Population status of the Oblong turtle in Armadale's wetlands

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Executive summary

The Oblong turtle (*Chelodina oblonga*) is becoming a flagship species for Perth wetlands. As an apex predator the species plays an essential role in wetland ecosystem health. However, urban populations appear to be in decline due to numerous threats including habitat modification and destruction, wildlife-vehicle mortality, and predation. Three wetlands within City of Armadale were identified by the Armadale Gosnells Landcare Group as potentially significant sites for populations of the Oblong turtle. No baseline information on the presence and/or population status of *C. oblonga* within these wetlands currently exists. Modified funnel traps and fyke nets were deployed for an overnight trapping period in each wetland during October 2020. In total, thirty-four turtles were captured and released from the wetlands. The turtles captured were mainly adults and the few juveniles captured were >100 mm. Sex ratio varied from heavily male-dominated to slightly female-dominated. The results suggest that these populations have been experiencing low recruitment, and sex biased mortality at the heavily male dominated population. Continued monitoring of these populations as well as expansion of surveys to additional wetlands will enable a deeper understanding of *C. oblonga* population dynamics within the City of Armadale, as well as wetland-specific management recommendations.

Background

The Oblong turtle (*Chelodina oblonga*) is an iconic keystone species that inhabits the wetlands within southwestern Western Australia. *Chelodina oblonga* is endemic, with a range that extends along the coast from the Hill River (inland from Jurien Bay), southeast to the Fitzgerald River National Park (Cann 1998). Within this range, *C. oblonga* inhabits a variety of permanent and semi-permanent wetlands that include natural and constructed lakes, swamps, rivers, and creeks (Burbidge 1967).

The species is the underwater apex predator within its range and is a generalist feeder and an opportunistic carnivore (Woldring 2001). As an apex predator, *C. oblonga* plays a crucial role in aquatic ecosystems and is valuable to humans as it helps to control insect populations. Furthermore, as it is a large-bodied species and visible in wetlands, it has an important role in community education on the value of maintaining biodiversity in wetlands, most of which have been severely altered or degraded on the Swan Coastal Plain (SCP) since European settlement.

Chelodina oblonga is currently listed as 'near threatened' by the IUCN (Tortoise & Freshwater Turtle Specialist Group 1996), although its status has not been assessed for over 20 years. The most comprehensive study on the species was recently conducted by (Santoro, Chambers et al. 2020), and involved surveying 35 Perth wetlands to explicitly determine the factors influencing the status and viability of the remnant populations. The study revealed abundances of *C. oblonga* in most Perth wetlands were alarmingly low. At ~60% of wetlands less than 25 turtles were captured, and no juvenile turtles were captured in ~40% of wetlands studied (Santoro, Chambers et al. 2020). Santoro, Chambers et al. (2020) identified that the accessibility of native vegetation surrounding urban wetlands was a significant factor impacting upon the abundances of *C. oblonga* and the presence of juveniles within the populations, likely owing to it providing suitable nesting sites. Importantly, the study also highlighted the need for better understanding and monitoring of the viability of the remnant populations.

Anecdotal reports suggest that several wetlands within the City of Armadale may be inhabited by *C. oblonga*. Many of the wetlands are located within regional parks and have been identified as environmentally significant for both conservation and recreation. The City of Armadale have identified a need to better understand the wetlands and their fauna in order to preserve and enhance their biodiversity values for present and future generations.

The current survey aimed to develop robust baseline information on the population status and viability of *C. oblonga* in the wetlands of Armadale. Survey methods will follow (Santoro, Chambers et al. 2020) to allow comparability with that study, as well as developing a standard protocol for turtle surveys in the future to facilitate ongoing monitoring.

Objectives

The purpose of the current report is to summarise turtle population data gathered between the 27th and 29th of October 2020 in wetlands within the City of Armadale. This includes:

- Characterising the *C. oblonga* population status and viability within each wetland, and as a region.
- Compare results of the current survey with those of Santoro, Chambers et al. (2020).
- Provide management recommendations to help ensure the long-term viability of this important species in the City of Armadale.
- Recommend additional surveys, monitoring, and research that may be required to fully assess the *C. oblonga* populations within the region.

Methods

Study sites

Three wetlands within the City of Armadale were surveyed for *C. oblonga* (Fig. 1). Wright Lake, Champion Lakes is a large water-based recreational facility. Its water level is maintained by diversion of water flow from the nearby Wungong River. However, when water flow in the Wungong River is too low, Wright Lake is topped up with 2500 ppm salt water (Hunter, pers. comm. 2020). The Wungong river is one of two major rivers within the City of Armadale and is a tributary to the Swan River. Gerald Russell Park, Hilbert is an urban reserve made up of three small lakes, that run alongside a small creek.

Trapping regime

Trapping for *C. oblonga* occurred once in each wetland between the 27th and 29th of October 2020. Each trapping session consisted of one overnight period: modified funnel traps (Kuchling 2003) and fyke nets were set and baited (tinned sardines in vegetable oil) in the afternoon, left overnight, and checked the following morning. Individual *C. oblonga* were prevented from eating the bait by only partially opening the tins, ensuring the bait remained active through to trap retrieval. Floats were placed in all traps to ensure access to the surface for any air-breathing species captured. The number of traps placed in each wetland was dependent upon the size of the wetland; there was a minimum of 10 m between traps (Table A1). See Appendix 1. for trap locations.

Turtle processing and identification

Upon retrieval of each trap, each *C. oblonga* was placed in a clean calico bag and weighed to the nearest 20 g (Rogue Digital Scale 40 kg)). Carapace length and extended tail length (from the base of the plastron to the tip of the tail) were measured to the nearest 1 mm with Vernier calipers (Fig. 2). Carapace length was used to classify individuals as juvenile (male: <129 mm, female: <159 mm) or adult (male: >130 mm, female: >160 mm) (Kuchling 1988, Kuchling 1989). Tail length relative to carapace length was used to determine an individuals' sex (Burbidge 1967). Each turtle (>100 mm) was electronically tagged with a Passive Integrated Transponder (PIT) tag inserted into a skin fold above the tail. Turtles were then released within 5 m of the location they were trapped.

