Understanding the environmental conditions that dictate the abundance and distribution of two threatened freshwater turtles of South-East Queensland

Sydney Collett

Bachelor of Science (Honours)

Thesis submitted by Sydney Collett - BEnvSc. in partial fulfilment of the requirements for the Degree of Bachelor of Science with Honours in the School of Environment, Faculty of Engineering, Health, Science and the Environment, Charles Darwin University.

Submitted on 31st October 2017.

Statement of Authorship

"I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references given."

Abstract

Animals require specific biotic and abiotic features to survive and reproduce. Identifying what these environmental features are and where they coincide in space and time is critical for the conservation and management of species. This study will assess the environmental features responsible for population abundance and distribution of two threatened freshwater turtle species endemic to south-eastern Queensland: the White-throated snapping turtle (*Elseya albagula*) and the Mary River turtle (*Elusor macrurus*).

To sample turtle abundance and distribution, we used double winged set-nets to capture turtles at twenty locations along the Mary River. There were six sampling episodes each 6-months apart over 3 years. The locations and capture protocol were identical for each sampling episode. Thirteen environmental variables were recorded at each site, for every sampling episode. The relative significance of each variable in determining population abundance and distribution was assessed for each species using negative binomial generalised linear mixed models.

E. macrurus abundance was found to be influenced by the presence of algae in the substrate, in-stream condition, and the presence of broad vegetation group 4b (Evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with *Archontophoenix* spp., fringing streams). Differently, the abundance of *E. albagula* was only found to be influenced by the high presence of pebbles in the bedrock material. *E. macrurus* is a specialised feeder with high level of mobility. The results show the importance of good environmental conditions and clear water for the presence of this species. Alternatively, *E. albagula* is a generalised feeder, and seems to be found throughout the river, without much specialisation of habitat. However, whilst this study encompassed many environmental variables, there may also be others which were not in the models.

The findings from this study may be useful in directing rehabilitation effort in the river by local authorities and community groups. As *E. macrurus* abundance is affected by the quality of river, this research reiterates the necessity for river management to prioritise activities that promote healthy river systems. Future research is recommended to investigate the influence of other variables, such as nutrient content and water quality, on the distribution of these species, and to expand the research into the tributaries to identify the role they play in the juvenile and adult population.

Table of Contents

Statement of Authorship 1
Abstract 2
List of Figures 5
List of Tables 6
Acknowledgements 7
1.0 Introduction 8
1.1 Freshwater turtles in trouble 8
1.2 Turtles and their habitat 8
1.3 The Mary and its turtles 9
1.3.1 The Mary River, Queensland 9
1.3.2 *Elseya albagula* – White-throated Snapping turtle 10
1.3.3 *Elusor macrurus* – Mary River Turtle 11
1.4 Study Aims 11
2.0 Methods 12
2.1 Study area 12
2.2 Turtle Research Methods 13
2.3 Data collection 14
2.3.1 Turtle capture 14
2.3.2 Turtle processing 15
2.3.3 Environmental characteristics 17
2.4 Data analysis 19
3.0 Results 20
3.1 Temporal effects on capture rate 20
3.2 Spatial effects of capture rate 22
3.3 Environmental variables and their influence on capture rate 25
3.3.1 Testing model assumptions 25
3.3.2 Environmental variables associated with *E. macrurus* 25
3.3.3 Environmental variables associated with *E. albagula* 28
4.0 Discussion 30
4.1 Temporal trends in capture rate 30
4.2 Spatial trends on capture rates 30
4.3 Relationship between species abundance and environmental characteristics 31
4.3.1 *Elusor macrurus* 31
4.3.2 *Elseya albagula* 32

4.4 Limitations of the study 33
4.5 Significance of this study & Implications for management.... 34
4.7 Future research 35
5.0 References 37
Appendix 43

List of Figures

Figure 1: Adult female *E. albagula* basking on a log.

Figure 2: Juvenile *E. macrurus* basking on a log.

Figure 3*:* Location of the Mary River catchment in South-East Queensland, Australia.

Figure 4: Double-winged set net deployed at a site in the mid catchment.

Figure 5: a) Straight carapace length (SCL) of an adult female *E. albagula* being recorded; **b)** Tip to plastron tail length of an adult male *E. macrurus* being recorded.

Figure 6: Ventral view of **a)** *E. albagula* **b)** *E. macrurus*.

Figure 7: a) Distinguished tail of an adult male *E. macrurus*. **b)** Adult male *E. macrurus* with a tip to plastron length of 180mm. **c)** Distinctive white lower face and throat of an adult female *E. albagula*. **d)** Adult female *E. albagula* showing a common also distinctive pink nose.

Figure 8: Total captures of *E. macrurus* and *E. albagula* at each of the study sites.

Figure 9: Total captures of *E. macrurus* and *E. albagula* per sampling day.

Figure 10: Total female *E. macrurus* and *E. albagula* captured per season.

Figure 11: Mean *E. macrurus* and *E. albagula* capture rate for the four hydraulic units, upstream and downstream of each net.

Figure 12: Total number of *E. macrurus* and *E. albagula* individuals trapped per location.

Figure 13: Arrangement of male, female, and juvenile of *E. macrurus* and *E. albagula* across the four study locations.

Figure 14: Location of nets and riffles with remnant broad vegetation groups in **a)** lower catchment; **b)** mid-low catchment; **c)** mid catchment; **d)** upper catchment.

Figure 15: Total captures of *E. macrurus* and the presence or absence of broad vegetation group 4b and algae, and in moderate in-stream condition, and degraded in-stream condition.

Figure 16: Average capture rate of *E. albagula* and the percent of pebble in the bedrock material.

List of Tables

Table 1: Descriptions of variables analysed.

Table 2: Summary data for male, female and juvenile *E. macrurus* and *E. albagula* caught across the four study locations.

Table 3: Negative Binomial values for most parsimonious environmental variables and total *E. macrurus* counts.

Table 4: Negative Binomial values for two environmental variables and total *E. macrurus* counts.

Table 5: Negative Binomial values for two environmental variables and total *E. macrurus* counts.

Table 6: Negative Binomial values for four environmental variables and total *E. macrurus* counts.

Table 7: Summary of ANOVA results for negative binomial models for *E. macrurus* catch rate and environmental variables.

Table 8: Negative binomial values for most parsimonious environmental variable and total *E. albagula* counts.

Table 9: Negative binomial values for two environmental variables and total *E. albagula* counts

Table 10: Negative binomial values for four environmental variables and total *E. albagula* counts

Table 11: Negative binomial values for three environmental variables and total *E. albagula* counts.

Table 12: Summary of ANOVA results for negative binomial models for *E. albagula* catch rate and environmental variables.

Acknowledgements

I would like to thank the many people who have supported me though my Honours year.

First and foremost, I would like to express my gratitude to my supervisor, Dr Hamish Campbell, who generously provided his expert advice, read countless drafts and who made this project successful. A special thank you to fellow CDU Masters Student, Marilyn Connell, who initiated my interest in researching these unique turtles, and whose continued technical and moral support was unfailing. Thank you to Dr Mirjam Kaestli, who provided continual support and expert advice for the statistical analysis. A very big thank you to Dr Mariana Campbell, who's always positive energy and encouragement was always refreshing, and who was continually generous with her support and advice.

I would also like to thank those at Tiaro & District Landcare Group who provided technical support and whose dedicated interest in these turtles has played a key role in building the knowledge for these species. I would also like to thank those at the Mary River Catchment Co-ordinating Committee, for their continued interest, expertise, and technical support for this project.

A huge thank you to the extensive number of volunteers who spent countless early mornings measuring and recording on very little coffee. In particular, I would like to extend a special thank you to Chris and Peter Stiler, Mary Starky, Glenda Pickersgill, Saranne Guidice and Ian Mackay for continuing to provide assistance year after year. I would also like to acknowledge the landowners who very generously allowed me access to the river through their property.

I would also like to extend my gratitude to Charles Darwin University and Tiaro & District Landcare Group for providing financial assistance with this project and who generously allowed me the use of their equipment.

Finally, I would like to thank my friends and family for their continued encouragement, and unconditional love. I would especially like to express my eternal gratitude to my mum, who always leant a helping hand, read any number of drafts, and who always helped with the tedious task of cleaning gear.

1.0 Introduction

1.1 Freshwater turtles in trouble

Freshwater turtles are one of the most threatened animal groups in the world, and are at a much higher risk of extinction than any other vertebrate (Buhlmann et al., 2009; Ocock et al., 2017). Of the 300+ species described, over half are threatened with extinction (Buhlmann et al., 2009; IUCN, 2017; Ocock et al., 2017; TCC, 2011). For many species, over-exploitation and pet trades are the main causes of population declines. However, there are other threats that are becoming more prominent as time passes, including habitat fragmentation and destruction, pollution, and traditional medicines (Buhlmann et al., 2009, TCC, 2011; Ocock et al., 2017; Van Dijk et al., 2000). In Australia, many turtle species have lost habitat due to increasing frequency and severity of droughts and extreme weather events (Chessman, 2011). The most significant habitat modification, however, lies within the riparian landscapes adjacent to river banks, where there is extensive livestock access and clearing of riparian vegetation, as well as within the river itself with water extraction for irrigation and the implementation of dams and weirs (Micheli-Campbell et al., 2013; Limpus et al., 2006; TCC, 2011). Freshwater turtles have become of particular interest to conservationists, as they are a good indicator of the quality of freshwater ecosystems (Blamires & Spencer, 2013).

There are many threats to freshwater turtles across the world. For many of the species in the United States and Australia, terrestrial and aquatic predators play key roles in the decline of populations. Hatching success in turtles can be as low as 5%, with nests subject to heavy predation from native and non-native species (Freeman, 2011; Hamann et al., 2008; Limpus, 2008; Micheli-Campbell et al., 2013; TSSC, 2014). This extensive loss of eggs and drastic change in sex ratios is known to influence a lack in recruitment, only exacerbating the decline in population numbers (Limpus, 2008). In Asia and Indo-China, the continued collection and trade of these turtles are still the primary cause of decline for many species, and have been attributed to the extinction of two freshwater turtle species (Van Dijk et al., 2000). Whilst over exploitation is the main cause of the decline in turtle populations around the world, the loss and fragmentation of both terrestrial and aquatic habitat have also been identified as key drivers of population declines (Ocock et al., 2017).

1.2 Turtles and their habitat

Terrestrial habitats often play critical roles for the survival of freshwater turtle species (Anthonysamy et al., 2013; Dudley et al., 2015; Steen et al., 2012; Stokeld et al., 2014). The most important of which, often described as ‘core zones’, are the terrestrial zones adjacent to water bodies. These habitats not only deposit debris into the waterbody, but they are also essential for nesting (Steen et al., 2012). The deposition of trees into the river by flood or bank collapse play pivotal roles for some species providing critical refuges for hatchlings and basking platforms (Dudley et al., 2015; Ocock et al., 2017). The bedrock material of the adjacent banks and land are influential to the selection of nesting sites, with many freshwater turtles preferring softer sandy banks (Hamann, 2008; Micheli-Campbell et al., 2013; Paterson, 2011).

On a large spatial scale, many turtle species favour permanent water bodies such as pools in a river and perennial wetlands, as they provide a reliable food source and have low predation risk (Blamires & Spencer, 2013; Micheli-Campbell et al., 2013). However, when looking at a finer spatial scale, it has been proposed that areas within these larger scale habitats, which supply particular food sources or shelter, may influence the occupancy of turtles (Blamires & Spencer, 2013; Micheli-Campbell et al., 2013, 2017; Paterson, 2011). Some of these microhabitat preferences include substrate, in-stream vegetation, and water quality (Dudley et al., 2015; Ocock et al., 2017; Paterson, 2011; Stokeld et al., 2014). These characteristics have been known to influence the presence and abundance of food sources and refuge for turtles. The reduction and destruction of critical aquatic habitats affects the critical feeding and breeding areas, and can have consequential impacts on the distribution of turtles throughout a waterway (Ocock et al., 2017).

1.3 The Mary and its turtles

1.3.1 The Mary River, Queensland

This study focused upon the Mary River catchment, located in South-East Queensland, Australia. The catchment covers 9600 km^2 and stretches 307 km from the headwaters in the Conondale Range at Kenilworth to the mouth at River Heads, Hervey Bay (MRCCC, 2001). It is considered the “most significant, least regulated river in coastal south-eastern Queensland” (Walker, 2008). The Mary River is characterised by perennial, shallow riffles, sandy/gravelly bed material, deep pools containing large woody debris, and sandy/loamy banks (DoEWHA, 2008). The complex arrangement or riffles, runs, and pools has been noted as key attributes for the Australian lungfish, Mary River cod, and the six turtle species found in the river (DoEWHA, 2008; Walker, 2008).

