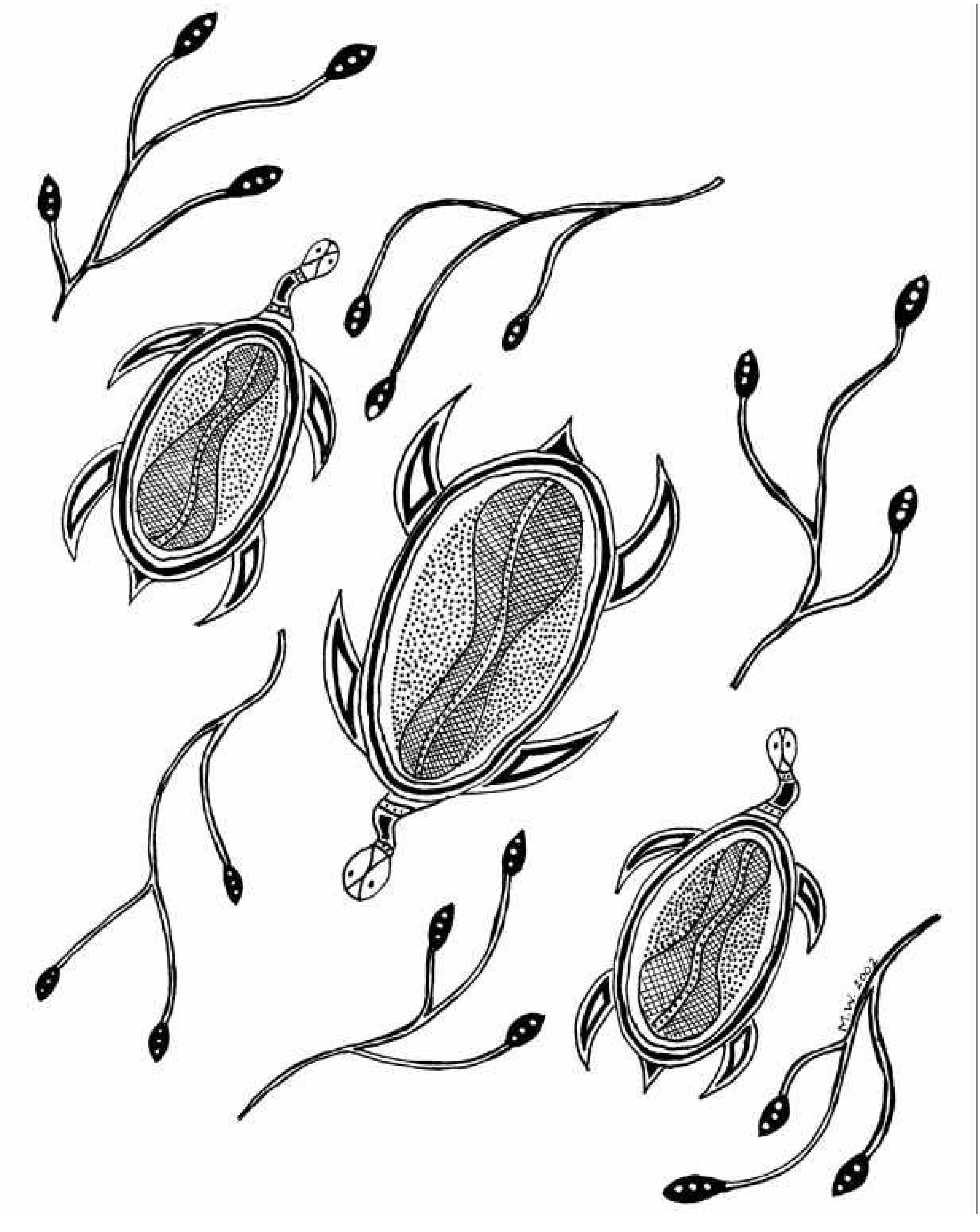
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THE COOPER CREEK TURTLE PERSISTING UNDER PRESSURE : A STUDY IN ARID AUSTRALIA

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DECLARATION

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ABSTRACT

I studied parameters of population structure and growth in the Cooper Creek turtle *Emydura macquarii* among waterholes of varying permanency in the disconnected waterhole system of the Cooper Creek in southwest Queensland. Data from this study, April 2002 was augmented with data collected in April and September 2001. We captured a total of 1,148 turtles, of which 16 were recaptures.