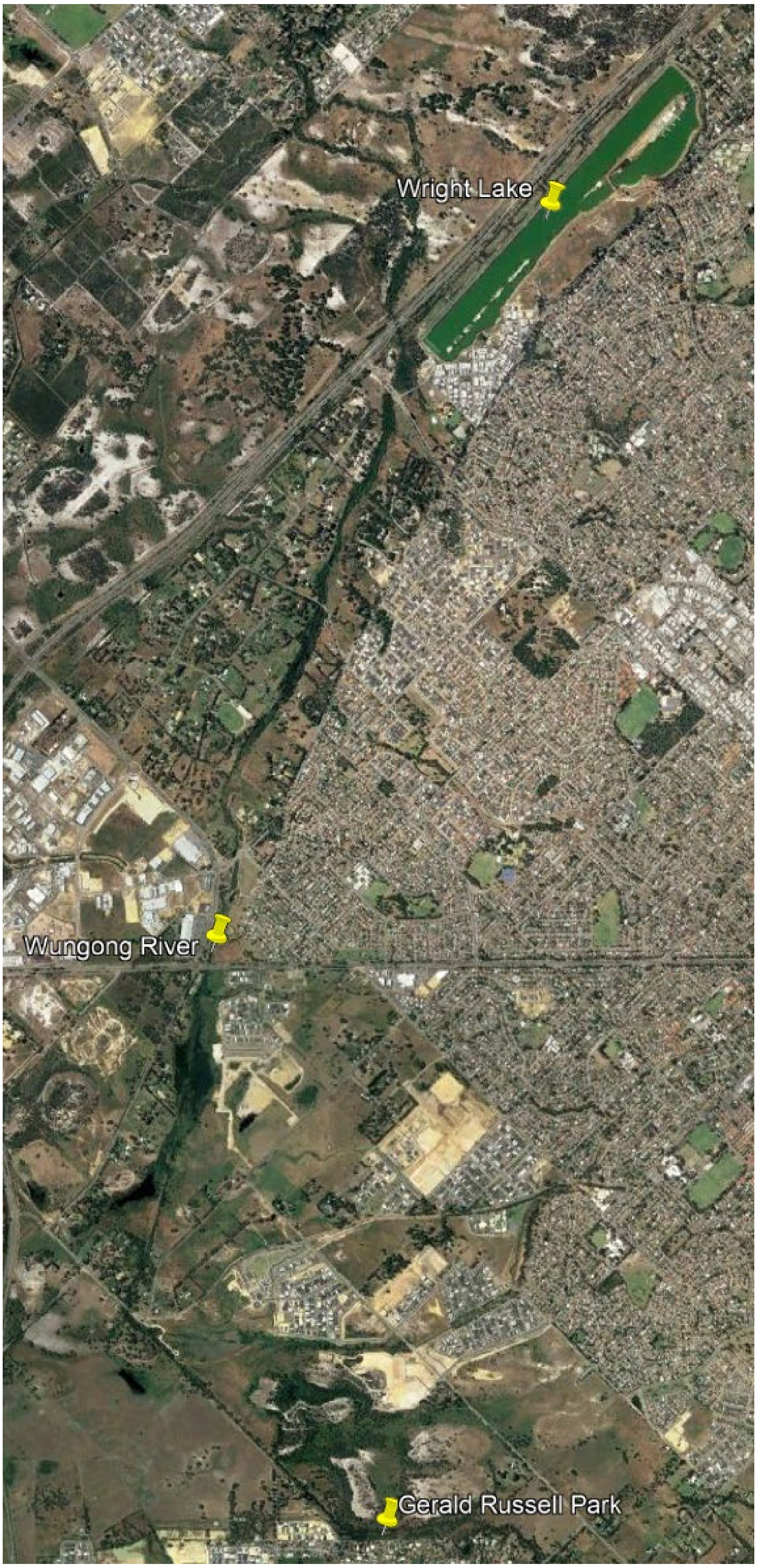

Figure 1. The locations of the three wetlands sampled for *Chelodina oblonga* between 27th and 29th October 2020 on the Swan Coastal Plain, southwest Australia.

Figure 2. Researchers measuring carapace length of a captured *Chelodina oblonga.*

Data analysis

Relative abundance was estimated based on the catch per unit effort (CPUE) for each wetland. As trap effort differed among wetlands, CPUE was calculated for each wetland with the formula CPUE = T / Tn / TH, where T = total number of *C. oblonga* captured, Tn = number of traps, and TH = trap hours. This equation standardised turtle captures to relative abundance so they could be compared among wetlands of different size. Chi-squared tests of homogeneity were used to analyse whether sex ratios were biased in *C. oblonga* populations. Sex ratios (male:female) at each wetland were compared against a 1:1 ratio. These analyses were performed in R (Studio version 1.2.1335, 2019; R Development Core Team, 2013).

Results

A total of 34 *C. oblonga* were captured during the study and *C. oblonga* were present in all (100.0%) of the wetlands (Fig. 3). Less than 10 turtles were captured at Wungong River (Fig. 3). One fyke and one funnel trap were removed by unknown third parties from the eastern pond of Gerald Russell Park between setting and clearing; it is unclear whether the remaining funnel trap in that pond caught no turtles or was emptied.

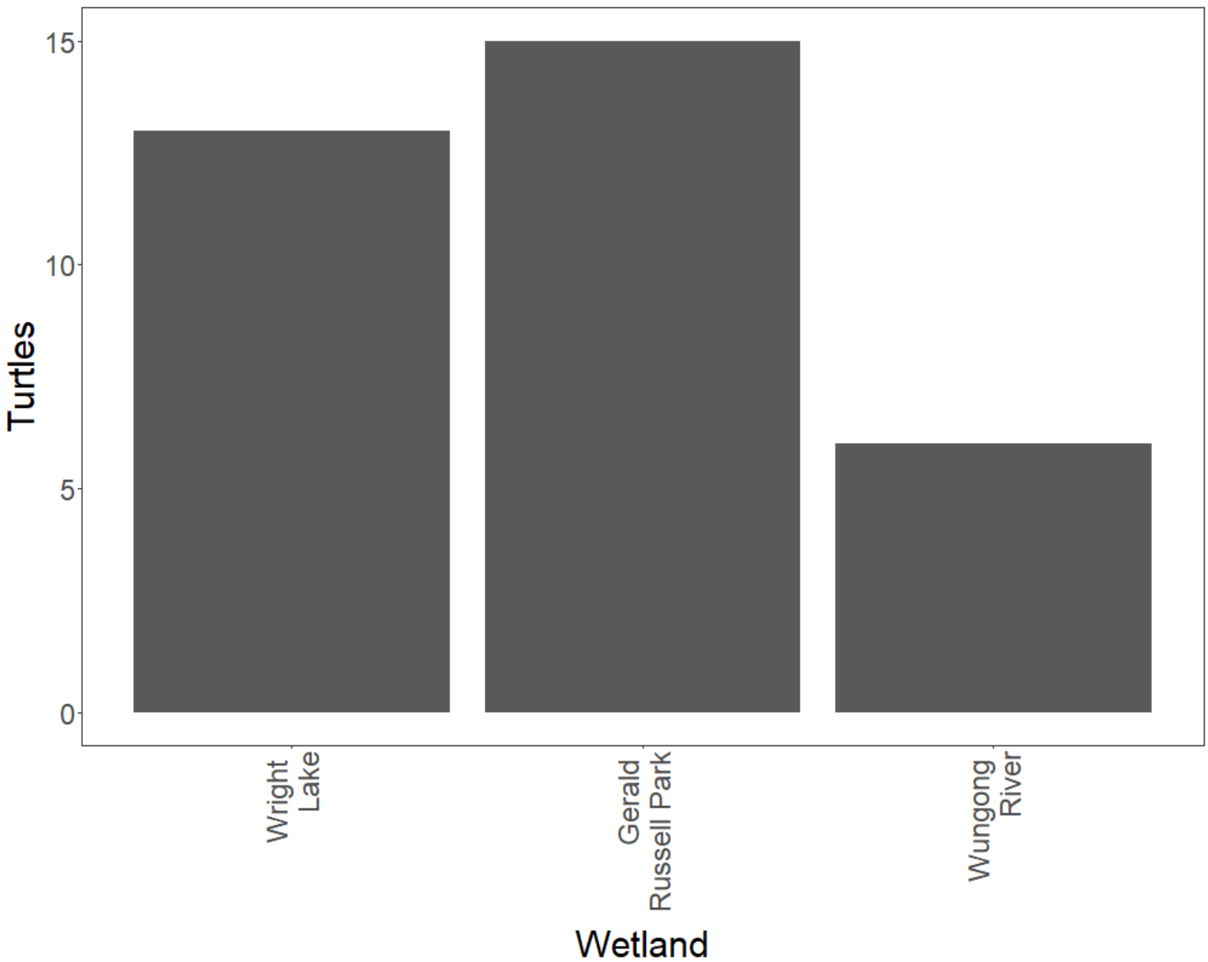

Figure 3. Raw number of turtles captured per wetland

Relative abundance

At wetlands where *C. oblonga* was captured, CPUE ranged from 0.129 to 0.235 (turtles/trap/hour) for fyke nets and from 0.009 to 0.092 (turtles/trap/hour) for modified funnel traps (Fig. 4). The average CPUE for fyke nets was 0.168 (±0.034 SE) (turtles/trap/hour) and 0.037 (±0.028 SE) (turtles/trap/hour) for modified funnel traps.