The Mary River catchment primarily contains *Eucalyptus* (spp.) dominated open forest woodlands drainage lines and alluvial plains, but also includes other broad vegetation types such as Notophyll vine forest, and dry to moist eucalypt woodlands and open forests (Science, Information Technology and Innovation, 2017). Whilst the Mary River still contains many native water plants such as Ribbon weed (*Vallisneria gigantea*), non-native plants and invasive plants such as Water

Hyacinth (*Eichhornia crassipes*) and Salvinia (*Salvinia molesta*) have been found throughout the catchment (Walker, 2008).

The Mary River is of significant scientific interest as the catchment is home to 12 threatened and 2 endemic fauna species (Walker, 2008). This research will study two of these species, both listed as threatened under the EPBC Act 1999.

1.3.2 *Elseya albagula* – White-throated Snapping turtle

The White-throated snapping turtle (Figure 1), *Elseya albagula* (Thompson et al., 2006) occurs in the Burnett, Fitzroy, and Mary River catchments (Cann & Sadlier, 2017; Thompson et al., 2006). They are one of the largest Chelid species in the world, with females reaching up to 390mm, and males reaching up to 260mm (Hamann et al., 2007; Limpus, 2008). Whist the movement of these turtles has not been extensively studied, *E. albagula* is known to prefer permanent, slow flowing pools with suitable shelters and refuges (Cann & Sadlier, 2017; Micheli-Campbell et al., 2017; Thompson et al., 2006). They have small home ranges, generally less than 1.5km, with daily movements limited to 200-250m per day (Hamann et al., 2007; Micheli-Campbell et al., 2017). It is proposed that these turtles can dive for up to three hours, aided by the ability to absorb oxygen through their cloacal bursae whilst under water (Cann & Sadlier, 2017). Stable isotope analysis suggests that *E. albagula* predominately feed on crustaceans and filamentous algae (Micheli-Campbell et al., 2017). These turtles are of conservation concern due to their low reproductive success, late maturity, and their limited distribution.

Figure 1: Adult female *E. albagula* basking on a log.

1.3.3 *Elusor macrurus* – Mary River Turtle

The Mary River turtle (Figure 2), *Elusor macrurus* (Cann & Legler, 1994) is endemic to the Mary River catchment (Cann & Legler, 1994). They are the largest turtle species found within the river. Unlike *E. albagula*, males are the larger sex, reaching up to 420mm, and females reaching up to 350mm (Cann & Sadlier, 2017; Limpus, 2008). Males also have a very large and distinct tail, which extends to 70% of the carapace length (typically over 170mm long) and up to 260mm circumference (personal data; Flakus, 2002). These tails are also important to this species as the dive time of *E. macrurus* could be extended with the assistance of cloacal bursae (Cann & Sadlier, 2017; Flakus, 2002; Limpus, 2008; TSSC, 2008). *E. macrurus* is known to prefer fast flowing, well-oxygenated waters, such as are found in riffle zones (Micheli-Campbell et al., 2017; TSSC, 2008). They are also known to feed on invertebrates found in these areas, such as bivalves, gastropods, and crustaceans (Micheli-Campbell et al., 2017). This species has a moderate home range of over 4km (Micheli-Campbell et al., 2017). Compared to *E. albagula*, this species travels a five-time greater distance each day, covering over 1km in river distance, per day (Micheli-Campbell et al., 2017). *E. macrurus* is from an ancient taxonomic lineage, with no close relatives (Walker, 2008). It is due to this unique taxonomic history, as well as it's endemicity and isolate home range that *E. macrurus* is of particular conservation interest (Cann & Legler, 1994; Limpus, 2008; Walker, 2008).

Figure 2: Juvenile *E. macrurus* basking on a log.

1.4 Study Aims

A fundamental aspect of ecology is understanding the distribution and habitat use of organisms (Paterson, 2011). Whist the dive behaviour and food preferences of these turtles are somewhat understood, their distribution and abundance throughout the river is not. Furthermore, the causes of any differing composition of the two turtle species has not been studied.

These turtles were once presumed to fill the same ecological niche, occupying the same areas and relying on the same food sources (Limpus, 2008). A recent study however, found these species to occupy quite different ecological niches within the same river (Micheli-Campbell et al., 2017).

This study aims to improve the current knowledge of the ecology of those two species of freshwater turtle, by assessing the environmental characteristics that determine their abundance and distribution throughout the river. The present study tested the following hypotheses: 1/ the relative abundance of each species will vary between stretches of the river due to differences in environmental characteristics; and 2/ *E. macrurus* is a river specialist and will favour intact stretches of river with good water conditions, whilst *E. albagula* is a generalist species and likely to be less selective in its habitat. In doing so, this study will also investigate the effectiveness of the fyke net methods in studying lotic inhabiting freshwater turtles. This will help aid the study design of future study designs to optimise sample numbers.

2.0 Methods

2.1 Study area

For this study, turtles were sampled from 20 sites across four locations (Figure 3) throughout the Mary River catchment, in Autumn and Spring 2015-17 (total of 6 survey episodes). The Mary River catchment is an environmentally significant river system in South-East Queensland (DoEWHA, 2008; MRCCC, 2001; Walker, 2008). The river contains many significant breeding areas and known nesting banks for the threatened species found in its waters (Walker, 2008). The Mary River is situated in primarily a sub-tropical climate (Pointon & Collins, 2000). Rainfall across the catchment varies greatly, however the summer-dominated rainfall, often results in flooding of a destructive nature (MRCCC, 2001). The southern and coastal areas on the river are considered moist sub-tropical with average annual rainfall of 2000mm, whereas the western side of the catchment is dry sub-tropical, with a mean annual rainfall of 80mm (MRCCC, 2001; Pointon & Collins, 2000). The Mary River catchment has been subject to extensive logging since European settlement. As such, there is very little remnant vegetation left (MRCCC, 2001). The remaining vegetation is typically open forest (canopy cover 35-81%) or woodland (canopy cover 1-52%) which is dominated by Eucalyptus spp. (MRCCC, 2001; Neldner et al., 2010).

This study will assess the environmental features and turtles capture rates at four different reaches of the river, encompassing approximately 180km (Figure 3). These reaches were chosen as they are of approximately equal distance apart (approx. 60km), have different riparian and instream environmental characteristics, and are known to contain the two species of interest. The upper reaches of the Mary have a steep gradient, falling 300m in the first 5km (a bed gradient of 6%), with the rest of the study area (Kenilworth to Tiaro) having a slow, constant gradient of 0.04% (MRCCC, 2001; Pointon & Collins, 2000). The upper reaches are comprised primarily of riffles, runs and glides due to this steep decline, with the remaining stretches of the river made up of sequences of riffles and pools (MRCCC, 2001).

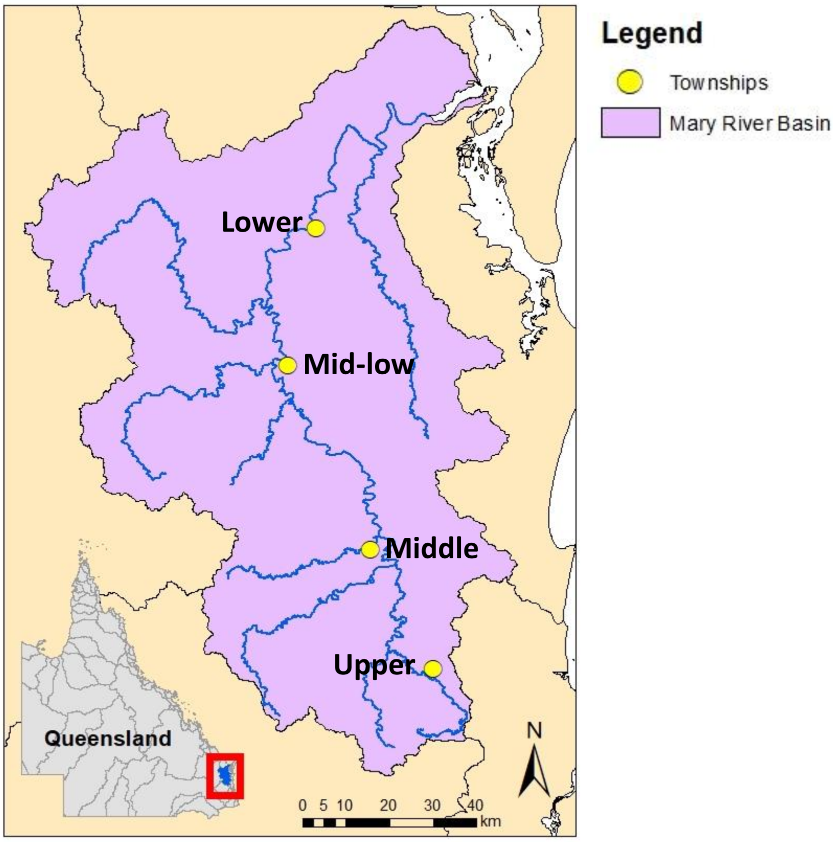

Figure 3*:* Location of the Mary River catchment in South-East Queensland, Australia.

2.2 Turtle Research Methods

This study will use a relatively new capture method for freshwater turtles – double winged set nets, also called fyke nets. Fyke netting is a repeatable, standardised trapping method for monitoring small aquatic species (Breen & Ruetz, 2006; Micheli-Campbell et al., 2017). Whilst typically used for monitoring fish populations, these nets have been specifically modified to capture the range of freshwater turtles found in the Mary River. This method enables the handling and subsequent tagging of individual turtles, which allows the continued monitoring of populations. Handling these turtles enables us to distinguish the life stage of the individual by measuring straight carapace length, and sex, by taking tail length. This will help to address whether the population dynamics of *Elusor macrurus* and *Elseya albagula* differ between the upper, middle and lower catchments.

As these nets are placed in the same location for each trapping episode, we are able to gather characteristics of the river morphology such as hydraulic units upstream and downstream of the net. As these characteristics can change between episodes due to bank erosion, flooding and low river height, we can correlate a change in these with the abundance of turtles. This enables us to draw inferences about any environmental characteristics which would influence the distribution of turtles throughout the river, as well as address the relative parameters of effective net setting techniques.

Two episodes of data will be collected through field work for this thesis. However, due to the short time period of the honours program, this data will be integrated with archival population data collected over 2015 and 2016 to create a total of 6 trapping episodes. Both the *E. macrurus* and *E. albagula* datasets will be continued to added to in the future.

2.3 Data collection

2.3.1 Turtle capture

To assess the population size and structure at these twenty locations across the river set nets were deployed during autumn (March-May) and spring (September-October). Turtles were trapped using modified double-winged set nets (2mm mesh size; 0.9m diameter; 10m leader length with a 1.2m drop). These nets have a series of 4 hoops (also called the 'cod end') which contains a number of tunnels to contain and direct animals (Figure 4). Animals are funnelled into this upstream facing section by the 10m (l) x 1.2m (d) wings which are weighted to ensure they consistently touch the river bed. Nets were strategically placed at locations with characteristics known to be utilised by these species, such as riffles and pools (Micheli-Campbell et al., 2017). However, sites were also limited by the logistics of these nets as they only have a diameter of 0.9m. This method has been an effective method for capturing bottom dwelling mobile species, such as these turtle species (Breen & Ruetz, 2006; Micheli-Campbell et al., 2017).

Figure 4: Double-winged set net deployed at a site in the mid catchment (Ka5).

2.3.2 Turtle processing

Each turtle was implanted with an identifying PIT tag; had morphological measurements taken; weighed and was sexed based on external characteristics. Each turtle had a microchip inserted under the epidermis into the front left leg. Upon capture each turtle was scanned for the presence of a microchip, to ensure that recaptures were not recounted and included in the abundance analysis. Passive turtle capture methods were used to enable consistency in the probability of turtle capture through space and time. It is thus proposed that the rate of turtle capture within each net was directly proportional to the size of the local population of each species.

Morphometric measurements were recorded to assign individuals to both age and sex class. Measurements were taken with Haglof™ 65cm calipers (to the closest 0.1cm) and included straight carapace length (SCL) (Figure 5a), straight carapace width (SCW) and tip to plastron tail length (Figure 5b). Weight was recorded to the closest 0.01kg with a digital spring balance.

Figure 5: a) Straight carapace length (SCL) of an adult female *E. albagula* being recorded with Haglof calipers; **b)** Tip to plastron tail length of an adult male *E. macrurus* being recorded.