The central findings of this project revealed that the *Em. macquarii* form from the Cooper Creek has life-history traits that enable its persistence in the harsh 'boom and bust' environment. Biological features of the Cooper Creek turtle include; large body size, delaying sexual maturity and indeterminate growth.

Waterhole permanence, waterhole morphology, biotic attributes such as productivity and, sadly, the intensity of illegal fishing with gill nets has a marked effect on the population structure of the Cooper Creek turtle. The highest abundance of turtles were in permanent waterholes that were not netted for fish. These permanent waterholes also supported a high adult : juvenile ratio. A semi-permanent waterhole also not netted for fish had a low abundance of turtles and was dominated by juveniles. We predict that during floods turtles disperse onto the productive floodplain and with the receding waters cue onto permanent waterhole attributes of size, depth and riparian vegetation. A trade-off exists between permanent and semi-permanent waterholes. Permanent waterholes are relatively less productive than ephemeral waterholes and support a high abundance of turtles with a low growth coefficient whereas, ephemeral waterholes are relatively more productive and support a low abundance of turtles with a high growth coefficient. The trade-off exists because turtles in the semi-permanent and ephemeral waterholes have an increased chance of mortality, as they will decimate if the waterhole dries before the next flood.

The impact of illegal fishing with gill and drum nets have a detrimental affect on the population structure of the Cooper Creek turtle. It was found that waterholes under intense illegal netting were lacking the adult proportion of the turtle population, suggesting that gill nets are size selective of < 225 mm carapace length. We sampled three turtle populations that are recovering from illegal netting. Netting was stopped in these permanent waterholes 10 – 15 years ago. The turtle populations exhibited a low adult : juvenile ratio but had a relatively large proportion of sub-adults concluding that future recruitment will increase and the population will recover and reach a stable climax state.

In conclusion, the findings of this study have made an important contribution to the ecology of freshwater turtles and their use of dryland refugia under the influence of sporadic flooding. This study has improved our understanding of the life-history attributes of the *Em. macquarii* complex from the Cooper Creek and how the turtles interact with the boom-bust ecology of the dryland river system. Consequently, this project provided knowledge of the attributes of dryland refugia important to turtles and knowledge of how quickly they can or cannot respond to population reduction will be important in guiding management action in the Cooper drainage.

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CHAPTER ONE

1 INTRODUCTION

1.1 Background and Aims

1.1.1 The Landscape and Processes

Rainfall in the arid interior of Australia is highly variable in timing, duration and intensity, compared with other arid regions of the world (Stafford Smith and Morton, 1990). Seventy per cent of Australia is arid, receiving less than 200-500 mm mean annual rainfall (Comin and Williams, 1994; Kingsford et al., 1999). Rainfall in arid Australia tends to be episodic and arid zone rivers are characterised by extreme flow variability, long periods without flow and flood-dominated flow regimes (Knighton and Nanson, 2001).

Arid zone wetlands range in size from a few square metres to thousands of square kilometres and support a diverse biota (Williams, 1981; Roshier et al., 2001). These standing waters can be terminal water bodies filled by major drainage systems (eg. Lake Eyre), lakes filled by local drainage or creeks, overflow lakes associated with major drainage systems, and waterholes associated with distributaries such as those that occur along Cooper Creek and the Darling, Paroo and Warrego Rivers (Knighton and Nanson, 1994; Puckridge, 1998). Dryland rivers are comprised of dry channels that connect a network of permanent and ephemeral waterholes during flood episodes. The longest and arguably most important dryland river in Australia is Cooper Creek that flows to Lake Eyre Basin. Its floods replenish many thousands of hectares of wetlands (Kingsford et al., 1999).

In dryland rivers, the dominant cycles are not wholly seasonal or annual but are related, at least in part, to weather anomalies associated with the El Niño Southern Oscillation (ENSO) (Walker et al., 1997). Inflows to Lake Eyre have been shown to be most associated with the La Niña phase of the ENSO phenomenon (Allan, 1985; Isdale and Kotwicki, 1987; Kotwicki and Isdale, 1991; Puckridge et al., 2000; Roshier et al., 2001). The ENSO phenomenon provides a strong influence on tropical cyclone patterns in the Australian region (Hastings, 1990; Evans and Allan, 1992). Flooding events in the Lake Eyre Basin have been linked to extreme rainfall events resulting from the passage of tropical cyclone remnants or more isolated synoptic events occurring in conjunction with enhanced monsoonal conditions (Allan, 1985; Roshier et al., 2001). The Cooper Creek itself may not receive rainfall but indirectly receives substantial flows due to monsoonal events in northern Australia and rainfall in the upper catchments.