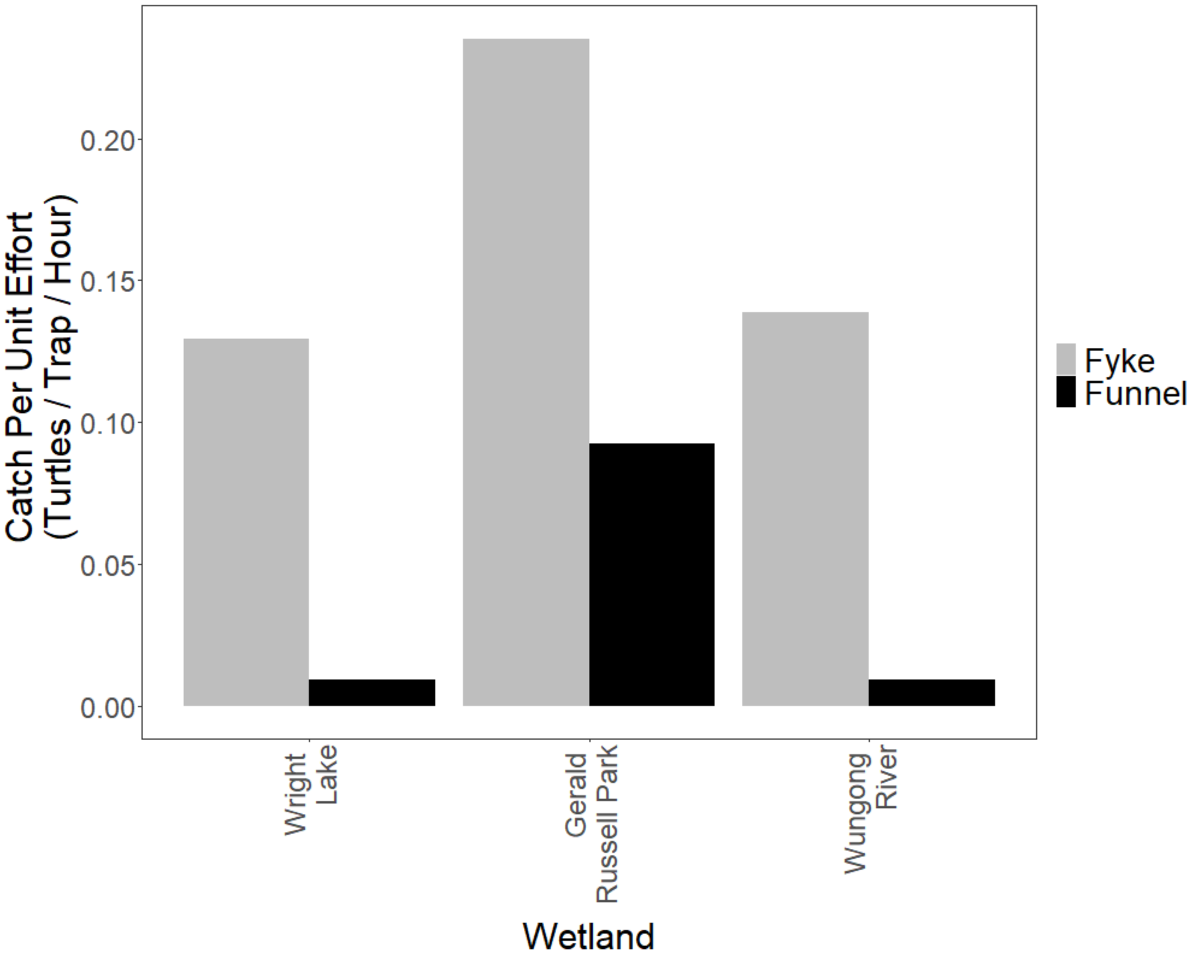

Figure 4. CPUE of turtles per wetland

Population structure

Size distribution

Carapace lengths ranged from 106 mm to 261 mm, with an average size of 182 mm (±5.7 SE) (Fig. 5). Male carapace lengths ranged from 120 mm to 203 mm (Fig. 8). Female carapace lengths ranged from 106 mm to 261 mm (Fig. 8). Zero individuals with carapace length <100 mm were captured (Fig. 5).

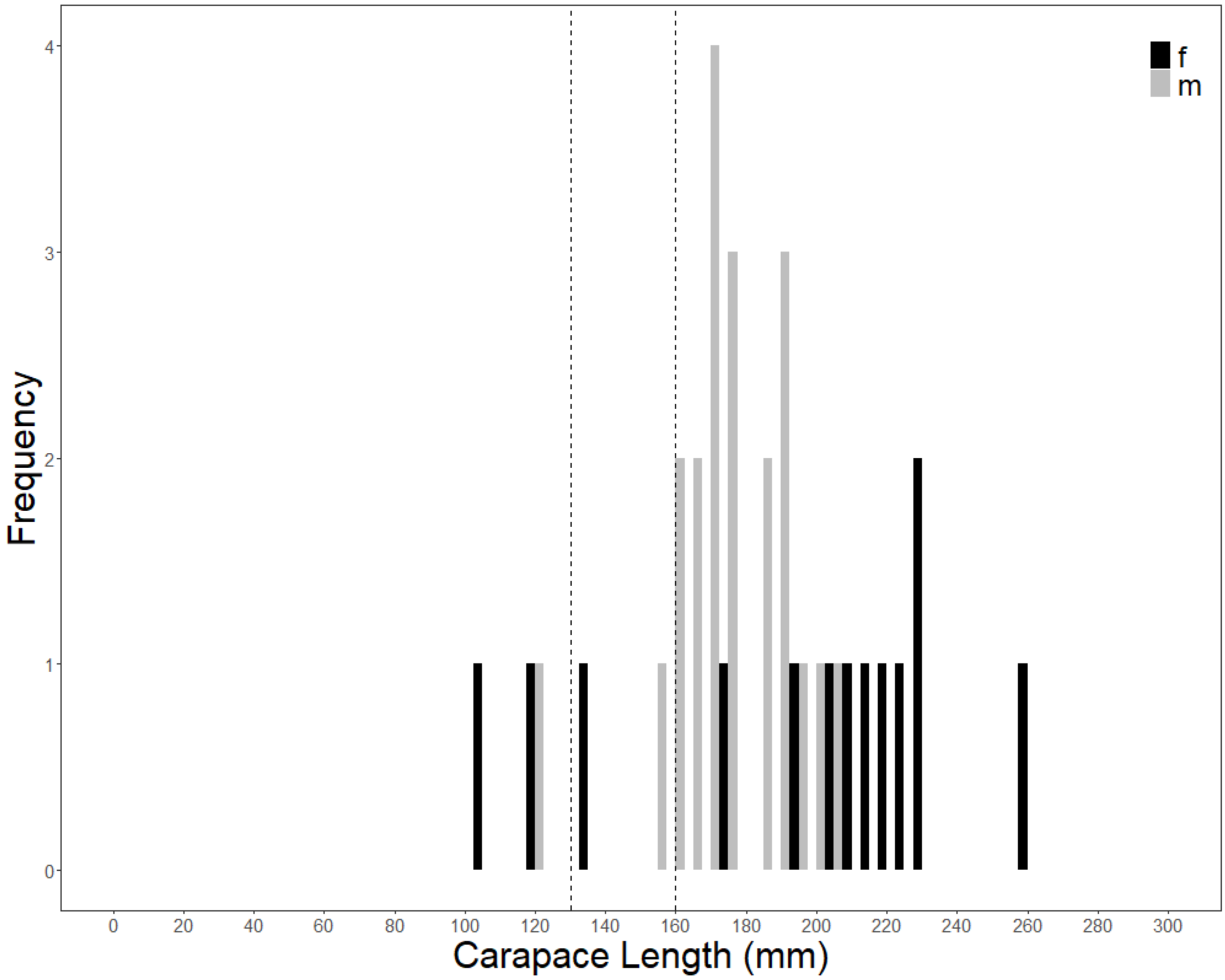

Figure 5. Carapace length distribution of *Chelodina oblonga* pooled among the wetlands sampled. Dashed lines indicate size at sexual maturity for males (130 mm) and females (160 mm), respectively.

The turtles captured at Wright Lake consisted entirely of adults (Fig. 6). Similarly, the turtles captured at Gerald Russell Park were all adults except for a single male and a single female (Fig. 6). The males captured at Wungong River were both adults of approximately the same size (176 and 198 mm), while the female size distribution was much larger (106 – 261 mm) and included two juveniles (Fig. 6).