The sex of each turtle was determined through external dimorphic characteristics (Figure 6). *E. albagula* females are larger than their male counterparts, with adult females having a SCL of >235mm (>213mm for males) and shorter tails. *E. macrurus* males are the larger sex in this species. Adult males will have a SCL of >375mm (females = >317mm) and significantly larger tails (Figure 7a, b) (Cann and Legler, 1994; Limpus, 2008; Thompson et al., 2006). Female *E. albagula* have a very distinctive white/cream throat (Figure 7c), with this colouration spreading from the lower jaw to the front legs, and occasionally a very pink nose (Figure 7d).

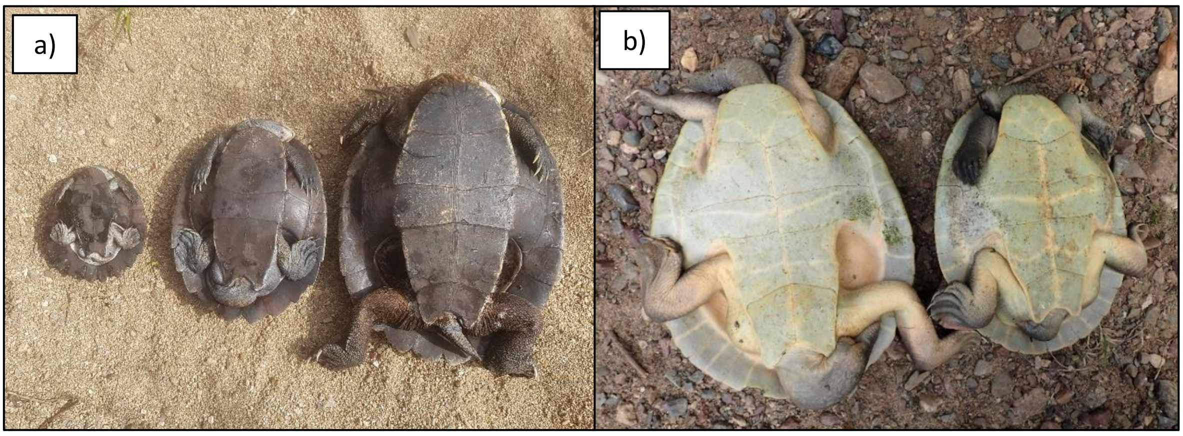

Figure 6: Ventral view of **a)** *E. albagula* (left: juvenile; middle: adult male; right: adult female); **b)** adult *E. macrurus* (left: male; right: female).

Figure 7: a) Distinguished tail of an adult male *E. macrurus*. **b)** Adult male *E. macrurus* with a tip to plastron length of 180mm. **c)** Distinctive white lower face and throat of an adult female *E. albagula*. **d)** Adult female *E. albagula* showing a common also distinctive pink nose.

2.3.3 Environmental characteristics

Several environmental variables were recorded during each trapping episode. These included the presence of macrophytes and algae on the substrate, flow speed at the fyke net (sec/1m), river depth at mouth of fyke (cm) and the hydraulic units upstream and downstream of the net. Hydraulic units were recorded as riffle, run, pool or backwater. For this study, a riffle was described as shallow (0.5-1m deep) with fast flowing water; a run, as mid-depth (1-2m deep) with a high flow rate; a pool was described as slow-moving and deep (3-6m) and a blackwater as a still body of deep water (Micheli-Campbell et al., 2013). A 1.5m PVC pipe with 1cm increments was used for measurements such as river depth, and flow speed. River depth was measured at the mouth of the fyke net, whilst flow speed was recorded in the middle of the two wings.

ArcGIS 10 (ESRI Arc Map version 10.4.1) was used to determine broad vegetation groups within 50m of the net, and potential spatial predictors such as distance to the closes riffle and distance to the middle of pool. Broad vegetation groups were as per Neldner et al. (2010) and were recorded as a presence or absence.

Variables related to the morphology of the river were as recorded from Mary River Catchment Coordinating Committee's Mary River and tributaries Rehabilitation Plan (Table 1) (MRCCC, 2001). The variables included in-stream condition, bedrock material, bed stability and riparian vegetation condition. This plan divided the Mary River into 14 separate stretches (labelled Mary1-14) based on stream morphology, riparian zone characteristics and in-stream characteristics. lower and mid-low catchment nets were set in the Mary11 stretch, mid catchment nets in the Mary9 stretch, and the upper catchment nets covered Mary4-7. This data, whilst developed in 2001, is still believed to be representative of what the river looks like in present time, by those who undertook the original study (Brad Wedlock, MRCCC, pers comms.).

Table 1: Descriptions of variables analysed.

Variable	Description
Net setting Parameters	
Hydraulic units upstream of net	River hydraulics upstream of the net location. Recorded as 'pool', 'riffle', 'run', 'backwater'.
Hydraulic units downstream of net	River hydraulics downstream of the net location. Recorded as 'pool', 'riffle', 'run', 'backwater'.
Flow speed	Flow speed was recorded in the middle of the two wings of the net. Speed was recorded as seconds per 1m. Speed of more than 10 seconds were recorded as no flow.
River depth	River depth was taken at the opening of the cod end of the net. This was recorded in centimetres.
Distance to closest riffle	The river distance from the net to the closest riffle. Analysed through ArcGIS and recorded in meters.
Distance to middle of pool	River distance from the net to the middle of the closest pool. Analysed in ArcGIS and recorded in meters.

Environmental Characteristics	
Macrophytes	Assessed the presence of macrophytes in the substrate. This was recorded as presence or absence.
Algae	Assessed the presence of algae in the substrate. This was recorded as presence or absence.
In-stream condition	Overall in stream condition assessed macrophyte richness and abundance, fish species richness, large woody debris abundance, and bank overhang. It was recorded as 'very good', 'good', 'moderate', 'degraded' or 'poor' (MRCCC 2001).
Bedrock material	Assessed the character of the bedrock material in the river. This was recorded as percent 'silt/clay', 'sand', 'gravel', 'pebble', 'cobble', and 'boulders'.
Bank stability	Assessed the level of disturbance in relation to natural levels of accretion and deposition. Recorded as 'occasional minor disturbance', 'isolated minor disturbance', 'frequent minor disturbance', 'frequent major disturbance', 'frequent major erosion', 'common minor-moderate erosion', and 'common major disturbance' (MRCCC, 2001).
Broad vegetation group – 4b 16a 16c	The three broad vegetation groups (BVG) found within 50m of the 20 nets, as per Neldner et al. (2010). BVG 4b is 'Evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with *Archontophoenix* spp., fringing streams'. BVG 16a is 'open forests and woodlands dominated by *Eucalyptus camaldulensis* (river red gum) and/or *E. coolabah* (coolibah) fringing drainage lines'. BVG 16c is 'woodlands and open woodlands dominated by *Eucalyptus coolabah* (coolibah) or *E. microtheca* (coolibah) or *E. largiflorens* (black box) or *E. tereticornis* (blue gum) or *E. chlorophylla* on floodplains'. This was assessed through ArcGIS software and was recorded as presence or absence of each of the vegetation groups within 50m of the net (Science, Information Technology and Innovation, 2017).
Vegetation condition	Assessed condition and structure of vegetation in the riparian zone, including strata classes, disturbance level and weed growth. Recorded as a percent of 'good', 'minor disturbance', 'major disturbance' and 'no native vegetation' throughout the stretch (MRCCC, 2001).

The different variables and factors measured to assess against turtle capture rate.

2.4 Data analysis

The relationship between the day of capture and the number of turtle caught, as well as the environmental variables and number of turtles caught was investigated through using Generalised Linear Mixed Models (GLMMs). As this study used factors, and repeated measures (episode, season and year) in performing regression analyses, GLMM/s as opposed to GLMs were necessary. GLMMs account for right skewed data and include both fixed and random effects in their analysis (Bolker et al., 2009). When analysing the effect of season on each of the sexes, a zero-inflation model was used. This is due to the large number of zeros which are recorded in the data when looking at sexes individually.

Due to there being more variation in the environmental characteristic data than predicted in the model, negative binomial models were used to account for model overdispersion. The data for '% cobble', 'good vegetation condition', 'distance to closest riffle', and 'distance to middle of pool' were log transformed to normalised and homogenise residuals. Categorical variables, such as bank stability, were converted to factors to enable this analysis. Net ID and Location were noted as random effect in this model.

Twenty-three variables were analysed in this study (Table 1; Appendix B & C). Models were run with a number of different variable combinations. Variables which had a $p<0.1$ were kept in the model and those with $p>0.1$ were removed (Appendix B & C). To compare models with different variables, Analysis of variance (ANOVA) were used. For *E. macrurus*, the most parsimonious model with the lowest AIC had three variables - algae, in-stream condition, and BVG 4b (Table 3), and for *E. albagula*, the most parsimonious model only contained % pebble in the bedrock (Table 8).

Statistical analyses and graphing were performed using R software v3.4.1 (R Core Team 2017). Statistical libraries used include Linear Mixed-effects model using 'Eigen' and S4 (lme4), Trellis Graphics (lattice), Companion to applied regression (car), Grammar of Graphics (ggplot2), Data visualisation for statistics in social science (sjPlot) and Generalised Linear Mixed models using 'AD Model Builder' (glmmADMB) (Bates et al., 2015; Deepayan, 2008; Fournier et al., 2012; Fox & Weisberg, 2011; Lüdecke, 2017: Skaug et al., 2016; Wickham, 2009). A p-value of $p<0.05$ was used to guide significance and interpretation of results.

3.0 Results

3.1 Temporal effects on capture rate

Set-nets were deployed for a total of 96 trap-nights (48 autumn, 48 spring) over the 2015-2017 trapping seasons. A total of 867 turtles (404 *Elusor macrurus* and 463 *Elseya albagula*) were captured over these trap-nights. Turtle captures at individual nets varied from 4 (Ti2) to 101 (Ob1) (Figure 8) with the mean capture rate per night of 0.84 (SE = 0.06) and 0.96 (SE = 0.08) across all nets for *E. macrurus* and *E. albagula*, respectively.

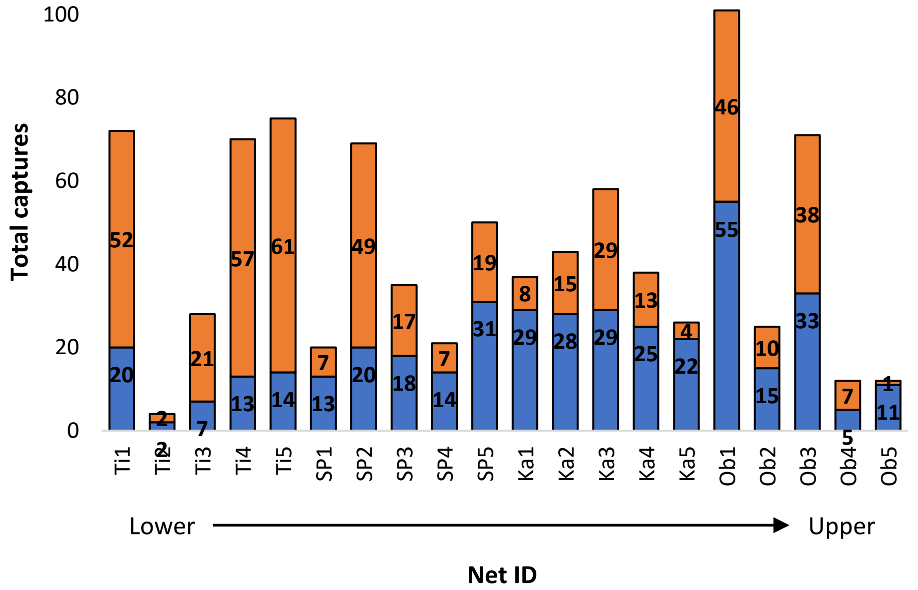

Figure 8: Total captures of *E. macrurus* (blue) and *E. albagula* (orange), at each of the net sites (Ti – Tiaro, SP – Scotchy Pocket, Ka – Kandanga, Ob – Obi Obi) from the lower catchment (Tiaro) to the upper catchment (Obi Obi).

There was no significant difference noted between the day of capture within each sampling episode, and the number of *E. albagula* (Df = 6, AIC = 1213.0, z = 0.593, p = 0.553) or *E. macrurus* (Df = 7, AIC = 1195.1, z = -0.281, p = 0.779) caught (Figure 9).

