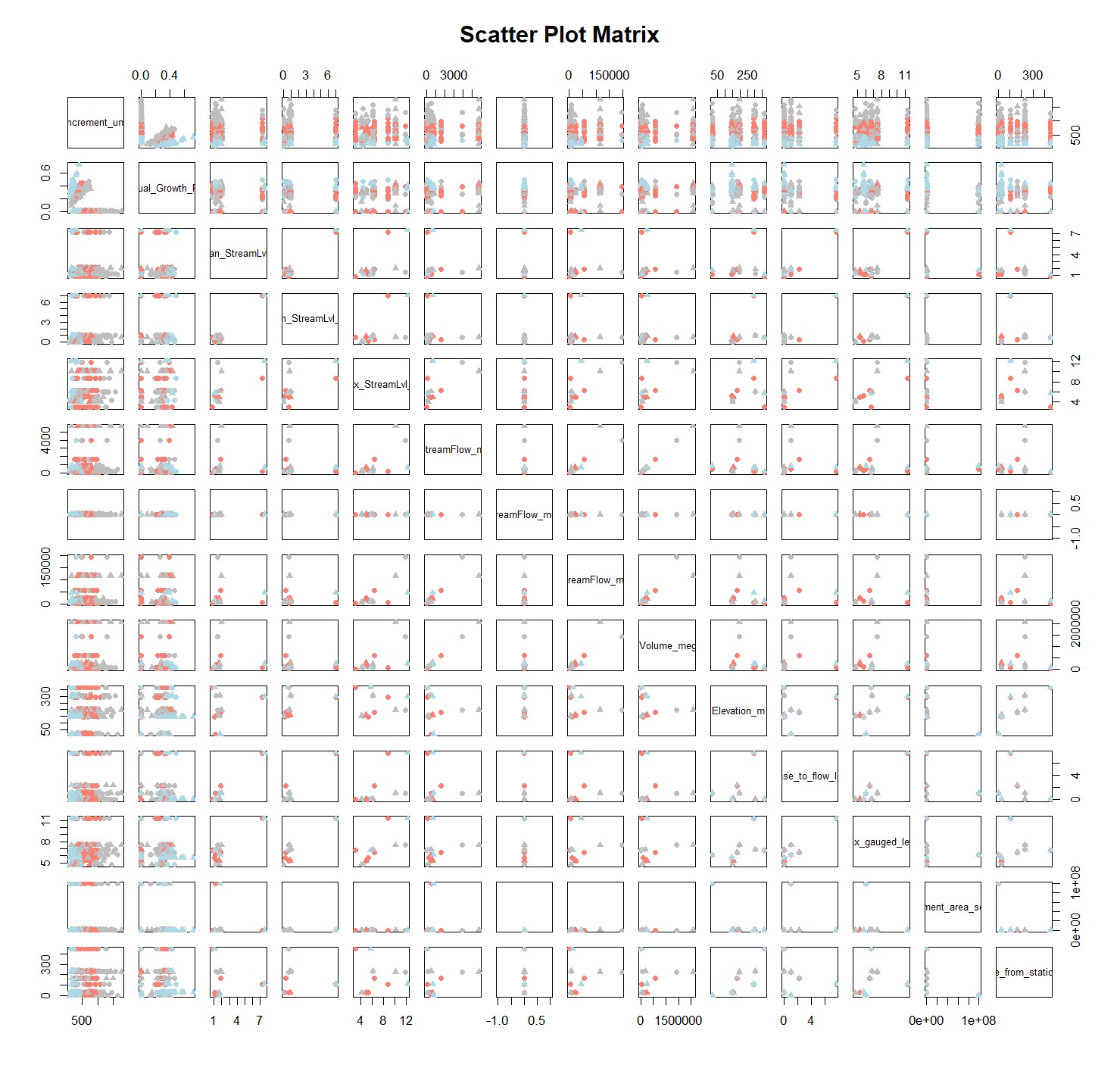
Prior to modeling, the dataset will be divided into training and testing sets to validate model performance on unseen data.

**Training Set:** This subset will include 80% of the original dataset, and will be used for model development and training, enabling algorithms to learn the relationship between the dependant and independent variables.

**Testing Set:** This subset will comprise the remaining 20% of data, it will be used to evaluate the performance of each model on ‘unseen’ data, to prevent overfitting.

An additional validation set will be used specifically for Artificial Neural Networks, to fine-tune the model parameters without impacting the test set, ensuring it remains an unbiased measure of model performance.