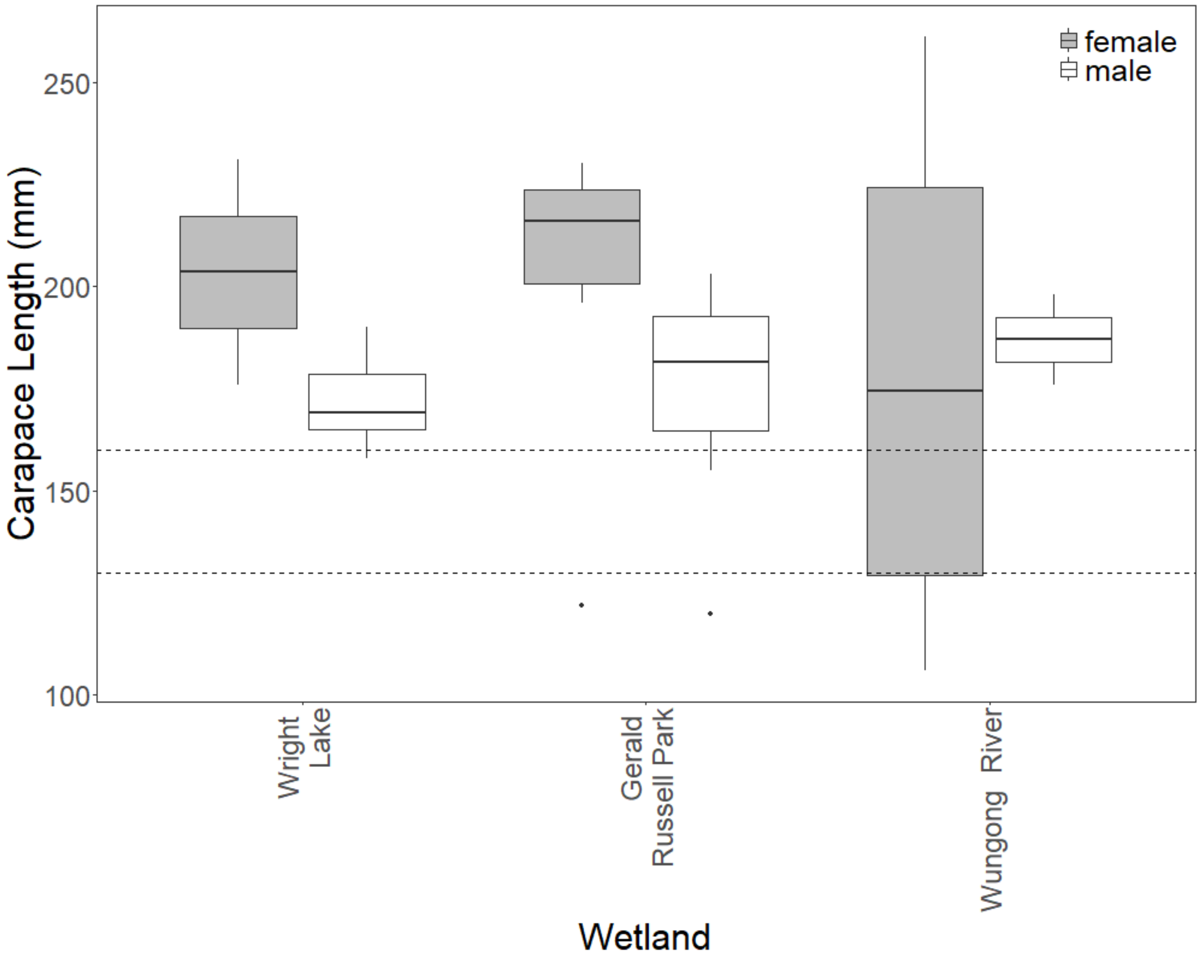

Figure 6. Distribution of carapace length of *Chelodina oblonga* by gender by wetland. Dashed lines indicate size at sexual maturity for males (130 mm) and females (160 mm), respectively.

Age class

Four (11.8%) individuals captured were juveniles, with juveniles not captured in Wright Lake (Figs. 6, 7). Juveniles made up less than 15% of the captured population at Gerald Russel Park (Fig. 7) and 33% of the captured population at Wungong River (Fig. 7).

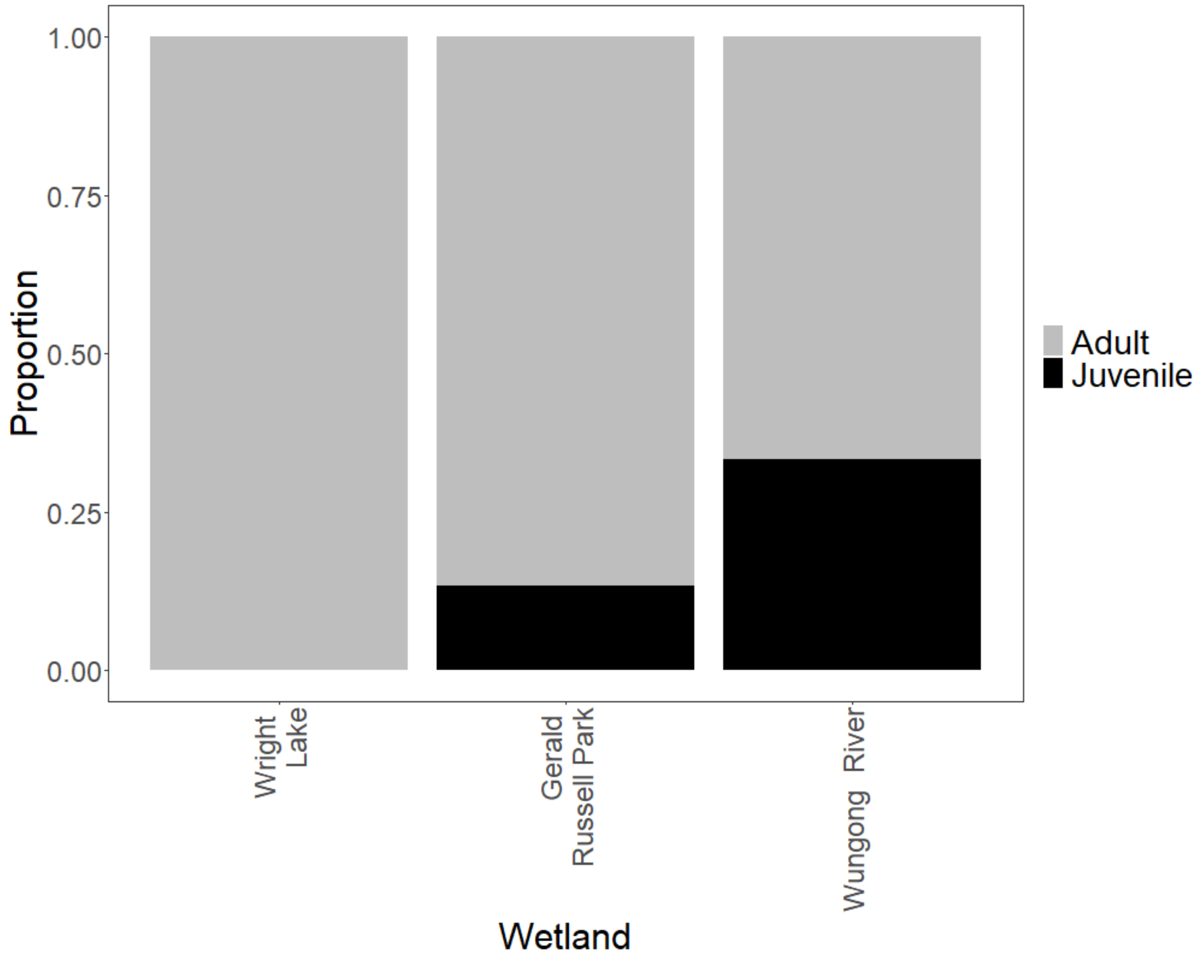

Figure 7. Proportion of each age class of *Chelodina oblonga* at each wetland.

Sex ratio

Wright Lake was male dominated, Wungong River was female dominated, and Gerald Russell Park was approximately even (Fig. 8). Sex ratios were not significantly different from 1:1 at Gerald Russell Park and Wungong River, but was significantly different at Wright Lake (Table 1).

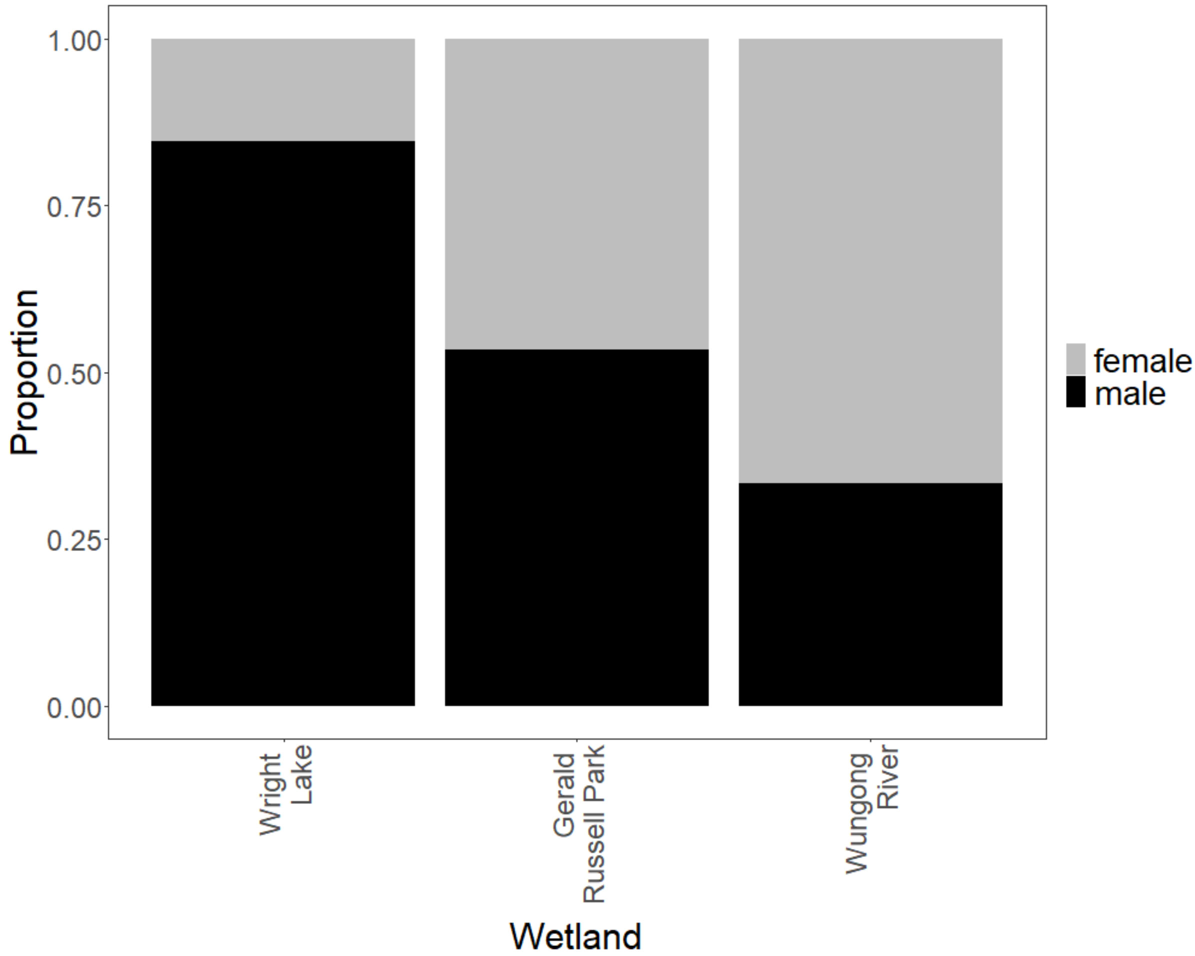

Figure 8. Proportion of each gender of *Chelodina oblonga* at each wetland.