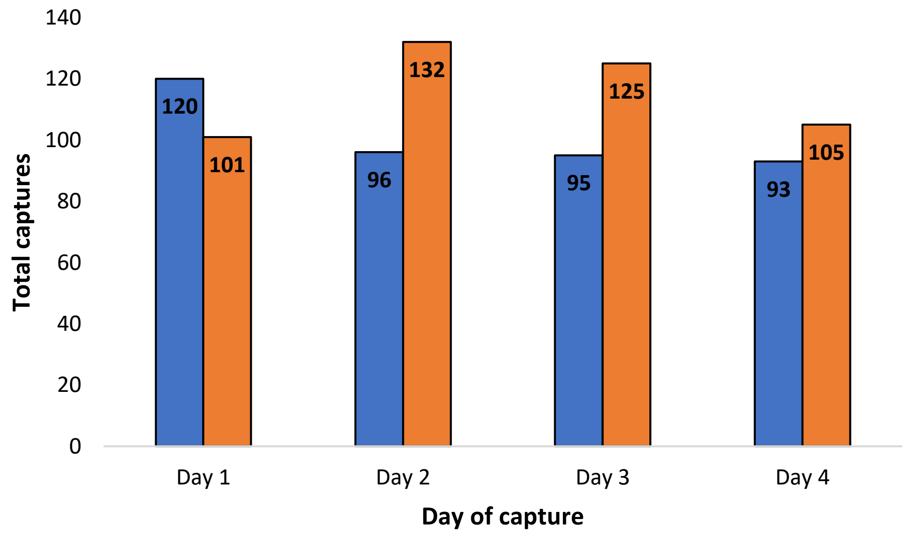

Figure 9: Total counts of *E. macrurus* (blue bars) and *E. albagula* (orange bars) per sampling day.

Whilst there was no impact from season (Df =7, AIC = 1195.1, z = 0.158, p=0.874) on the capture of *E. macrurus*, this was not the case for *E. albagula*, which increased in the spring trapping seasons (Df = 6, AIC = 1193.0, z = 4.107, p<0.01). However, whilst season did not influence total numbers of *E. macrurus* caught, it was shown to affect the sex, with more than twice the number of female *E. macrurus* caught in spring (Df = 5, AIC = 338.7, z = 2.24, p = 0.025), the same was observed with *E. albagula* (Figure 10).

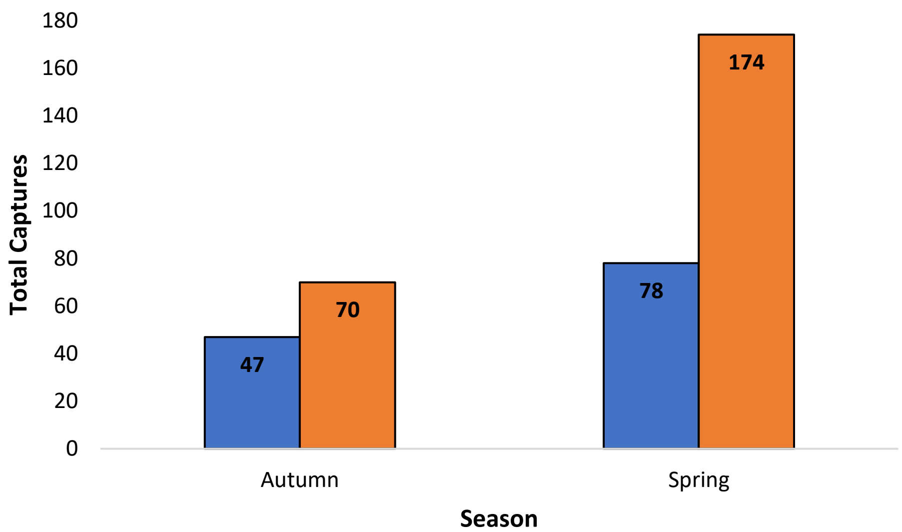

Figure 10: Total female *E. macrurus* (blue bars) and *E. albagula* (orange bars) captured per season.

3.2 Spatial effects of capture rate

The relation to the closest hydraulic unit (riffle[F], pool [P], run [R]) was shown not to have an impact on the capture rate of *E. macrurus* (UN: Df = 6, AIC = 567.31, z = [F]0.455; [P]0.722; [R]0.959, p= [F]0.649; [P]0.470; [R]0.338 - DN: Df =6, AIC = 567.79, z = [F]-0.855; [P]-0.793; [R]-0.464, p = [F]0.39276; [P]0.42772; [R]0.64299) (Figure 11). Similarly, *E. albagula* capture rate was not influenced by the closest hydraulic unit (UN: Df = 6, AIC = 573.84, z = [F]0.001; [P]-0.324; [R]-0.529, p= [F]0.999; [P]0.746; [R]0.597 - DN: Df =6, AIC = 570.65, z = [F]-0.286; [P]0.296; [R]-0.435, p = [F]0.775; [P]0.767; [R]0.644) (Figure 11).

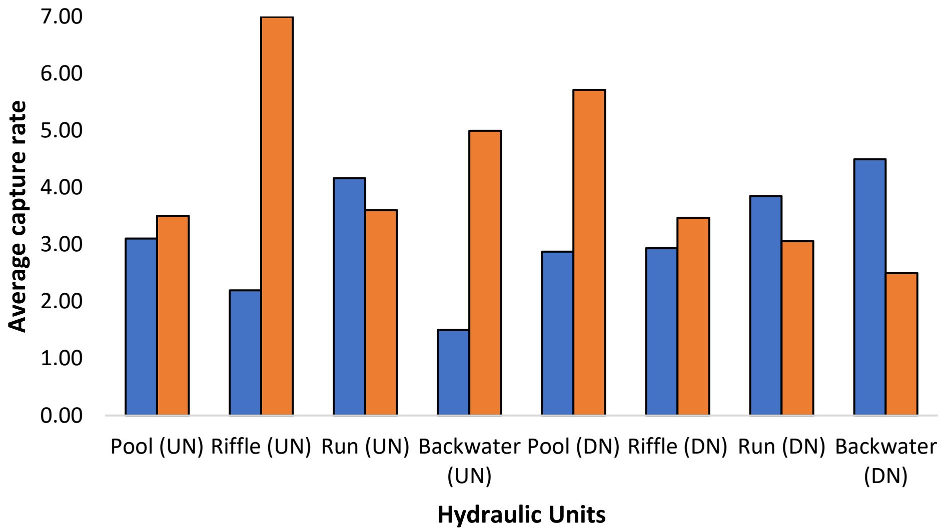

Figure 11: Mean *E. macrurus* and *E. albagula* capture rate for the four hydraulic units, upstream and downstream of each net.

Each of the 20 nets set throughout the river captured these two species of turtle. There was some difference seen between the total numbers of turtles caught between each of the four locations (Table 2; Figure 12). Overall, there was a higher capture of *E. macrurus* individuals in the middle stretch (mean = 4.43, SE = 0.67), compared to *E. albagula*, which had a higher total in the lower catchment (mean = 6.43, SE = 1.39) (Table 2; Figure 12).

Table 2: Summary data for male, female and juvenile *E. macrurus* and *E. albagula* caught across the four study locations.

	E. macrurus				*E. albagula*			
	Male	Female	Juvenile	**Total**	Male	Female	Juvenile	**Total**
Lower	43	12	1	**56**	106	87	0	**193**
Mid-low	68	28	0	**96**	43	55	1	**99**
Middle	92	35	6	**133**	22	47	0	**69**
Upper	57	50	12	**119**	32	55	15	**102**
Total	**260**	**125**	**19**	**404**	**203**	**244**	**16**	**463**

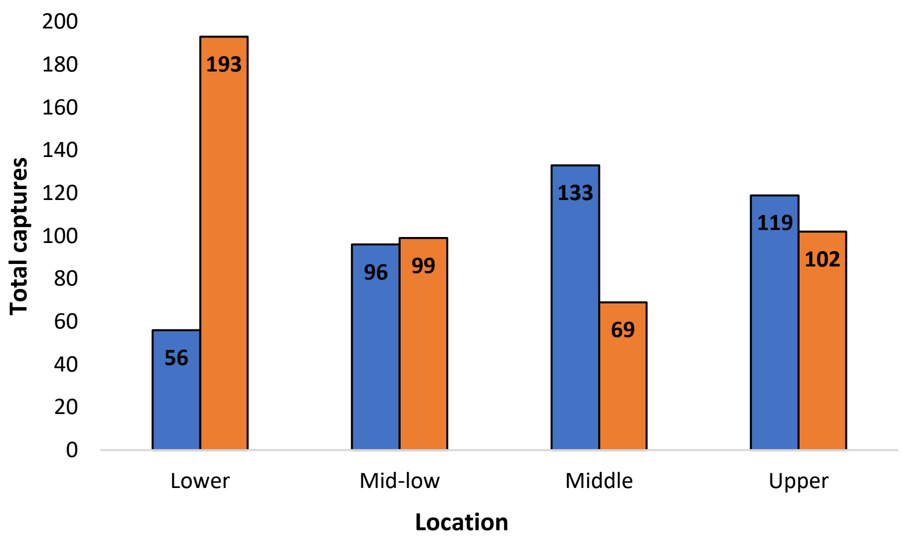

Figure 12: Total number of *E. macrurus* and *E. albagula* (blue bars and orange bars, respectively) individuals trapped per location.

For *E. macrurus*, the largest number of females (40%) and juveniles (63%) were trapped in the upper stretch, whilst the majority of males were found in the middle stretch (35%) (Table 2; Figure 13). The largest number of *E. albagula* females (36%) and over half the male (52%) were caught in the lower catchment, whereas the vast majority of juveniles were caught in the upper catchment (94%) (Table 2; Figure 13).

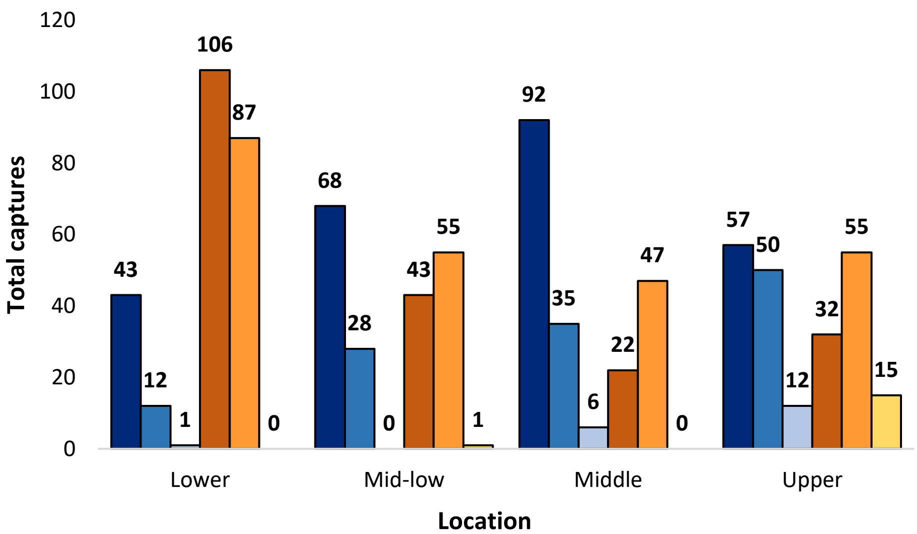

Figure 13: Arrangement of male (dark), female (mid-shade) and juvenile (light) of *E. macrurus* (blue) and *E. albagula* (orange) across the four study locations.

3.3 Environmental variables and their influence on capture rate

3.3.1 Testing model assumptions

The relationship between 23 variables/factors and the rate of capture of *E. macrurus* and *E. albagula* were statistically assessed. A total of 40 different combinations of variables were tested (Appendix B & C). Variable combinations with a Pr(>Chisq) value of <0.05, and with a low AIC were models with the best fit. The results of the finals models can be seen in Table 3 (*E. macrurus*) and Table 8 (*E. albagula*).

3.3.2 Environmental variables associated with *E. macrurus*

Of the environmental characteristics assessed, the variables with the strongest influence on the presence of *E. macrurus* were in-stream condition, BVG 4b and algae in the substrate (Table 3-7). BVG 4b contains 'evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with *Archontophoenix* spp., fringing streams' (Neldner et al. 2010). The number of *E. macrurus* caught, was significantly influenced by moderate in-stream condition where capture rates were higher, as opposed to those in a degraded state (Df = 6, AIC = 554.01, z = -2.830, p<0.01) (Figure 15). Conversely, the number of turtle captures increased with the presence of broad vegetation group 4b within 50m of the net (Df = 6, AIC = 554.01, z = 3.039, p<0.01) (Figure 15). Of the 14 broad vegetation groups found within the catchment, the groups 4b, 16a and 16c are the only groups which are found within 50m of where the nets were set (Figure 14). These are also the most frequently occurring vegetation groups within a 50m riparian zone of the river, with large sections of the river having no remnant vegetation (Figure 14c, d). Similarly, *E. macrurus* numbers increased when there was algae present in the substrate (Df = 6, AIC = 554.01, z = 2.186, p = 0.03) (Figure 15).