Results



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|  |  |  |
| --- | --- | --- |
| **Variable A** | **Variable B** | **CorrScore** |
| Mean stream level | Min stream level | 0.97 |
| Mean stream level | Cease to flow level | 0.98 |
| Mean stream level | Max Gauged Level | 0.87 |
| Min stream level | Cease to flow level | 0.95 |
| Min stream level | Max Gauged Level | 0.92 |
| Mean streamflow | Max Streamflow | 0.91 |
| Mean streamflow | Total volume | 1 |
| Max Streamflow | Total volume | 0.91 |
| Elevation | Catchment area | -0.87 |
| Elevation | Distance from station to mouth | 0.82 |
| Cease to flow level | Max Gauged Level | 0.89 |

# 3.0 Schedule

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | April | | May | | | |
| Milestone description | Start | Days |  | 3 | 4 | 1 | 2 | 3 | 4 |
| **Literature Review and Finalisation** | | | | | | | | | |
| Review background literature. | 15/04/24 | 2 |  |  |  |  |  |  |  |
| Finalize objectives and expected outcomes of the project. | 17/04/24 | 1 |  |  |  |  |  |  |  |
| **Accessing and Preparing Data** | | | | | | | | | |
| Combine datasets to create a comprehensive and consolidated dataset for modeling | 18/04/24 | 1 |  |  |  |  |  |  |  |
| Identify missing data points and inconsistencies | 19/04/24 | 1 |  |  |  |  |  |  |  |
| Preliminary data exploration and creating a tidy dataset | 20/04/24 | 3 |  |  |  |  |  |  |  |
| Data preprocessing: Normalize, standardize, or transform data as necessary. | 23/04/24 | 2 |  |  |  |  |  |  |  |
| Split data into training and testing sets (and validation set for ANNs). | 25/04/24 | 1 |  |  |  |  |  |  |  |
| **Modeling** | | | | | | | | | |
| Initiate modeling process with Multiple Linear Regression Models and Polynomial Regression Models. | 26/04/24 | 2 |  |  |  |  |  |  |  |
| Fit models, test assumptions, and evaluate initial results. | 28/04/24 | 2 |  |  |  |  |  |  |  |
| Continue modelling process with Generalized Linear Models (GLMs). | 30/04/24 | 2 |  |  |  |  |  |  |  |
| Evaluate the GLMs using AIC and BIC. | 02/05/24 | 2 |  |  |  |  |  |  |  |
| Start Random Forest modeling. | 04/05/24 | 2 |  |  |  |  |  |  |  |
| Evaluate predictor importance and model performance. | 06/05/24 | 2 |  |  |  |  |  |  |  |
| Start developing Artificial Neural Networks (ANNs). Adjust architectures and activation functions as needed | 08/05/24 | 2 |  |  |  |  |  |  |  |
| Validate models using the dedicated validation set to prevent overfitting | 10/05/24 | 1 |  |  |  |  |  |  |  |
| Evaluate the ANN models using MAE and RMSE | 11/05/24 | 1 |  |  |  |  |  |  |  |
| Compare all models side-by-side and identify the most accurate and efficient model(s) for predicting growth. | 12/05/24 | 1 |  |  |  |  |  |  |  |
| **Report Drafting** | | | | | | | | | |
| Draft a comprehensive report detailing methodologies, results, findings, and recommendations. | 13/05/24 | 5 |  |  |  |  |  |  |  |
| Review, edit, and finalize the report | 18/05/24 | 5 |  |  |  |  |  |  |  |
| **Seminar Preparation** |  |  |  |  |  |  |  |  |  |
| Synthesize key points from report | 18/05/24 | 2 |  |  |  |  |  |  |  |
| Develop visual aids and prepare PowerPoint presentation | 20/05/24 | 3 |  |  |  |  |  |  |  |

# 4.0 Project Deliverables

The completion of this project will yield a suite of deliverables which are designed to provide insight into how various environmental and hydrological factors affect growth and movement in lotic fish species. These outputs will inform management interventions and conservation efforts, so that they can be better guided to reflect these relationships.

**Predictive Models and R Script:**

The outcomes will include code including a collection of rigorously developed models, such as Multiple Linear Regression, Mixed Effects Models, and Generalized Linear Models (GLMs), Random Forest, and Artificial Neural Networks (ANNs), all geared towards exploring how various factors affect growth in lotic species. In the interest of ensuring transparency and reproducibility, the full R code for each of these modeling processes will be shared via GitHub and other agreed means.

**Visualisation and Model Evaluation:**

Detailed visual representations will be used to illustrate the dynamics between fish growth and environmental factors, complemented by graphical representations and plots showing the predictive abilities of each model. Where Artificial Neural Networks are utilised, architecture diagrams will also be included, depicting layers and activation functions.

Detailed statistical evaluations of each model's performance, including R-squared values, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE) will be presented.

**Final Report:**

This document will compile the research findings, outlining the methodology, data analysis, and interpretations of how environmental and hydrological conditions influence lotic fish species. Recommendations for management actions and potential areas for further investigation will be highlighted, aiming to contribute to sustainable ecosystem management.

**Seminar Presentation:**

The key findings of the research will be synthesized into a PowerPoint presentation and will be designed to encourage dialogue on the practical applications of the research and prospective directions for advancing current knowledge and practices in riverine ecosystem conservation.

These deliverables collectively aim to provide stakeholders, researchers, and policymakers with the knowledge and tools necessary to predict and respond to the impacts of environmental changes on the growth and population dynamics of riverine fishes, thereby supporting informed decision-making for ecosystem management and conservation.

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