The Lake Eyre Basin is unique in the Australian context because of its large size (1140 000 km^2) and the internal drainage (Walker et al., 1997). Its northern parts extend into the tropics and the rivers that drain it have a very high ratio of floodplain area to total catchment area (Graetz, 1980; Roshier et al., 2001) and shallow gradients (Puckridge, 1998; Roshier et al., 2001). Flood events range in duration from minutes to months as floodwaters flow quickly down dry drainage lines or traverse many hundreds of kilometres of river channel in the larger drainage basins (Roshier et al., 2001). Therefore, most rivers within the basin inundate vast areas of their floodplain. These characters combine with spatial variability in topography and hydrography to produce a diverse range of wetland habitats and biotic assemblages (Puckridge, 1998; Roshier, 2001). Fluvial dynamics from flooding play a major role in maintaining a diversity of lentic, lotic and semi-aquatic habitat types, with each represented by a diversity of successional stages. Ecotones (transition zones between patches) and connectivity (the strength of interaction across ecotones) are structural and functional elements that result and contribute to the spatio-temporal dynamics of riverine ecosystems (Ward et al., 1999). Connectivity in dryland river systems is an important factor promoting gene flow among populations but also affects to the extent to which ecotones alter dispersal, movement or migration by species (Ward et al., 1999).

Dry periods create fragmentation of dryland riverine communities. The fragmented landscape forms sub-populations of species, ranging from trees, invertebrates, fish and reptile populations. Habitat fragmentation in rivers result from a variety of river processes that occur when flow ceases either during a decrease in discharge or drought. The still waters that are retained in deeper expanded channel segments are termed waterholes (Knighton and Nanson, 1994). These isolated waterholes occur throughout a floodplain and in arid areas serve as a refuge for the riverine wildlife that depends upon surface waters.

Biological processes in arid zone rivers are a rarely studied factor due to our knowledge being geographically biased (Kingsford, 1995; Williams, 1998; Kingsford et al., 1999). On a broad scale the relationship between biology and hydrology in large rivers is defined by the Flood Pulse Concept (Junk et al., 1989) that riverine communities respond to variations in the rates of rise and fall and the amplitude, duration, frequency and regularity of floods (Junk et al., 1989). The spatial and temporal parameters of a flood pulse are especially important for the flora and fauna of arid-zone rivers (Walker et al., 1997). However, the spatial and temporal scales of the variances must be considered in the context of the target organism or process. For example, an animal with a brief aquatic stage that coincides with the period of filling in a temporary wetland is not likely to be as affected by the water regime as another whose aquatic life-cycle extends beyond the duration of filling (Boulton and Brock, 1999). Episodic flooding events initiate biological processes (Ruello, 1976; Maher and Carpenter, 1984; Briggs and Maher, 1985; Briggs et al., 1985; Puckridge et al., 1998; Kingsford et al., 1999) in organisms such as fish, invertebrates, birds, plants and turtles. This may include dispersal, reproduction and growth. Organisms in arid Australia and worldwide have developed adaptive strategies that promote success. In drought-prone areas, species often evolve life-history or behavioural characteristics that enhance their survival and recovery (Niemi and Yount, 1990; Gagen et al., 1998). These characteristics extend into freshwater turtle populations and may range from clutch size, growth, diet, and size at sexual maturity.

1.1.2 The Turtles

An important theme in evolutionary ecology is the life history variation that occurs within and between species. A life history is a suite of coevolved characteristics that directly influences population parameters (Congdon and Gibbons, 1990). Several important determinants of life history variation within a genus or family are local adaptation, plasticity of response to local environmental heterogeneity, and physiological constraints (Dunham and Miles, 1985). For reptiles, life-history traits such as age at maturity, clutch size and survivorship are often strongly correlated with body size or growth rate (St. Clair et al., 1994).

Turtles exhibit the evolution of separate adaptive strategies between sexes and species (Berry and Shine, 1980). In general male turtles mature at smaller sizes than do females; it is less common for males to mature at similar sizes as females, or larger than females (Congdon and Gibbons, 1990). Sexual dimorphism is linked to mating tactics and territoriality for where large males are larger, and to selection for greater fecundity where females are larger (Berry and Shine, 1980).