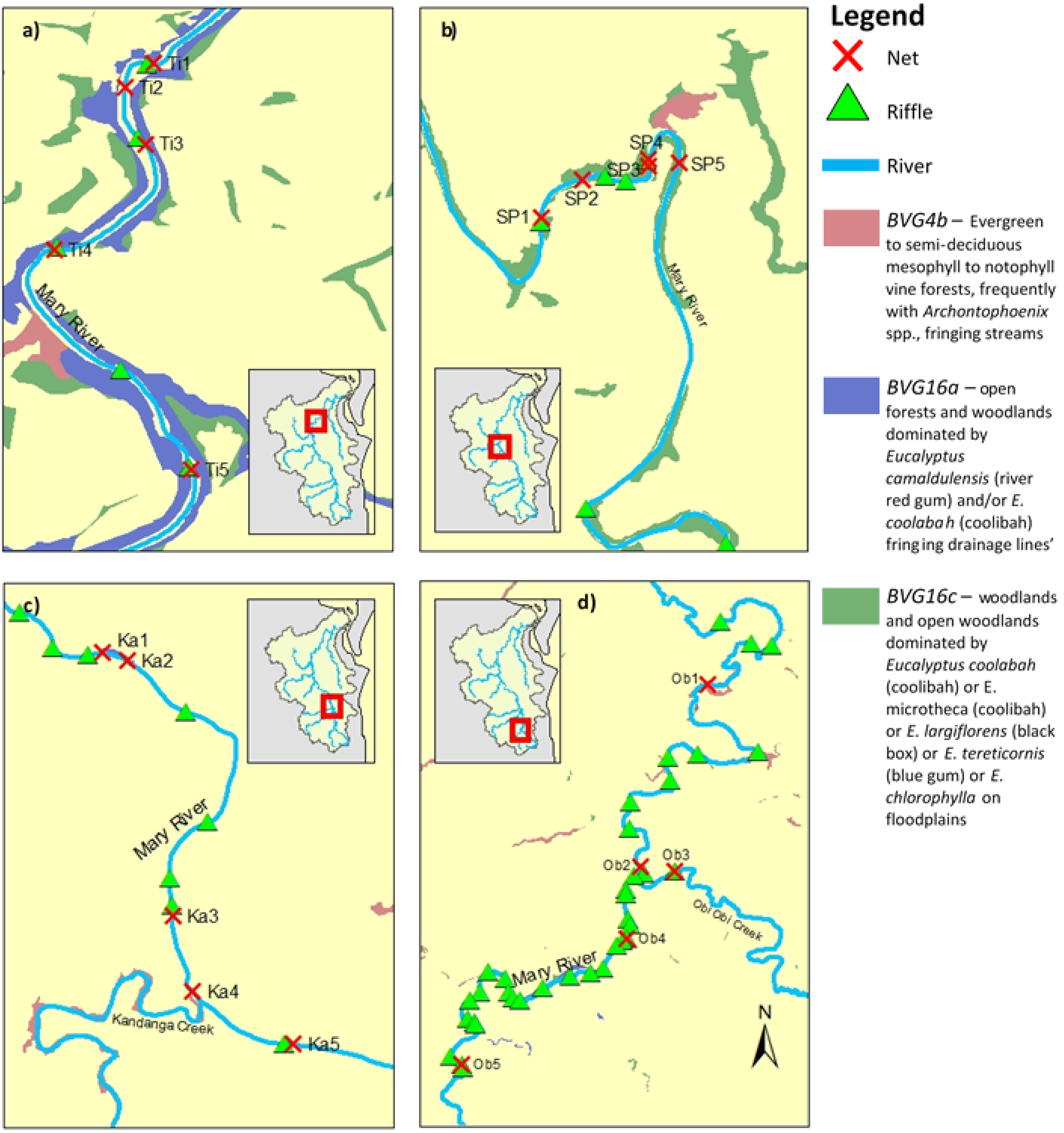

Figure 14: Location of nets and riffles with remnant broad vegetation groups in **a)** lower catchment; **b)** mid-low catchment; **c)** mid catchment; **d)** upper catchment.

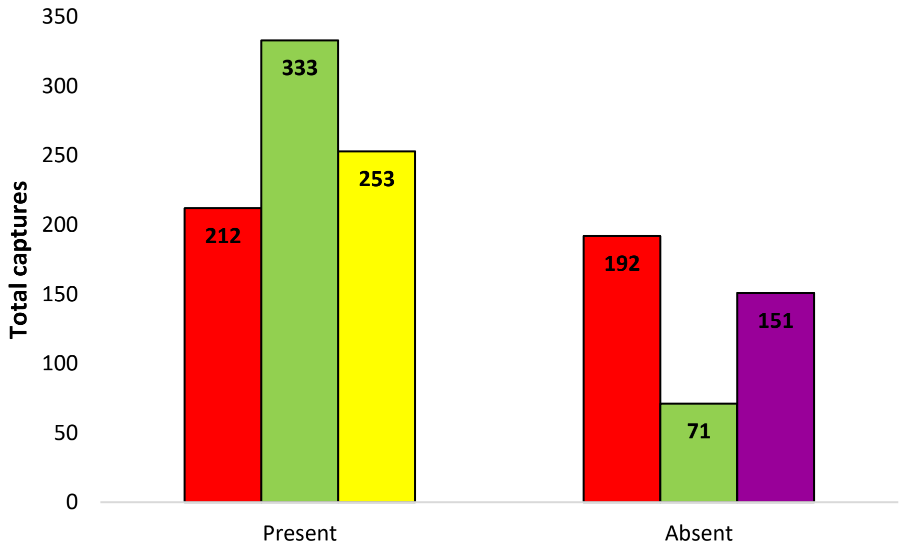

Figure 15: Total captures of *E. macrurus* and the presence or absence of broad vegetation group 4b (red bars) and algae (green bars), and in moderate in-stream condition (yellow bars), and degraded in-stream condition (purple bars).

Table 3: Negative Binomial values for three environmental variables and total *E. macrurus* counts.

Model 1	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	0.9248	0.2454	3.768	0.000164
Moderate In-stream Condition	-0.6762	0.2390	-2.830	0.004662*
BVG 4b	0.6910	0.2274	3.039	0.002377*
Algae Present	0.4626	0.2116	2.186	0.028797*

*Indicates statistical influence ($p<0.05$).
Full set of models can be found in appendix B

Table 4: Negative Binomial values for two environmental variables and total *E. macrurus* counts.

Model 2	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	0.405739	0.259852	1.561	0.1184
BVG 4b	0.544451	0.220235	2.472	0.0134*
Moderate Disturbance/No Vegetation	0.011365	0.004623	2.458	0.0140*

*Indicates statistical influence ($p<0.05$).
Full set of models can be found in appendix B.

Table 5: Negative Binomial values for two environmental variables and total *E. macrurus* counts.

Model 3	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	0.5415	0.2323	2.331	0.0198
BVG 4b	0.4663	0.2480	1.880	0.0601
Algae Present	0.4574	0.2131	2.147	0.0318*

*Indicates statistical influence ($p<0.05$).
Full set of models can be found in appendix B.

Table 6: Negative Binomial values for four environmental variables and total *E. macrurus* counts.

Model 4	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	-0.027937	0.994776	-0.028	0.9776
% Silt/Clay	0.002222	0.018501	0.120	0.9044
BVG 4b	0.518745	0.221006	2.347	0.0189*
Algae Present	0.439004	0.212214	2.069	0.0386*
Major Disturbance/No Native Vegetation	0.012404	0.012491	0.993	0.3207

*Indicates statistical influence (p<0.05).
Full set of models can be found in appendix B.

Table 7: Summary of ANOVA results for negative binomial models for *E. macrurus* catch rate and environmental variables.

	Df	**AIC**	**Deviance**	**Chisq**	**Pr(>|Chisq|)**
Model 1•	6	554.01	542.01	7.1645	0.007436*
Model 2	5	558.15	548.15	0.00	1.00
Model 3	5	559.17	549.17	0.00	1.00
Model 4	7	558.03	544.03	0.00	1.00

*Indicated a statistical influence (p<0.05).
• Indicates final model used in analysis.

3.3.3 Environmental variables associated with *E. albagula*

The only variable which was seen to have a significant influence on the presence of *E. albagula,* was the percent of pebble in the bedrock material (Tables 8-12). Capture rates were seen to increase as % pebble increased (Df = 5, AIC = 566.4, z = 2.318, p = 0.021) (Figure 16).

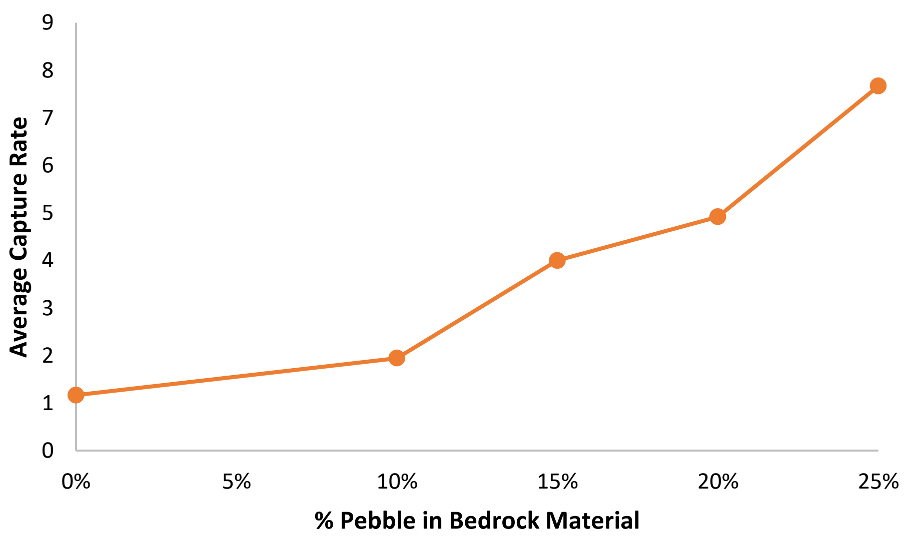

Figure 16: Average capture rate of *E. albagula* and the percent of pebble in the bedrock material.

Table 8: Negative binomial values for most parsimonious environmental variables and total *E. albagula* counts.

Model 5	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	-0.26605	0.57512	-0.463	0.6437
% Pebble	0.07798	0.03365	2.318	0.0205*

*Indicates statistical influence (p<0.05).
Full set of models can be found in appendix C.

Table 9: Negative binomial values for two environmental variables and total *E. albagula* counts.

Model 6	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	-0.29865	0.57111	-0.523	0.6010
% Pebble	0.09683	0.04045	2.394	0.0167*
Moderate In-stream Condition	-0.41100	0.49969	-0.822	0.4108

*Indicates statistical influence (p<0.05).
Full set of models can be found in appendix C.

Table 10: Negative binomial values for four environmental variables and total *E. albagula* counts.

Model 7	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	-0.470300	0.962454	-0.489	0.6251
% Pebble	0.083847	0.044004	1.905	0.0567
Bank Stability – Frequent Major Disturbance	-0.518857	0.850563	-0.610	0.5419
Bank Stability – Frequent Moderate Disturbance	-0.346040	0.592751	-0.584	0.5594
Moderate Disturbance/No Vegetation	0.004377	0.009809	0.446	0.6554
BVG 4b	-0.033685	0.442397	-0.076	0.9393

*Indicates statistical influence (p<0.05).
Full set of models can be found in appendix C.

Table 11: Negative binomial values for three environmental variables and total *E. albagula* counts.

Model 8	**Estimate**	**Standard Error**	**z-value**	**p-value**
(Intercept)	-0.60181	0.80331	-0.749	0.4538
% Pebble	0.08307	0.03588	2.315	0.0206*
Bank Stability – Frequent Major Erosion	-0.38114	0.84818	-0.449	0.6532
Bank Stability – Frequent Moderate Disturbance	-1.18750	1.13147	-1.050	0.2939
Vegetation Condition – Good	0.06901	0.07827	0.882	0.3780

*Indicates statistical influence (p<0.05).
Full set of models can be found in appendix C.

Table 12: Summary of ANOVA results for negative binomial models for *E. albagula* catch rate and environmental variables.

	Df	**AIC**	**Deviance**	**Chisq**	**Pr(>|Chisq|)**
Model 5•	4	566.40	558.40	4.6757	0.0306
Model 6	5	567.73	557.73	0.6751	<0.001
Model 7	8	573.58	557.58	2.2613	0.1327
Model 8	7	571.00	557.00	0.00	1.00

* Indicated a statistical influence (p<0.05).
• Indicates final model used in analysis.