Table 1. The ratio of male to female *Chelodina oblonga* captured from each study site in the City of Rockingham. Significant difference ($p<0.05$) from the expected 1:1 in bold. ^ indicates a small sample size, where the test may not be accurate.

Wetland	Ratio of M:F	p-value
Wright Lake	5.5:1	**0.0126**
Gerald Russell Park	1.1:1	0.7963
Wungong River	0.5:1	0.4142 ^

Other species captured

Bycatch was recorded at all study sites, with a total of 7 native and 4 non-native species captured (Table 2). Native species were captured at all sites. Invasive species were captured and observed at two of the study sites (Table 2). Wungong River had both the highest number of native (4) and non-native species (3) (Table 2).

Table 2. Species of bycatch captured in fyke nets during sampling for *Chelodina oblonga*

	Species	Wright Lake	Gerald Russel Park	Wungong River
Native	Western Pygmy Perch (*Nannoperca vittata*)	0	0	147
	Western Minnow (*Galaxias occidentalis*)	0	0	22
	Freshwater Cobbler (*Tandanus bostocki*)	0	1	0
	South-Western Goby (*Afurcagobius suppositus*)	~60	1	0
	Nightfish (*Bostockia porosa*)	0	0	1
	South-Western Glass Shrimp (*Paleomonetes australis*)	0	~40	0
	Motorbike Frog (*Litoria moorei)*	0	0	1
Invasive	Yabby (*Cherax destructor*)	0	0	12
	Eastern Mosquito Fish (*Gambusia holbrooki*)	0	0	~350
	Pearl Cichlid (*Geophagus brasiliensis*)	0	0	1

Discussion

This is the first targeted survey of *C. oblonga* to take place within wetlands in the City of Armadale. Sampling of three wetlands revealed some variance in *C. oblonga* abundance and population structure among wetlands, an observation that is consistent with previous studies on *C. oblonga* living in urban environments (Guyot and Kuchling 1998, Tysoe 2005, Giles, Kuchling et al. 2008, Bartholomaeus 2016, Santoro, Chambers et al. 2020, Santoro, Summers et al. 2020). As discussed below, the study has implications for the conservation of the species within the City of Armadale, as well as the Swan Coastal Plain.

Relative abundance and population structure

There was some variance of relative abundance of *C. oblonga* between the wetlands surveyed, however, the CPUE values fall within the range reported in previous Oblong turtle surveys (Santoro, Chambers et al. 2020, Santoro, Summers et al. 2020). This assessment found that overall, *C. oblonga* populations were dominated by adults; an observation that is also consistent with previous studies (Santoro, Chambers et al. 2020, Santoro, Summers et al. 2020). Sex ratios observed in the current study varied from male dominated to female dominated. The sex ratios reported by previous studies of *C. oblonga* have varied widely with no pattern evident (Clay 1981, Guyot and Kuchling 1998, Tysoe 2005, Giles, Kuchling et al. 2008, McKeown 2010, Giles 2012, Bartholomaeus 2016, Santoro 2017).

Wright Lake

The observed turtle population at Wright Lake appears unviable. A heavy male bias was observed, and juveniles were absent from captures, with individuals of both sexes averaging SCL ~40 mm larger than size at maturity. Further, very few turtles were caught at Wright Lake considering the size of the wetland. There are several reasons this could be occurring. Firstly, the surrounding terrestrial area is relatively urbanised, and roads are in close proximity to ~75% of the water's edge. As highlighted in several studies on freshwater turtles globally, the terrestrial habitat surrounding a wetland plays an important role in providing nesting habitat (Steen, Gibbs et al. 2012, Hamer, Harrison et al. 2018, Santoro, Chambers et al. 2020), and roads are often linked to mortality of nesting females (Giles 2001, Steen and Gibbs 2004, Aresco 2005). Second, the lake is a water-based recreational facility, with high levels of human activity including the use of motorised boats. Human recreation involving motorboats has been linked to increased occurrence of injuries (Bennett and Litzgus 2014) and mortality (Laverty, Korol et al. 2016). There is the possibility that the increased presence of humans within the waterbody relative to other wetlands may disturb the turtles who then may seek shelter elsewhere and migrate to nearby wetlands. Finally, the water level is maintained with 2500 ppm salt water. While *C. oblonga*'s tolerance to salt water has not been determined, it is likely that if the water is to saline for *C. oblonga*'s preferences, individuals may seek alternate habitats. Further research on *C. oblonga*'s tolerance to water-based human recreation and water quality parameters would provide valuable insight into future management of the species within Wright Lake, and the Swan Coastal Plain.

<u>Gerald Russell Park</u>

The highest CPUE was recorded at Gerald Russell Park. The captured population was mainly adults, with a single juvenile of each sex. However, the juveniles were ~120 mm, suggesting they are approximately a decade old. The captured populations sex-ratio was approximately even, which is unexpected in urban environments due to the additional mortality risk faced by females during nesting movements (Spencer 2002, Steen, Aresco et al. 2006). This is an interesting finding considering the three lakes within the park are all bordered by walls. It's possible that the limestone walls are preventing the females from leaving the wetland on nesting journeys, and therefore preventing recruitment while also reducing mortality of females. Determining the impact of walls bordering urban lakes on *C. oblonga*'s ability to exit for nesting migrations is necessary for future conservation of the species in urban wetlands.

<u>Wungong River</u>

Of the study sites, Wungong River had the fewest captures, but had the largest variance in female SCL, including two juveniles. Due to the nature of rivers, it is possible that individual *C. oblonga* may occupy sections of the river and thus sampling of larger sections of river may be needed to accurately assess the population. It is also likely that individuals will move between areas based on the suitability at particular times of year. This is the first targeted survey of *C. oblonga* within rivers and thus, comparison cannot be made to previous surveys. Interestingly, all captures were made in the northern portion of the river relative to Lake Rd. This may be due to the relatively low water levels and flow rate experienced south of Lake Rd during sampling. Further research on *C. oblonga* populations within rivers, including their movements and home-ranges should be considered.

Other species captured

The Western Minnow (*G. occidentalis*), Western Pygmy Perch (*N. vittata*) and Nightfish (*B. porosa*) were all captured within the Wungong River. These species are of high ecological importance to the river systems of South-western Australia (Beatty & Morgan 2010) for the crucial role they play in structuring and regulating the aquatic food web. These species predate upon primary consumers such as benthic invertebrates, ostracods, and copepods (Pen & Potter, 1991) and are also an effective biological control for pest species such as mosquitos and midges as they predate upon dipteran larvae and pupae (Pen & Potter, 1991; Lawrence et al, 2016). Experimental studies have also demonstrated the ability of these species to be more effective at controlling mosquito and midge populations than the Eastern Gambusia (*G. holbrooki)* (Lawrence et al. 2016) that was specifically introduced to Western Australia in the 1930's for this purpose but is now ironically considered a major pest species itself (Beatty and Morgan, 2013).

The Eastern Gambusia were also found in considerable abundances within the Wungong River with over 350 individuals captured across different stages of their reproductive cycle, suggesting there is a subsisting population within the system. The species is a prolific breeder, have a high reproductive output, fast maturation rate and possesses broad environmental tolerances (Macdonald and Tonkin 2008) which has ultimately contributed to their successful establishment throughout southwest of Western Australia (Morgan, Gill et al. 2004; Beatty and Morgan, 2013). This is of concern because this species can have a significant impact on local macro-invertebrate and phytoplankton communities once established. This in turn may disrupt fragile food web dynamics by reducing or removing available prey resources from native species of fish and/or juvenile *C. oblonga* that are dependent on that resource at different stages of life (Morgan, Gill et al. 2004).