Variation in body size is an important determinant of reproductive success in both sexes. It is necessary to understand the influence of body size on reproductive output within and among individuals, but also how body size variation arises (Congdon and Van Loben Sels, 1991). Kuchling (1999) reports that large female chelonians of several chelid species lay more or larger eggs per clutch and have a higher reproductive success and higher quality offspring than smaller sized females (Congdon and Tinkle, 1982; Congdon and Gibbons, 1983; Congdon et al., 1983; Congdon et al., 1987). Therefore, body size may be driven by a wide scope of life history attributes including a trade-off between early reproduction and large body size.

Once a turtle matures, energy is directed towards reproduction at the expense of growth. Individuals that mature earlier reproduce at a smaller body size than individuals with later maturity (Ford and Seigel, 1994). Costs of delaying sexual maturity include increased risk associated with death prior to first reproduction and lengthened generation times (Congdon et al., 1993). There also may be considerable variability within and among populations of the size and age at which different individuals reach maturity (Kuchling, 1999). Some confusion exists about the pattern of interaction of body size and age at sexual maturity among turtle species (Congdon and Gibbons, 1990). Moll (1979) reported that age at maturity is not correlated with body size.

Growth rate is an important factor that affects a juveniles exposure to sources of mortality, attainment of maturity, fecundity when clutch size is correlated with body size, the maximum size achieved, and the adult lifespan (Germano, 1994). Thus, growth should be subject to intense selective pressure because of its direct link to fitness. Growth rate is, in part, genetically determined, it may also be influenced markedly by environmental factors such as temperature or diet (St. Clair et al., 1994). Brown et al. (1994) reported that turtles might exhibit faster growth, larger size, and higher reproductive output in situations of increased quality or quantity of food associated with productive water bodies. The density and biomass of turtle populations may increase with productivity (Brown et al., 1994) or habitat suitability (Galbraith et al., 1988).

Another population parameter that varies in turtle populations is the ratio of males to females. Sex ratio is an important demographic measurement because of its potential influence on effective population size in population dynamics (Gibbons, 1990). Unbalanced sex ratios have sometimes been attributed to sampling bias, difference in behaviour between sexes, uncertain determination of size at maturity, or a combination of these factors (Gibbons, 1990).

Assuming there is no sampling bias, differences in adult sex ratio can result from four causal factors (Lovich, 1996).

1. Sexes can experience differences in mortality (eg. females being more vulnerable to predation when leaving the water to lay eggs).
2. Sexes may exhibit differences in emigration or immigration (male turtles of some species move more frequently or greater distances than females).
3. Temperature-Dependant Sex Determination (TSD) may cause fluctuations in the primary sex ratio within cohorts among years.
4. Timing of sexual maturity where the sex that matures the earliest is expected to predominate numerically.

It has also been suggested that sexual dimorphism may be linked to adult sex ratios under influences of TSD (Ewert and Nelson, 1991). Adult sex ratios are predicted to be male-biased in species that females are the larger sex, and female-biased when males are the larger sex (Lovich, 1996). Nevertheless this does not explain why sexual size dimorphism occurs in GSD (genetic sex determination) turtles (Ewert and Nelson, 1991).

Incubation studies of *Em. macquarii* confirm that sex is genetically determined rather than temperature dependent (Thompson, 1983; Bull et al., 1985). Therefore, TSD cannot explain any population sex bias in *Em. macquarii*.

Among Australian freshwater turtles, the short-necked turtle *Em. macquarii*, typically associated with permanent waters in riverine systems is recognised as a widespread species and displays large geographic variation in body size, even though this is poorly documented in the literature. Life history data for this species is available from the Murray River (Chessman, 1978; Thompson, 1983), Fraser Island; *Em. krefftii* (Georges, 1983), and Murray, Brisbane, Macleay, Hunter, and Nepean Rivers (Judge, 2001), providing the opportunity to explore the difference of geographic variation in their biological traits and population dynamics. The status of the turtle *Emydura* in the Cooper Creek is contentious, but is thought to be a form of *Em. macquarii* with some individual traits due to its isolation and persistence in central Australia (A. Georges pers comm.).