4.0 Discussion

This study used rate of turtle capture as a measure of *Elusor macrurus* and *Elseya albagula* abundance throughout the Mary river in Queensland. Capture rates from 96 trapping nights distributed over twenty locations showed that *E. macrurus* dominated the upper and middle catchment, *E. albagula* dominated the lower catchment, with both species equally represented in the mid-low catchment. Generalised linear mixed models revealed that the abundance of *E. macrurus* was significantly influenced by the presence of algae in the river, the presence of broad leafed vegetation along the river banks, and an improved in-stream condition. In contrast, *E. albagula* abundance distribution was only influenced by one of the 13 environmental variables tested. This variable was the presence of pebbles within the river, with more *E. albagula* occurring where pebbles formed a high proportion of the substratum. These results are discussed in the context of the biology of each species, and the implications for river restoration and management of these endangered species.

4.1 Temporal trends in capture rate

It has been documented that the method of capture can result in bias when assessing population from capture rates (Carothers, 1979). Here we show that neither species became trap shy or trap 'happy' over time, and capture rates showed no significant trend with the sequential day within each trapping episode. There was also no significant difference in the observed spatial distribution in abundances of species over time. There was however, a significant seasonal effect on the relative abundance of the sex captured. A higher abundance of female *E. albagula* were captured in winter and female *E. macrurus* in spring. These observed seasonal shifts in the capture rate of females correlate with the time of year that the females from each species would be moving to nesting sites (Micheli-Campbell, 2012; TSSC, 2014).

4.2 Spatial trends on capture rates

Previous studies have reported these two species to be found throughout the Mary River (Thompson, 2006; Limpus, 2008). Whilst this study agrees with this previous work, it further revealed that the relative abundance of each species shifts throughout the upper, middle, and lower catchments. The observed inter-species difference in abundance distribution throughout the river are likely related to the differences in stream morphology between the upper, middle and lower catchments. The upper catchment is characterised by shallow fast-flowing runs, glides and riffles, the middle by runs, riffles and small pools, and the lower catchment with long, deep pools (MRCCC, 2001). These relative differences in stream morphology will result in very different environmental characteristics, and the relative preference of each species to specific environmental characteristics is discussed below (section 4.3).

A larger number of juveniles, of both species, were captured in the upper reaches with a reduction in numbers in the middle and lower catchments. The reason for this greater number of juveniles captured in the upper reaches is unlikely to have been influenced by the capture technique, because the method of capture was replicated identically throughout the river. Other reasons for lack of juveniles in the lower catchment may have been reduced water quality, food availability, and increased levels of predation. In this study, as by-catch, there was a higher number of forked-tail catfish (*Arius graeffei*) over 0.5m which were captured in the lower catchment (Appendix D). This species has been known to predate on juvenile freshwater turtles (Blamires & Spencer, 2013; Micheli-Campbell et al., 2013). The deep, turbid pools in the lower reaches would also be unsuited for juveniles due to high anoxia levels. Both these species respire aquatically through capillary bursae in the tail, and empirical studies have shown that as water oxygen levels decrease, juveniles of these species need to surface more frequently (Clark, 2002; Dinkelacker et al., 2005; Ultsch, 2005). This would result in increased predation in low oxygenated waters for these species.

4.3 Relationship between species abundance and environmental characteristics

4.3.1 *Elusor macrurus*

Elusor macrurus is considered a dietary specialist (Micheli-Campbell et al., 2017). Specialists are typically impacted more heavily with the fragmentation of their habitat and with negative changes in their environment (Pandit et al., 2009). For this study, in-stream condition was measured by macrophyte richness and abundance, fish species richness, large woody debris (LWD) abundance, and bank overhang (MRCCC, 2001). LWD can provide microhabitats for food sources, shelter and basking opportunities for turtles (Bodie, 2001; Hamann et al., 2008; Paterson, 2011; Sterrett et al., 2011). Bank overhang contributes to LWD in the river, and also provides food resources (e.g. dropped leaves and fruit) and shades the river, preventing high mid-day summer water temperatures. The presence of good to moderate in-stream condition significantly influenced the abundance of *E. macrurus*.

E. macrurus abundance was also influenced by the presence of algae in the river. Stomach content analysis of *E. macrurus* has suggested that they predominately feed on algae (Flakus, 2002;

Limpus, 2008; Tucker, 2000). However, stable isotope analysis has showed that their diet also includes the invertebrates that feed on the algae (Micheli-Campbell et al., 2017). The dependence on algae as food sources is reported to differ between adults and juveniles, with juveniles predominately feeding on aquatic invertebrates, with only a small portion of their diet consisting of plant material (Flakus, 2002). Whether or not algae are the dominant food source of *E. macrurus*, its presence in the river is important for other potential food sources of these turtles, (Marescaux et al., 2016).

The final environmental characteristic that was significant in influencing *E. macrurus* abundance was the broad vegetation group (BVG) 4b. This group is described as 'evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with *Archontophoenix* spp., fringing streams' (Neldner et al., 2010). This BVG, unlike others found throughout the catchment, is typically found in leptic tenosis soils (Neldner et al., 2010) which are characterised by a shallow (<0.5m) topsoil, underlain with a hard layer of unweathered rocks (Isbell, 2016). Whilst many of the emergent species typically have extensive root systems (Noosa and District Landcare Group, n.d), it is possible that this hardened layer prevents these trees, and those in the canopy and understory from developing deep, stabilising roots. In years of flooding, which is typical for the Mary River Catchment, these trees which have shallow root systems would be ripped up and end up as large woody debris (LDW) in the river (Noosa and District Landcare Group, n.d). It is likely that this forms ideal habitat for *E. macrurus* to refuge within.

The presence of these three environmental characteristics in influencing *E. macrurus* abundance makes sense biologically. This species like to refuge in submerged woody debris, with access to safe sun basking platforms, yet remaining close to fast flowing shallow water to feed on algae and the invertebrates that feed upon algae.

4.3.2 *Elseya albagula*

Previous studies have reported *E. albagula* to also be environmental specialists, preferring clear, well aerated waters (Hamann et al., 2008; Thompson et al., 2006; TSSC, 2014). However, a more recent study using acoustic telemetry and tissue stable isotope analysis reported them to have a more generalist lifestyle, consuming a wide variety of food sources, and also with a fairly wide distribution (Mary, Burnett and Fitzroy catchments) (Limpus & Sadlier, 2017; Micheli-Campbell et al., 2017; Thompson et al., 2006). Species which have a generalist lifestyle are typically very adaptable to changes in their environment, including the availability of food. In the case of a degraded river, such as the Mary River, it is beneficial to be adaptable in food sources as it enables them to persist in poor conditions for longer than this with more specific requirements (Moll & Moll, 2004). This study is in agreement with the finding that *E. albagula* is a generalist feeder (Micheli-Campbell et al., 2017). Out of the thirteen environmental characteristics tested only one was significant in influencing the abundance of *E. albagula.* The one variable that was significant in determining abundance was the percentage of pebble in the bedrock. Capture rates of *E. albagula* increased with higher proportions of pebble in the bedrock, however, this study did not cover a full spectrum of % pebble (only covered 0%-25%). It is therefore unknown what the optimal percentage of pebble in the bedrock is for this species. As this species are generalists in habitat and food resources, it is not understood why pebble in the substratum would influence *E. albagula* distribution. It is likely to relate to a resource.

4.4 Limitations of the study

A limitation of this study was the spatial scale of the environmental assessments. Whilst the MRCCC assigned reaches based on similarity of river characteristics, these characteristics may not be representative of the smaller scale changes in these characteristics surrounding the turtle capture nets used in this study. For example, the Mary 11 stretch covers approximately 80km of river and as such would encompass numerous small-scale differences in river characteristics. Similarly, it could cover a number of pockets which have favourable characteristics and therefore are hot spots for these species.

Another limitation was that there may be other environmental characteristics which were not assessed which could have been influencing turtle abundance. Other characteristics such as dissolved oxygen, water temperature and nutrient levels are important for variables which are influential for turtle distribution (Smith et al., 1999). We did not however, have access to these data for the duration of this study. Similarly, climate processes (i.e. rainfall, cyclones, heatwaves) and lunar cycles have been shown to influence turtle behaviour, food abundance and nesting schedules, and thus could alter turtle abundance throughout the river (Jensen & Indraneil, 2008). However, our results were consistent over the 6 trapping episodes, demonstrating that the environmental characteristics which were selected were relevant.

A major limitation for this study was that the river is extensively degraded throughout, so there is no section of river which can compare against pristine conditions. Also study sites did not encompass a full scale of some variables (e.g. only 0-25% pebble, only moderate and degraded in stream condition), and therefore it was difficult to estimate the optimal conditions. It would be expected that with better river condition these species would thrive, as better river condition is conducive to more abundant food resources and biodiversity at whole (Bodie, 2001).

There was also a potential bias towards the capture of adult turtles using the fyke net capture technique. This is because adult turtles have larger home ranges, move greater daily distances and are generally more active than juveniles (Micheli-Campbell, 2012; Micheli-Campbell et al., 2017). Therefore, the probability of adults being captured in this type of passive net was greater than for juveniles. However, we standardised the net setting techniques between the locations and so the relative difference between adult and juvenile capture rate is likely to be actual.

4.5 Significance of this study & Implications for management

Elusor macrurus is currently listed as 'endangered' under both national, EPBC Act 1999 & Nature Conservation Act 1992, as well as under international legislation, IUCN Red List (IUCN, 2017). *E. albagula* is listed as 'critically endangered' under national legislation and is yet to be assessed for IUCN listing (IUCN, 2017). Whilst the results from this study does not alter their classification, it does provide some information stated in the conservation advice for these species and highlight the inadequacies in the current management of these species. Current conservation advice prioritises the protection of nests and nesting banks for both these species as well as the maintenance of water flow (TSSC, 2008; 2014). The suggested management for these priorities however, is not representative of their respective habitat requirements, particularly with respect to in-stream condition and riparian vegetation for *E. macrurus*.

This study has provided information as to the environmental elements which influence the distribution which could be extrapolated to identify hotspots throughout the river, and direct future management plans. The plan for *E. macrurus* needs to redirect some management efforts into the improvement of the river quality which as yet, it currently doesn't consider. This could be in the form of revegetating the banks and riparian zones with species found in broad vegetation group 4b. This would have considerable beneficial effects on in-stream condition by preventing bank slumping, limiting the access by stock, as well as providing a buffer for the polluted runoff from farms. The current management plan for *E. albagula* suggests management authorities prioritise the improvement of water quality and maintenance of water flow. However, for *E. albagula* in the Mary River catchment, these were shown not to influence their distribution. There was also no mention of prioritising habitat for their food sources, including pebble zones, which were shown to be a key driver of their population distribution.

It is proposed that *E. albagula* populations could be reduced by up to 96% in one generation without management interventions, due to an extreme lack of recruitment (McDougall et al., 2015). As such, management efforts for these turtles need to be effective, with well-guided advice. The management plans for these turtles emphasise the need for actions to increase the recruitment into the population, through hatchery programs and egg protection. As there is currently no official hatchery program for these turtles, there needs to be investment in this area of focus, in order to improve hatchling recruitment. However, there also needs to be a focus on aquatic predators of hatchlings, particularly in the lower stretches where this research suggests predation is very high.

Also nest protection for both these species is concentrated in the lower catchment. This study found few juveniles in this stretch of river, suggesting this is poor juvenile habitat. Surveys need to be undertaken in the upper catchment for nesting habitat, and a nest protection program established in these sections of the river.

4.7 Future research

This research has provided insight into the environmental characteristics which drives the population distribution and abundance of these two endangered species, however, in doing so it has also indicated the areas of their life which requires more study, primarily the early years. As both these species have aging populations due to the lack of recruitment, it is important to comprehensively understand the processes which are driving this. If it were that immatures and juveniles migrated up tributaries where there is improved water quality and fewer predators, river management authorities and conservation groups should monitor these areas to note any changes which could cause these areas to become unfavourable.

With the constantly changing climate conditions occurring across the world and in Australia particularly, there needs to be long term research to identify how these are affecting these turtles and freshwater turtles as a whole. The Mary River catchment is located in a unique climate for aquatic animals, with annual floods and extreme drought conditions (BOM, 2017). These both have drastic impacts on river systems, causing fragmentation, loss of food sources and reduced water quality (Gibbons et al., 1997; Ocock et al., 2017), however with this new insight into the environmental requirements of *E. macrurus* and *E. albagula,* it is crucial to understand how these turtles are affected by these weather events.