The non-native Yabby (*Cherax destructor*) has also been identified as a high risk species to aquatic environments, owing to its broad environmental tolerances (Withnall 2000, McCormack 2008) and *r*-selected life cycle characteristics that gives the species the capacity to reproduce all year round, proliferate in high densities and successfully colonise new habitats under the right conditions (Beatty, Morgan et al. 2005, McCormack 2008, Tricarico, Vilizzi et al. 2010). Bradsell, Prince et al. (2002) documented a number of negative interactions between adult *C. destructor* and *C. oblonga* hatchlings in aquaria with *C. destructor* demonstrating aggressive and predatory behaviour towards *C. oblonga* hatchlings. While adult turtles are known predators of juvenile crayfishes (Kuchling unpublished data, Santoro Pers Obs) Yabbies may still poses a potential threat to the survival of *C. oblonga* hatchlings in systems where co-habitation occurs. The impact of yabbies on the survival of *C. oblonga* hatchlings and their recruitment into the population therefore needs to be considered in future management programmes for the conservation of *C. oblonga.* Furthermore, the presence of the species poses a number of implications for native freshwater crayfish such as the Gilgie (*C. quinquecarinatus)* and Marron (*C. cainii*) (Beatty, Morgan et al. 2005a, b) (not detected in the current study but known from the catchment). Yabbies share similar habitats and food preferences with the native Gilgie (Lynas 2002, Beatty 2006), attains a larger maximum size and are naturally a more aggressive species than the Gilgie. Experimental studies have documented the capacity for Yabbies to outcompete the native Gilgie from preferred habitats (Lynas, Storey et al. 2007). In areas of co-habitation where food and resources may be limited, interactions between Yabbies and Gilgies are likely to result in displacement of native crayfish populations (Lynas 2002, Lynas, Storey et al. 2007) and/or facilitate the spread of parasites, both of which have the potential to impact population viability and overall health of the crayfish population (Beatty 2006).

The native South-Western Goby (*A. suppositus*) was the only native species capture at Wright lake. This is not surprising considering this system is brackish in nature and this species is known to inhabit both freshwater and estuarine environments throughout the southwest (Morgan, Gill & Potter, 1998). The endemic southwest Glass Shrimp (*P. australis*) was only captured at Gerald Russell Park in moderate abundance (Table 2). The southwest Glass Shrimp is an important inhabitant of aquatic ecosystems as they are omnivorous and serve to consume and breakdown plant or animal material and are a valuable protein source for juvenile and adult turtles, crayfish and fishes.

Management recommendations

This preliminary study has provided an insight into the presence or absence of *C. oblonga* as well as a basic indication of the population demographics of each wetland sampled. While the study design of this assessment was robust, it is important to note that without a secondary sampling period, and therefore mark-recapture figures, population estimates are preliminary. With only one sampling session it can also be difficult to determine precise recruitment dynamics. Furthermore, the history of the populations in these wetlands is unknown, therefore if some populations have been influenced by human intervention, such as female turtles being returned to a wetland they did not originate from when nesting, this data will not have been accounted for in the assessment. The primary way to address these limitations is of course further study and an ongoing monitoring regime.

For a deeper understanding of *C. oblonga* population viability and dynamics within the City of Armadale, continued monitoring alongside expansion to additional wetlands is advised. As there appears to be a link between fringing vegetation and *C. oblonga* population viability, it is suggested that priority goes to the study of wetlands with some level of in-tact terrestrial vegetation. Long term population monitoring will be a vital tool in understanding the specific causes of mortality and poor recruitment within *C. oblonga* populations, which in turn can significantly improve and help focus management actions. This ongoing monitoring should include the assessment of fringing vegetation and available nesting habitat surrounding each wetland, whether mature females in each population are gravid or not, whether the red fox (*Vulpes vulpes*) are present in the area, and an assessment of the intensity of nest predation. Completion of these assessments will allow prioritisation of threats and in-depth, accurate, and wetland-specific recommendations that may include:

- the introduction of suitable nesting areas of soft soil and native vegetation
- fencing of identified nesting areas and/or installation of nesting refuges
- fox control programs
- management of roads surrounding wetlands (speed bumps, fencing, culverts)
- increasing connectivity of wetlands via wildlife corridors

Often underestimated in environmental science is the role that public education can play in improving ecosystems. As many of the peripheral issues affecting wetland health identified by this assessment stem from lack of public awareness and/or concern, it is suggested that a small-scale education campaign may help to ameliorate further wetland disturbance. Getting the local public up to speed on, and interested in, the correct ways to handle a turtle crossing a road, the consequences of releasing aquarium fish into waterways, and the potential damage that off-lead dogs can do to wildlife, can make small changes that add up to become significant over time.

Including fish, crayfish and macro invertebrate surveys in the City of Armadale's future wetland and river monitoring programs would provide valuable insight into the distribution and abundance of native & non-native species throughout the City of Armadale and a better understanding of the scale of the impacts non-native species are having on aquatic fauna within the region. Targeted fish, crayfish and macro-invertebrate surveys can be conducted alongside turtle surveys with the deployment of modified fyke nets as well as the addition of in-situ box and opera traps (all fitted with turtle exclusion mesh). Expansion of these surveys throughout other wetlands within the City of Armadale would provide a robust dataset on top level predators in these systems and provide meaningful insight into the systems food web dynamics and overall ecological health and functionality.

References

Aresco, M. J. (2005). "The effect of sex-specific terrestrial movements and roads on the sex ratio of freshwater turtles." Biological Conservation **123**(1): 37-44.

Bartholomaeus, C. J. (2016). Understanding the Decline of Urban Wildlife : The Critical Role of Combining Ecological and Social Research PhD, Murdoch University.

Beatty, S. (2006). "The diet and trophic positions of translocated, sympatric populations of *Cherax destructor* and *Cherax cainii* in the Hutt river, Western Australia: evidence of resource overlap." Marine and Freshwater Research **57**: 825-835.

Beatty, S., D. Morgan and H. Gill (2005a). "Role of Life History Strategy in the Colonisation of Western Australian Aquatic Systems by the Introduced Crayfish Cherax destructor Clark, 1936." Hydrobiologia **549**(1): 219-237.

Beatty, S.J., Morgan, D.L. & Gill, H.S. (2005b). Life history and reproductive biology of the gilgie Cherax quinquecarinatus, a freshwater crayfish endemic to south-western Australia Journal of Crustacean Biology 25(2): 251-262.

Beatty, S.J. & Morgan, D.L. (2010). Teleosts, agnathans and macroinvertebrates as bioindicators of ecosystem health in a south-western Australian River. Journal of the Royal Society of Western Australia 93:65-79.

Beatty, S.J. & Morgan, D.L. (2013). Introduced freshwater fishes in a global endemic hotspot and implications of habitat and climatic change. Bioinvasions Records 2(1): 1-9.

Bennett, A. M. and J. D. Litzgus (2014). "Injury Rates of Freshwater Turtles on a Recreational Waterway in Ontario, Canada." Journal of Herpetology **48**(2): 262-266.

Bradsell, P., J. Prince, G. Kuchling and B. Knott (2002). "Aggressive interactions between freshwater turtle, *Chelodina oblonga*, hatchlings and freshwater crayfish, *Cherax* spp.: implications for the conservation of the critically endangered western swamp turtle, *Pseudemydura umbrina*." Wildlife Research **29**: 295-301.

Burbidge, A. A. (1967). The biology of south-western Australian tortoises. PhD, The University of Western Australia.

Cann, J. (1998). Australian freshwater turtles, Beaumont Pub.

Clay, B. T. (1981). "Observations on the breeding biology and behaviour of the long-necked tortoise." Journal of the Royal Society of Western Australia **4**(1): 27-32.

Giles, J. C. (2001). The effect of roads on oblong turtle Honours, Murdoch University.

Giles, J. C. (2012). Summary of the baseline survey of Oblong turtles within Bibra Lake, with an assessment of habitat and management recommendations for the maintanence of the turtle population in a drying climate.

Giles, J. C., G. Kuchling and J. A. Davis (2008). Populations of the snake-necked turtle *Chelodina oblonga* in three suburban lakes of Perth, Western Australia. Urban Herpetology. J. C. Mitchell, R. E. Jung Brown and B. Bartholomew. Salt Lake City, Utah, Society for the Study of Amphibians and Reptiles.

Guyot, G. and G. Kuchling (1998). Some ecological aspects of populations of oblong turtles (*Chelodina oblonga*) in the suburbs of Perth (Western Australia). Current Studies in Herpetology: Proceedings of the 9th Ordinary General Meeting of the Societas Europaea Herpetologica. Le Bourget du Lac, France, SEH.

Hamer, A. J., L. J. Harrison and D. Stokeld (2018). "Terrestrial habitat and individual fitness increase survival of a freshwater turtle in an urban landscape." Urban Ecosystems **21**(1): 71-83.