1.1.3 Aims

This study investigates the biological and demographic factors that enable freshwater turtles to persist in the arid environment of the Cooper Creek catchment in southwest Queensland. Several competing models of the interaction between turtle populations and the spatial-temporal dynamics of the Cooper Creek system were formulated, and data gathered to distinguish between these models.

The turtles may strongly select among available standing waters those that are permanent or most likely to be so. They would presumably use cues correlated with waterhole permanence. Such cues might include waterhole size, depth or other morphological attributes, water compositional cues that indicate groundwater input, or cues drawn from aquatic or riparian vegetation that are strongly correlated with waterhole permanence. High fidelity to site would be a feature of their biology and only permanent waterholes would be occupied. Waterholes that are ephemeral on a time scale mis-matched with turtles life history would not be occupied by any but a few wayward individuals (Figure 1.1). Contribution to the future regional gene pool would occur only in the permanent waterholes (Figure 1.1). I refer to this as the Habitat Specialisation Model.

At the other extreme, turtles may disperse during floods to occupy a range of permanent and ephemeral waterholes. Populations in the permanent waterholes would persist, whereas populations occupying the ephemeral waterholes would perish when the ephemeral waterholes dried. Depending upon the frequency of drying of the ephemeral waterholes, little or no recruitment to the breeding population would occur there. Thus both permanent and ephemeral waterholes are occupied under this model, contribution to the future regional gene pool would be made again only in the permanent waterholes. Animals dispersing to the ephemeral waterholes would be dispersing to a ‘sink’. I call this model the Source-Sink Model (Figure 1.2).

The focal area model lies somewhere between these two extremes. During floods, turtles will disperse and occupy a range of permanent and ephemeral waterholes. Turtles may strongly select the permanent waterholes using cues from waterhole attributes such as morphology and riparian vegetation, while using the same mechanisms to select the ephemeral waterholes but at a lesser extent. The main contribution to the regional gene pool would be from the turtle

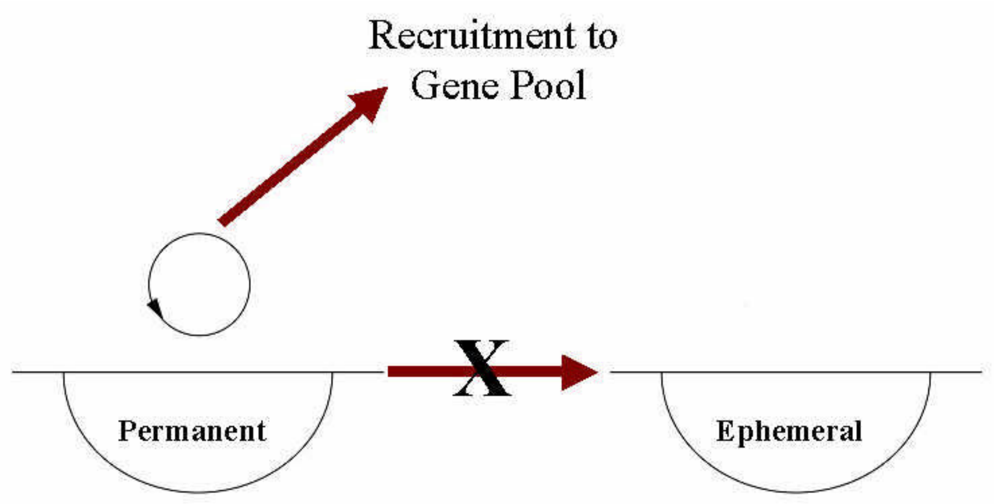


Figure 1.1 Habitat Specialisation Model where the only contribution to the regional turtle gene pool is coming from the permanent waterholes