The overall goal of this research was to gain an understanding of the habitat preferences of two endangered turtle species throughout the Mary River. *E. albagula* and *E. macrurus* were originally thought to have similar habitat and dietary requirements, which has led to them being managed in the same manor. *E. albagula* in particular was thought to prefer fast flowing, however this study has demonstrated that the capture of these turtles is higher in the stretches of the river which contain slow-moving pools. This is consistent with recent telemetry studies of this species which suggests they tend to forage in these areas. The results from this study has generated new insight into the environmental variables which drive this difference in distribution and lifestyle for these turtles. It has also highlighted the inadequacy of the current recovery plans for these species which manages them as if they have similar habitat requirements. Finally, this study highlighted the disproportionate abundance of juveniles in the upper compared to the lower catchment. Most of the identified nesting habitat for both these species is in the lower catchment. The distance between these stretches of river is hundreds of kilometres, and acoustic telemetry studies have suggested that juvenile turtles do not naturally migrate up river (Micheli-Campbell et al., 2012). Therefore, further research should concentrate on understanding the disparity between the location of nests and presence of juveniles in the river. This information is urgently required for the persistence and reversal of decline for both these threatened species in the Mary River.

5.0 References

Anthonysamy, W, Dreslik, M & Phillips, C, 2013, ‘Disruptive Influences of Drought on the Activity of a Freshwater Turtle’, American Midland Naturalist, vol. 169, no. 2, pp, 322-335.

Bates, D, Maechler, M, Bolker, B & Walker, S, 2015, ‘Fitting Linear Mixed-Effects Models Using lme4’. *Journal of Statistical Software*, vol. 67, no. 1, 1-48. doi:10.18637/jss.v067.i01.

Bellinger, E., & Sigee, D, 2015, *Freshwater Algae Identification, Enumeration and Use as Bioindicators*, 2nd ed., Hoboken: Wiley.

Blamires, S & Spencer, RJ, 2013, ‘Influence of habitat and predation on population dynamics of the freshwater turtle *Myuchelys georgesi*’, *Herpetologica*, vol. 69, no. 1, pp, 46-57.

Bodie, J.R., 2001, ‘Stream and riparian management for freshwater turtles’, *Journal of Environmental Management*, vol. 62, no. 4, pp.443-455.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H. and White, J.S.S., 2009, ‘Generalized linear mixed models: a practical guide for ecology and evolution’, *Trends in ecology & evolution*, vol. 24, no. 3, pp.127-135.

Breen, M. J. & Ruetz, C. R, 2006, ‘Gear Bias in Fyke Netting: Evaluating Soak Time, Fish Density, and Predators’, *North American Journal of Fisheries Management,* vol.26, no. 1, pp. 32-41.

Buhlmann, K, Akre, T, Iverson, J, Karapatakis, D, Mittermeier, R, Georges, A, Rhodin, A, van Dijk, P & Gibbons, J, 2009, A Global Analysis of Tortoise and Freshwater Turtle Distributions with Identification of Priority Conservation Areas, *Chelonian Conservation and Biology,* vol. 8, no. 2, pp. 116-140.

Bureau of Meteorology [BOM], 2017, *Mary River Flood Warning System*, [online] Bom.gov.au, <http://www.bom.gov.au/qld/flood/brochures/mary/mary.shtml#PreviousFlooding>, accessed 14 Sep. 2017.

Cann, J. & Legler, J. 1994, ‘The Mary River tortoise: a new genus and species of short-necked *chelid* from Queensland, Australia (Testudines: Pleurodira)’, *Chelonian Conservation and Biology*, vol. 1, pp. 81–96.

Cann, J & Sadlier, R 2017, *Freshwater turtles of Australia*, CSIRO Publishing.

Carothers, A, 1979, ‘Quantifying Unequal Catchability and its Effect on Survival Estimates in an Actual Population’, *Animal Ecology*, vol. 48, no. 3, pp. 863-869.

Chessman, B 2011, ‘Declines of freshwater turtles associated with climatic drying in Australia’s Murray–Darling Basin’, *Wildlife Research*, vol. 38, pp. 664-671.

Clark, N, 2008, *The diving physiological ecology of Australian freshwater turtle hatchlings*, PhD thesis, University of Queensland.

Deepayan, S, 2008, *Lattice: Multivariate Data Visualization with R*. Springer, New York. ISBN 978-0-387-75968-5.

Department of Environment, Water, Heritage and the Arts [DoEWHA] 2008, *Threatened Ecological Community Nomination Form - for listing or changing the status of an ecological community under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act),* Department of Environment, Water, Heritage and the Arts, Australian Government.

van Dijk, P, Stuart, B & Rhodin, A, 2000, *Asian Turtle Trade: Proceedings of a Workshop on Conservation and Trade of Freshwater Turtles and Tortoises in Asia--Phnom Penh, Cambodia, 1-4 December 1999*. Lunenburg, Mass.: Chelonian Research Foundation.

Dinkelacker, S, Costanzo, J & Lee Jr, R, 2005, Anoxia tolerance and freeze tolerance in hatchling turtles, *Journal of Comparative Physiology Biology*, vol. 175, no. 3, pp. 209-217.

Dudley, M, Ho, M & Richardson, C, 2015, Riparian Habitat Dissimilarities in Restored and Reference Streams are Associated with Differences in Turtle Communities in the Southeastern Piedmont, *Wetlands*, vol. 35, no. 1, pp. 147-157.

Flakus, S. 2002, *Ecology of the Mary River Turtle*, Elusor macrurus, M.Sc. Thesis, University of Queensland.

Fournier DA, Skaug HJ, Ancheta J, Ianelli J, Magnusson A, Maunder M, Nielsen A and Sibert J, 2012, ‘AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models.’, *Optim. Methods Software*, vol. 27, pp. 233-249.

Fox J, & Weisberg S, 2011, *An {R} Companion to Applied Regression*, Second Edition. Thousand Oaks CA: Sage. URL: http://socserv.socsci.mcmaster.ca/jfox/Books/Companion

Freeman, A, 2011, ‘*Johnstone River Snapping Turtle (Elseya irwini Johnstone) on the Atherton Tablelands: Summary report for the 2011 monitoring’*, Department of Environment and Resource Management, Queensland Government.

Gibbons, J.W., Burke, V.J., Lovich, J.E., Semlitsch, R.D., Tuberville, T.D., Bodie, J.R., Greene, J.L., Niewiarowski, P.H., Whiteman, H.H., Scott, D.E. and Pechmann, J.H., 1997, Perceptions of species abundance, distribution, and diversity: lessons from four decades of sampling on a government-managed reserve, *Environmental Management*, vol. 21, no. 2, pp.259-268.

Hamann, M, Schäuble, C, Limpus, D, Emerick, S, and Limpus, C, 2007, Management plan for the conservation of Elseya sp. [Burnett River] in the Burnett River Catchment. Brisbane, QLD.

Hamann, M, Schäuble, C, Emerick, S, Limpus, D & Limpus, C, 2008, 'Freshwater turtle populations in the Burnett River', *Memoirs of the Queensland Museum*, vol. 52, no. 2 pp. 221–232, Brisbane.

Isbell, R., 2016. *The Australian soil classification*. CSIRO publishing.

The IUCN Red List of Threatened Species [IUCN], version 2017-1, <www.iucnredlist.org>, accessed on 09 June 2017.

Jensen, K.A. and Indraneil, D, 2008, Observations on the influence of seasonality, lunar cycles, and weather condition on freshwater turtle activity in Sarawak, East Malaysia (Borneo), *Asiatic Herpetological Research*, vol. 11, pp.37-42.

Limpus, D, Limpus, C and Hodge, W, 2006, *Impacts of dams and weirs on freshwater turtles: Fairbairn Dam, March 2006*, Environmental Protection Agency.

Limpus, C, 2008, 'Freshwater Turtles in the Mary River: Review of biological data for turtles in the Mary River, with emphasis on *Elusor macrurus* and *Elseya albagula'*, Brisbane, Queensland Government.

Lüdecke D, 2017, *sjPlot: Data Visualization for Statistics in Social Science*. R package version 2.3.1, <URL: https://CRAN.R-project.org/package=sjPlot>.

Marescaux J, Falisse, E, Lorquet, J, van Doninck, K, Beisel, J and Descy, J, 2016, Assessing filtration rates of exotic bivalves: dependence on algae concentration and seasonal factors, *Hydrobiologica*, vol. 777, no. 1, pp. 67-78.

Mary River Catchment Coordinating Committee [MRCCC] 2001, *Mary River and tributaries rehabilitation plan,* implementation edition, Mary River Catchment Coordinating Committee.

McCabe, D, 2010, Rivers and Streams: Life in Flowing Water, *Nature Education Knowledge* vol. 1, no. 12, pp. 1-14.

McDougall, A, Espinoza, T, Hollier, C, Limpus, D & Limpus, C, 2015, A Risk Assessment Approach to Manage Inundation of Elseya albagula Nests in Impounded Waters: A Win–Win Situation?, *Environmental management*, vol. 55, no. 3, pp.715-724.

Micheli-Campbell, M, 2012, *Habitat requirements for nesting and early life-stages of the endangered Mary River turtle (*Elusor macrurus*): Insights for conservation*, PhD Thesis, University of Queensland.

Micheli-Campbell, M, Campbell, H, Connell, M, Dwyer, R, Franklin, C, 2013, ‘Integrating telemetry with a predictive model to assess habitat preferences and juvenile survival in an endangered freshwater turtle’, *Freshwater Biology*, vol. 58, no. 11, pp. 2253-2263.

Micheli-Campbell, M, Connell, M, Dwyer, R. Franklin, C, Fry, B, Kennard, M, Tao, J, Campbell, H, 2017, ‘Identifying critical habitat for freshwater turtles: integrating long-term monitoring tools to enhance conservation and management’, *Biodiversity and Conservation*, vol. 26, no. 7, pp. 1675-1688.

Moll, D. and Moll, E.O., 2004, *The ecology, exploitation and conservation of river turtles*, Oxford University Press on Demand.

Neldner, V, Niehus, R, Wilson, B, McDonald, W, Ford, A & Accad, A 2010, *The Vegetation of Queensland: Descriptions of Broad Vegetation Groups*, Department of Science, Information Technology and Innovation, ver. 3, Queensland Herbarium, Atherton, QLD.

Noosa and District Landcare Group, n.d, *Native Trees & Shrubs recommended for creekbank planting,* <https://noosalandcare.org/support_documentation/CREEKBANK_PLANTING.pdf>

Ocock, J, Bino, G, Wassen, S, Spencer, J, Thomas, R and Kingsford, R, 2017, Identifying Critical Habitat for Australian Freshwater Turtles in a Large Regulated Floodplain: Implications for Environmental Water Management, *Environmental Management*, pp. 1-15.

Pandit, S, Kolasa, J & Cottenie, K, 2009, Contrasts between habitat generalists and specialists: an empirical extension to the basic metacommunity framework, *Ecology*, vol. 90, no. 8, pp.2253-2262.

Paterson, J, 2011, *Resource selection in a freshwater turtle community in central Ontario*, Master’s Thesis, School of Graduate Studies, Laurentian University.

Pointon, S & Collins A 2000, *Mary River Catchment Resource Atlas*, Mary River Catchment Coordinating Committee.

R Core Team, 2017, *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria, <https://www.R-project.org/>.

Science, Information Technology and Innovation, Queensland Government 2017, *Broad vegetation groups - pre-clearing and 2015 remnant - Queensland series*, ver. 3.0, GIS Dataset, https://data.qld.gov.au/dataset/broad-vegetation-groups-pre-clearing-and-2015-remnant-queensland-series/resource/3ebd5a2e-20a7-4a0a-a252-4f8721dbcd57

Skaug H, Fournier D, Bolker B, Magnusson A and Nielsen A, 2016, *Generalized Linear Mixed Models using 'AD Model Builder'*. R package version 0.8.3.3.

Smith, V, Tilman, G and Nekola, J, 1999, Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems, *Environmental pollution*, vol. 100, no. 1, pp.179-196.

Steen, D, Gibbs, J, Buhlmann, K, Carr, J, Compton, B, Congdon, J, Doody, J, Godwin, J, Holcomb, K, Jackson, D and Janzen, F, 2012, Terrestrial habitat requirements of nesting freshwater turtles, *Biological Conservation*, vol. 150, no. 1, pp.121-128.

Sterrett, S.C., Smith, L.L., Golladay, S.W., Schweitzer, S.H. and Maerz, J.C., 2011, The conservation implications of riparian land use on river turtles. *Animal Conservation*, vol. 14, no. 1, pp.38-46.

Stokeld, D, Hamer, A, van der Ree, R, Pettigrove, V & Gillespie, G, 2014, Factors influencing occurrence of a freshwater turtle in an urban landscape: a resilient species? *Wildlife Research*, vol. 41, no. 2, pp. 167-171.

Thompson, S. Georges, A. and Limpus, C. 2006, ‘Freshwater Turtle in the Genus *Elseya* (Testudines:- Chelidae) from Central Coastal Queensland, Australia’, *Chelonian Conservation and Biology*, vol. 5, no. 1, pp. 74-86.