Kuchling, G. (1988). "Gonadal cycles of the Western Australian Long-necked Turtles *Chelodina oblonga* and *Chelodina steindachneri* (Chelonia: Chelidae)." Records of the Western Australian Museum **14**(2): 189-198.

Kuchling, G. (1989). "Assessment of Ovarian Follicles and Oviductal Eggs by Ultra-Sound Scanning in Live Freshwater Turtles, *Chelodina oblonga*." Herpetologica **45**(1): 89-94.

Kuchling, G. (2003). "A new underwater trap for catching turtles." Herpetological Review **34**(2): 126-128.

Laverty, J. F., B. Korol and J. D. Litzgus (2016). " Measuring the effects of water-based recreation on the spatial ecology of Eastern Musk Turtles (*Sternotherus odoratus*) in a provincial park in Ontario, Canada." Copeia **104**(2): 440-447.
Lynas, J. (2002). Is the introduced yabbu, *Cherax destructor*, an ecological threat to species of local freshwater crayfish in Perth, Western Australia?. . Honours, The University of Western Australia.
Lynas, J., A. Storey and B. Knott (2007). Introduction and spread of crayfish (*Parastacidae*) in Western Australia and their potential to displace indigenous species. Biological invaders in inland waters: profiles, distribution and threats. F. Gherardi. Dordrecht, The Netherlands, Springer**:** 577-596.
Macdonald, J. and Z. Tonkin (2008). A review of the impact of eastern gambusia on native fishes of the Murray-Darling Basin. Murray-Darling Basin Authority.
McCormack, R. B. (2008). The freshwater crayfishes of New South Wales Australia. Karuah, NSW, Aquatic Biological Pty Ltd.
McKeown, E. (2010). Movements and population dynamics of oblong turtles outside of the Perth metropolitan area during drought conditions Honours, University of Western Australian.
Morgan, D. L., H. S. Gill, M. G. Maddern and S. J. Beatty (2004). "Distribution and impacts of introduced freshwater fishes in Western Australia." New Zealand Journal of Marine and Freshwater Research **38**(3): 511-523.
Santoro, A. (2017). The impact of urbanisation on the south-western snake-necked turtle (*Chelodina colliei*). Honours, Murdoch University.
Santoro, A., J. M. Chambers, B. J. Robson and S. J. Beatty (2020). "Land use surrounding wetlands influences urban populations of a freshwater turtle." Aquatic Conservation: Marine and Freshwater Ecosystems.
Santoro, A., V. Summers, J. Watsham, C. Davis and S. Beatty (2020). Population status of the southwestern snake-necked turtle in Rockingham's wetlands. Centre for Sustainable Aquatic Ecosystems, Murdoch University, Harry Butler Institute.
Spencer, R. J. (2002). "Experimentally testing nest site selection: fitness trade-offs and predation risk in turtles." Ecology **83**(8): 2136-2144.
Steen, D. A., M. J. Aresco, S. G. Beilke, B. W. Compton, E. P. Condon, C. Kenneth Dodd, H. Forrester, J. W. Gibbons, J. L. Greene, G. Johnson, T. A. Langen, M. J. Oldham, D. N. Oxier, R. A. Saumure, F. W. Schueler, J. M. Sleeman, L. L. Smith, J. K. Tucker and J. P. Gibbs (2006). "Relative vulnerability of female turtles to road mortality." Animal Conservation **9**(3): 269-273.
Steen, D. A. and J. P. Gibbs (2004). "Effects of roads on the structure of freshwater turtle populations." Conservation Biology **18**(4): 1143-1148.
Steen, D. A., J. P. Gibbs, K. A. Buhlmann, J. L. Carr, B. W. Compton, J. D. Congdon, J. S. Doody, J. C. Godwin, K. L. Holcomb, D. R. Jackson, F. J. Janzen, G. Johnson, M. T. Jones, J. T. Lamer, T. A. Langen, M. V. Plummer, J. W. Rowe, R. A. Saumure, J. K. Tucker and D. S. Wilson (2012). "Terrestrial habitat requirements of nesting freshwater turtles." Biological Conservation **150**(1): 121-128.
Tortoise & Freshwater Turtle Specialist Group. (1996). "*Chelodina oblonga* (errata version published in 2016)." The IUCN Red List of Threatened Species 1996 e.T4607A97260840 Retrieved 18th May, 2018.
Tricarico, E., L. Vilizzi, F. Gherardi and G. H. Copp (2010). "Calibration of FI-ISK, an invasiveness screening tool for nonnative freshwater invertebrates." Risk Analysis **30**(2): 285-292.
Tysoe, L. (2005). The population structure, reproduction and diet of two urban populations of oblong turtle *Chelodina oblonga* Honours, The University of Western Australia.
Withnall, F. (2000). Biology of Yabbies (Cherax destructor). . Aquaculture Notes of the Department of Natural Resources and Environment. Department of Natural Resources and Environment**:** 4.
Woldring, L. A. (2001). General ecology of the oblong turtle *Chelodina oblonga* (Testudines:Chelidae). Leeuwardern, The Netherlands, Van Hall Institute.

Appendix 1. Trap numbers and locations for each wetland

Table A1. Number of modified funnel traps and fyke nets used in each wetland.

Wetland	Modified Funnel Traps	Fyke Nets
Wright Lake	13	5
Gerald Russel Park	8	2
Wungong River	6	2

Figure A1.1. Aerial Image of Wright Lake, Champion Lakes. Red symbols indicate trap locations (star = modified funnel trap, and triangle = fyke net).

Figure A1.2. Aerial Image of Gerald Russell Park, Hilbert. Red symbols indicate trap locations (star = modified funnel trap, and triangle = fyke net). Yellow symbols indicate traps that were tampered with.

Figure A1.3. Aerial Image of Wungong River, Armadale. Red symbols indicate trap locations (star = modified funnel trap, and triangle = fyke net).

Appendix 2. *Chelodina oblonga* carapace distributions at each wetland

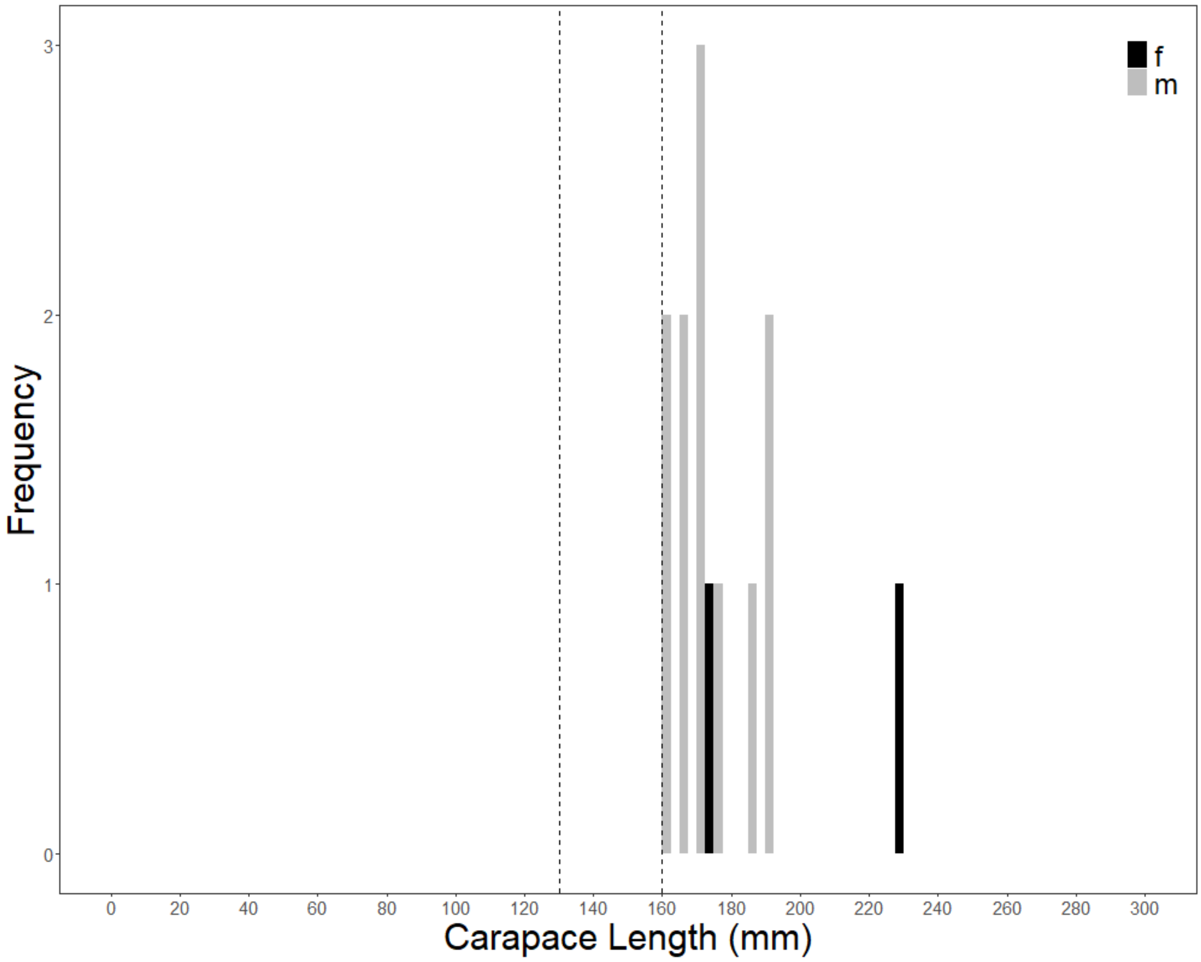

Figure A3.1. Carapace length distribution of *Chelodina oblonga* captured at Wright Lake, Champion Lakes. Dashed lines indicate size at sexual maturity for males (130 mm) and females (160 mm), respectively.