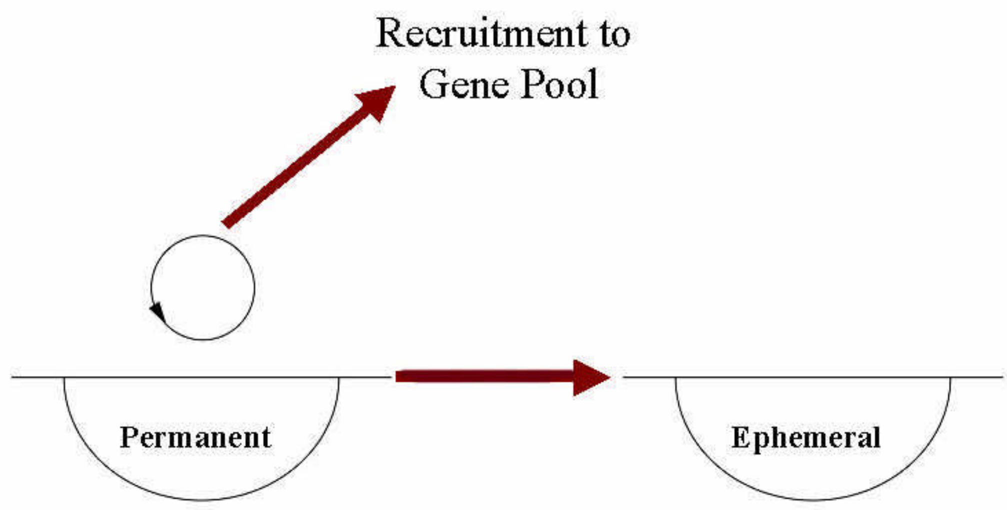


Figure 1.2 Source – Sink Model where the permanent waterholes are the source turtle populations and the ephemeral waterholes are the sink populations.

populations in the permanent waterholes. Depending on the frequency of drying of the ephemeral waterholes, waterholes that dry over a relatively long time-scale, for example 15 – 20 years may contribute to the regional gene pool if a flood passed through the system again before the turtle population is decimated with the drying waterhole. Thus both permanent and ephemeral waterholes are occupied under this model, with main contribution to the future regional gene pool being made from the permanent waterholes with secondary contribution being made from the ephemeral waterholes. I call this model the Focal Area Model (Figure 1.3).

The Pulse Model (Figure 1.4) is exhibited in the turtle *Chelodina longicollis* in Jervis Bay Kennett and Georges, 1990). Here, Kennett and Georges (1990) found that the turtles strategy is to wait out the dry unproductive periods, sometimes several years in permanent lagoons then migrate to productive ephemeral lagoons during the wet. It is here at the ephemeral lagoons that the turtles use the available resources to grow and reproduce. Once the ephemeral lagoons are dry, *C. longicollis* then migrates overland back to the permanent waterbodies to wait out the intervening dry period. The main contribution to recruitment and the regional gene pool is from the ephemeral lagoons. I call this model the Pulse Model (Figure 1.4). This same strategy can be tested for *Em. macquarii* in the Cooper System to see its viability.

Turtles may randomly disperse into waterholes with no selection processes. The population is divided into a network of subpopulations occupying waterholes of varying persistence. There is no discrimination among permanent and ephemeral waterholes with each population having equal chance of contributing to the regional gene pool. I refer to this model as the Metapopulation Model (Figure 1.5).

The primary objective of this study is to describe the pattern of distribution of turtles across waterholes in Cooper Creek. Including patterns in size structure, sex composition and growth, to select among the above models or develop a model of the processes that operate to allow turtles to persist in this dryland system.

For this study I compare turtle populations in the Cooper Creek and Warrego River catchments as a contrast of turtles persisting in two different drainages in southwest Queensland. Fieldwork was conducted during April and May 2002 to augment data that was collected in 2001. A total of three field trips were made to the Cooper Creek sites and two