Threatened Species Scientific Committee [TSSC] 2008, Commonwealth Conservation Advice on *Elusor macrurus* (Mary River Turtle), Department of the Environment, Water, Heritage and the Arts, http://www.environment.gov.au/biodiversity/threatened/species/pubs/64389-conservation-advice.pdf

Threatened Species Scientific Committee [TSSC] 2014, Conservation Advice for *Elseya albagula* White-throated snapping turtle, Canberra: Department of the Environment, http://www.environment.gov.au/biodiversity/threatened/species/pubs/81648-conservation-advice.pdf.

Tucker, A, 1999, *Cumulative effects of dams and weirs on freshwater turtles: Fitzroy, Kolan, Burnett and Mary Catchments*, Queensland Parks and Wildlife Service.

Tucker, A, Guarino, F and Priest, T, 2012, Where lakes were once rivers: contrasts of freshwater turtle diets in dams and rivers of southeastern Queensland. *Chelonian Conservation and Biology*, vol. 11, no. 1, pp.12-23.

Turtle Conservation Coalition [TCC] 2011, 'Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles—2011. Lunenburg, MA: IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Turtle Conservation Fund, Turtle Survival Alliance, Turtle Conservancy, Chelonian Research Foundation, Conservation International, Wildlife Conservation Society, and San Diego Zoo Global, 54 pp.

Ultsch, G.R., 2006, The ecology of overwintering among turtles: where turtles overwinter and its consequences, *Biological reviews*, vol. 81, no. 3, pp. 339-367.

Walker K 2008, *Environmental Impact Statement for Traveston Crossing Dam (Mary River, Queensland): A Review with regard for Species of Concern under the EPBC Act 1999.* Report to the Department of Environment, Water, Heritage and the Arts, Canberra. November 2008.

Wickham, H, ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2009.

Appendix

Appendix A – Net Setting parameters

Table 1: Key of variable acronyms and their meaning

Variables	
NID	Net ID
SEAS	Season of trapping – autumn or spring
DOC	Day of capture
LOC	Location of net – recorded as Obi Obi, Kandanga, Scotchy Pocket or Tiaro
MRTT	Total *E. macrurus* counts
MRTF	Total counts of female *E. macrurus*
MRTM	Total counts of male *E. macrurus*
WTSTT	Total *E. albagula* counts
WTSTF	Total counts of female *E. albagula*
WTSTM	Total counts of male *E. albagula*
HUN	Hydraulic units upstream of net
HDN	Hydraulic units downstream of net

Table 2: Summary of models and results assessing total *E. macrurus* counts with different combinations of variable. Location and day of capture (i.e. DOC|LOC) or location (1|LOC) were noted as a random variable(s) in the models.

Models	Df	AIC	p-value	GLMM Type
MRTT ~ DOC + SEAS + (DOC|LOC) •	7	1195.1	<0.001	Negative Binomial
WTSTT ~ SEAS + (1|LOC) •	4	1193.0	<0.001	Negative Binomial
WTSTT ~ DOC + (DOC|LOC) •	6	1213.0	1	Negative Binomial
WTSTT ~ DOC + SEAS + (DOC|LOC)	7	1198.5	FTC	Negative Binomial
WTSTT ~ DOC + SEAS + (1|LOC)	5	1194.9	FTC	Negative Binomial
MRTT ~ DOC + SEAS + (DOC|LOC)	6	1274.1	<0.001	Poisson°
WTSTT ~ DOC + SEAS + (DOC|LOC)	6	1323.5	0.289	Poisson°
MRTT ~ DOC + SEAS + (1|LOC)	4	1303.7	1	Poisson°
WTSTT ~ DOC + SEAS + (1|LOC)	4	1322.0	1	Poisson°
MRTF ~ SEAS + (1|LOC) •	5	338.8	0.02652	Zero-inflation
MRTM ~ SEAS + (1|LOC) •	5	473.9	1	Zero-inflation
MRTF ~ SEAS + (1|LOC)	4	336.6	0.019836	Negative Binomial
MRTF ~ SEAS + (1|LOC)	3	340.0	0.005316	Poisson°
MRTM ~ SEAS + (1|LOC)	4	474.7	<0.001	Negative Binomial
MRTM ~ SEAS + (1|LOC)	3	513.7	1	Poisson°

• Denotes model used in final analysis
FTC indicates a model failed to converge in analysis
° indicated that the model is over dispersed

Table 3: Summary of models and results assessing total *E. macrurus* counts with net setting parameters. Net ID is noted as a random variable in the models (i.e. 1|NID).

Model	Df	AIC	p-Value	GLMM type
MRTT ~ HUN + (1|NID) •	6	567.79	0.5863	Negative Binomial
MRTT ~ HDN + (1|NID) •	6	567.31	1.00	Negative Binomial
MRTT ~ HUN + HDN + (1|NID)	9	571.88	FTC	Negative Binomial
WTSTT ~ HUN + (1|NID) •	6	573.84	0.7453	Negative Binomial
WTSTT ~ HDN + (1|NID) •	6	570.45	<0.001	Negative Binomial

WTSTT ~ HUN + HDN + (1|NID)	9	575.65	FTC	Negative Binomial

• Denotes model used in final analysis

FTC indicates a model failed to converge in analysis

° indicated that the model is over dispersed

Appendix B – *Elusor macrurus* model results

Table 4: Key of variable acronyms and their meaning.

Variables	
NID	Net ID
MRTT	Total *E. macrurus* counts
MP	Macrophytes present
AP	Algae present
ISC	In-Stream Condition
PSC	Percent silt/clay in bedrock material
PSA	Percent sand in bedrock material
PGR	Percent gravel in bedrock material
PPE	Percent pebble in bedrock material
PCO	Percent cobble in bedrock material
BS	Bank stability
VFB	Broad vegetation group 4b
VSA	Broad vegetation group 16a
VSC	Broad vegetation group 16c
NRV	Non-remnant vegetation
VG	Good vegetation condition
MID	Vegetation condition – minor disturbance
MDNV	Vegetation condition – major disturbance/no native vegetation

Table 5: Summary of negative binomial models and results assessing total *E. macrurus* counts with different combinations of variable. Net ID noted as a random variable in the models (i.e. 1|NID).

Models	**Df**	**AIC**	**p-value**
MRTT ~ AP + VFB + ISC + (1|NID) •	6	554.01	<0.01
MRTT ~ VFB + AP + MID + (1|NID)	6	556.07	FTC
MRTT ~ VFB + AP + MDNV + (1|NID)	6	556.04	FTC
MRTT ~ PSC + VFB + AP + MID + (1|NID)	7	557.84	FTC
MRTT ~ VFB + AP + MDNV + MID + (1|NID)	7	557.86	FTC
MRTT ~ PSC + VFB + AP + MDNV + (1|NID)	7	558.03	1.000
MRTT ~ VFB + AP + BS + (1|NID)	8	565.04	1.000
MRTT ~ VFB + MP + BS + (1|NID)	8	569.40	1.000
MRTT ~ VSA + MP + ISC + BS + (1|NID)	9	570.40	1.000
MRTT ~ AP + MID + (1|NID)	5	560.06	0.0277
MRTT ~ AP + MDNV + (1|NID)	5	559.08	FTC
MRTT ~ VFB + MID + (1|NID)	5	558.10	FTC
MRTT ~ VFB + MDNV + (1|NID)	5	558.15	1.000
MRTT ~ VFB + MDNV + BS + (1|NID)	8	562.32	FTC
MRTT ~ VFB + MDNV + PSC + (1|NID)	6	560.15	1.000
MRTT ~ VFB + MDNV + ISC + (1|NID)	6	557.60	FTC
MRTT ~ VFB + AP + (1|NID)	6	559.17	1.000
MRTT ~ VBF + AP + ISC + MDNV + (1|NID)	7	555.19	FTC
MRTT ~ VFB + AP + ISC + PPE + (1|NID)	7	551.68	FTC
MRTT ~ VSC + MP + BS + PPE + (1|NID)	9	574.13	FTC

• Denotes model used in final analysis

FTC indicates a model failed to converge in analysis

Appendix C – *Elseya albagula* model results

Table 6: Key of variable acronyms and their meaning

Variables	
NID	Net ID
WTSTT	Total *E. macrurus* counts
MP	Macrophytes present
AP	Algae present
ISC	In-Stream Condition
PSC	Percent silt/clay in bedrock material
PSA	Percent sand in bedrock material
PGR	Percent gravel in bedrock material
PPE	Percent pebble in bedrock material
PCO	Percent cobble in bedrock material
BS	Bank stability
VFB	Broad vegetation group 4b
VSA	Broad vegetation group 16a
VSC	Broad vegetation group 16c
NRV	Non-remnant vegetation
VG	Good vegetation condition
MID	Vegetation condition – minor disturbance
MDNV	Vegetation condition – major disturbance/no native vegetation

Table 8: Summary of negative binomial models and results assessing total *E. albagula* counts with different combinations of variable. Net ID noted as a random variable in the models (i.e. 1|NID).

Models	**Df**	**AIC**	**p-value**
WSTT ~ PPE + (1|NID)	4	566.4	0.0306
WSTT ~ PPE + AP + (1|NID)	5	567.56	0.3606
WSTT ~ AP + MP + (1|NID)	5	570.47	1.00
WSTT ~ VG + AP + (1|NID)	5	571.74	1.00
WSTT ~ PPE + BS + AP + (1|NID)	7	570.74	0.5686
WSTT ~ PPE + BS + VG + (1|NID)	7	571.00	1.00
WSTT ~ PPE + BS + VFB + (1|NID)	7	573.53	1.00
WSTT ~ PPE + BS + MDNV + VFB + (1|NID)	8	573.58	0.1327
WSTT ~ BS + MID + VFB + (1|NID)	7	574.79	1.00
WSTT ~ BS + MDNV + PSC + (1|NID)	7	574.73	<0.001
WSTT ~ NRV + MDNV + ISC + (1|NID)	7	573.85	FTC
WSTT ~ AP + MDNV + ISC + (1|NID)	6	573.54	1.00
WSTT ~ MP + ISC + (1|NID)	5	570.80	<0.001
WSTT ~ PPE + ISC + (1|NID)	5	567.73	<0.001
WSTT ~ PPE + VSC + (1|NID)	5	567.07	<0.001
WSTT ~ PPE + VSC + BS + VG + (1|NID)	8	572.30	FTC
WSTT ~ PPE + VSC + MID + (1|NID)	6	569.06	<0.001
WSTT ~ PSA + VSC + BS + MDNV + (1|NID)	8	574.16	1.00
WSTT ~ PSA + MP + (1|NID)	5	568.36	1.00
WSTT ~ PSA + BS + VFB + MID + (1|NID)	8	575.33	1.00

• Denotes model used in final analysis

FTC indicates a model failed to converge in analysis

Appendix D – Summary of by-catch in nets

	Lungfish	Catfish		Eel	Mouth Almighty	Spangled Perch	Bony Bream	Sooty Grunter	Hyrtl's Tanden	Tilarpia	Bullrout	Other
		Eel-tailed	Fork-tailed									
Upper												
Ob1	8	11	7	16	-	10	7	-	-	-	-	3x Rainbow fish
Ob2	-	19	5	3	-	10	-	-	-	-	-	
Ob3	3	17	5	3	-	3	4	-	-	1	-	2x Mary River Cod
Ob4	2	5	8	2	-	-	-	-	-	-	-	
Ob5	-	6	-	6	-	1	-	-	-	-	-	
Middle												
SP1	2	2	3	4	1	1	1	1	-	-	-	
SP2	9	5	38	1	1	-	1	3	6	-	2	1x Gar 2x Bass
SP3	-	18	13	7	-	-	5	2	2	3	1	5x Bass
SP4	2	7	8	2	-	-	3	-	-	-	2	
SP5	26	7	7	1	-	-	-	1	-	-	1	1x Yellowbelly
Ka1	68	27	2	6	4	4	6	-	-	-	-	
Ka2	4	17	2	3	3	-	11	-	-	-	1	
Ka3	56	9	4	3	12	-	3	-	-	-	-	2x Saratoga
Ka4	27	3	2	-	-	-	10	-	-	-	-	
Ka5	9	4	4	-	2	-	10	-	-	-	-	
Lower												
Ti1	2	1	63	8	-	1	3	-	-	-	2	
Ti2	-	-	34	13	-	-	6	-	3	1	-	1x Freshwater mullet 1x Platypus 1x Gar
Ti3	-	-	118	9	-	-	6	-	-	-	5	
Ti4	-	-	10	8	-	-	10	-	1	1	3	2x Freshwater mullet
Ti5	-	3	12	7	-	-	7	-	2	1	-	