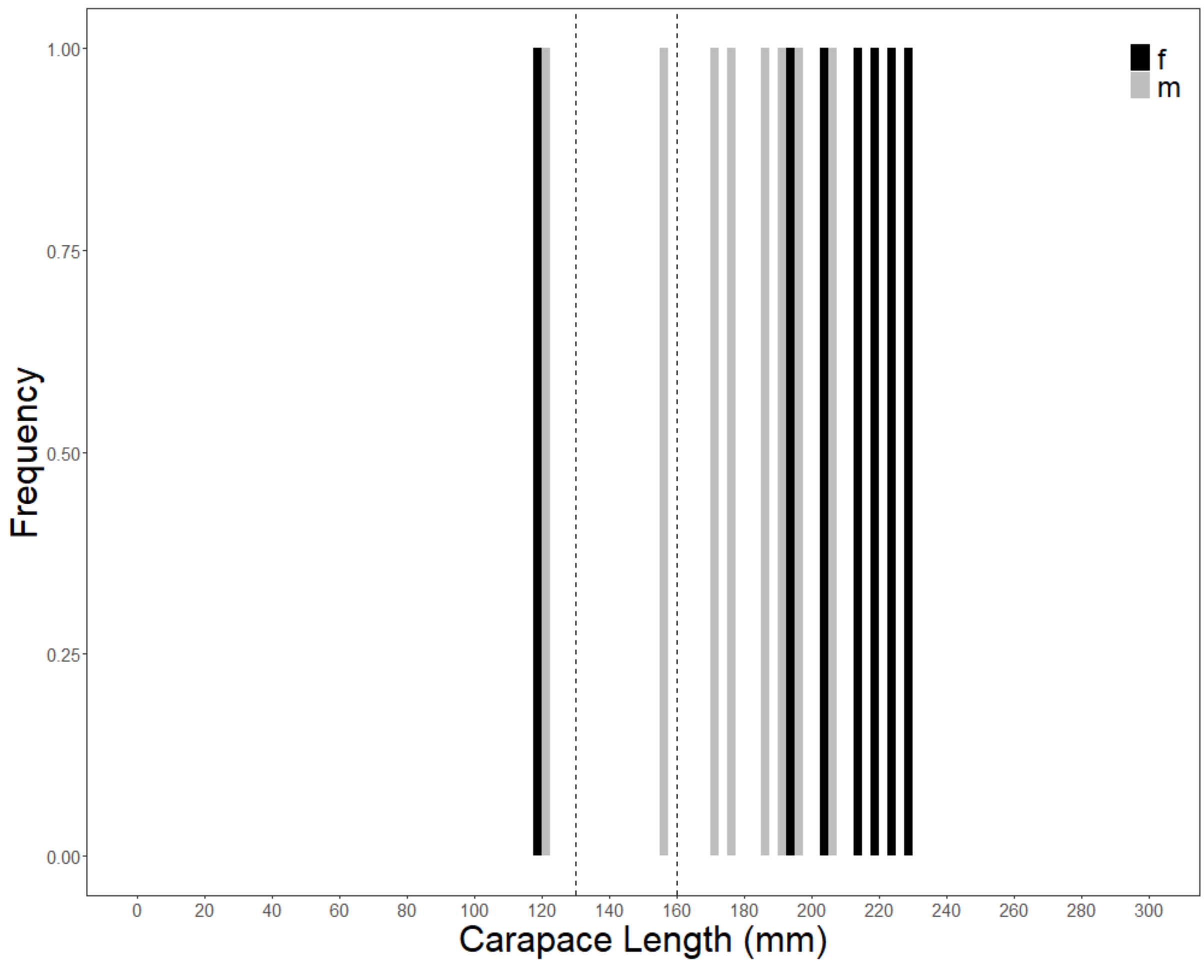

Figure A3.2. Carapace length distribution of *Chelodina oblonga* captured at Gerald Russell Park, Hilbert. Dashed lines indicate size at sexual maturity for males (130 mm) and females (160 mm), respectively.

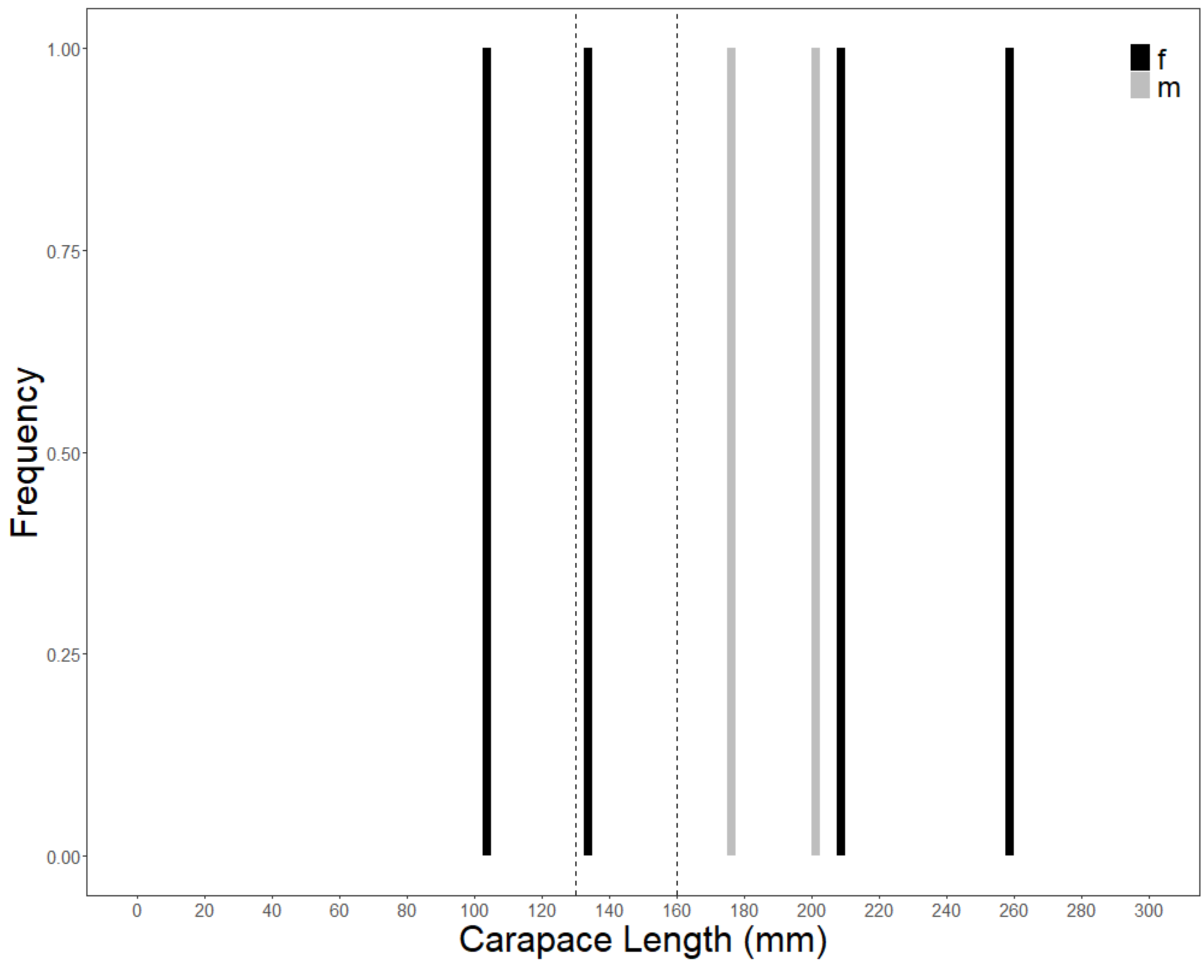

Figure A3.3. Carapace length distribution of *Chelodina oblonga* captured at Wungong River, Armadale. Dashed lines indicate size at sexual maturity for males (130 mm) and females (160 mm), respectively.