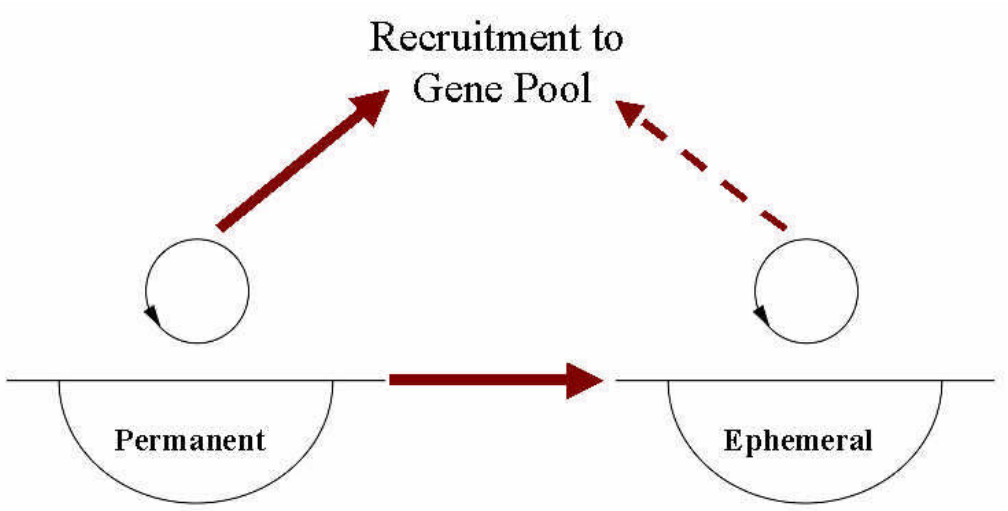


Figure 1.3 Focal Area Model where the main recruitment to the future gene pool is coming from the permanent waterholes, with the semi-permanent waterholes only contributing to the future gene pool if the waterhole does not dry before the next flood.

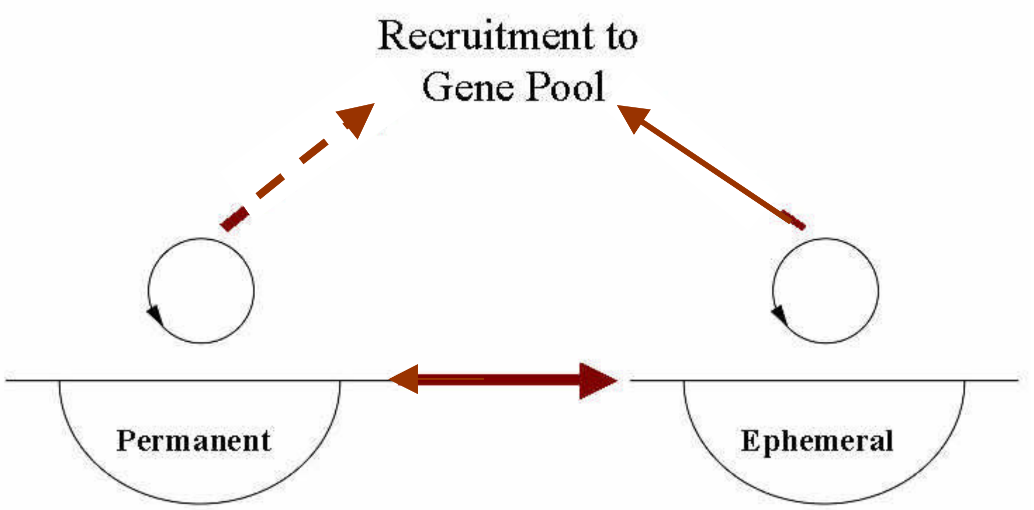


Figure 1.4 Pulse Model where the main recruitment to the gene pool is coming from the ephemeral waterholes.

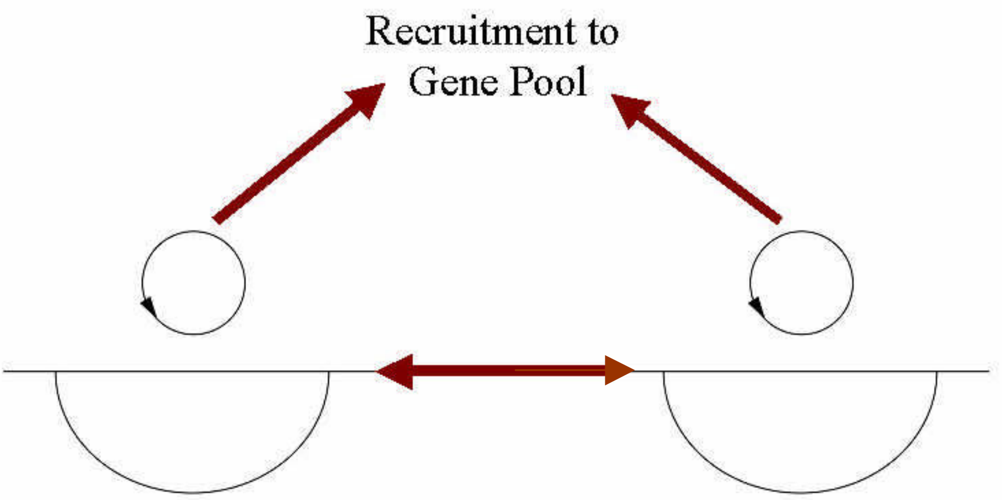


Figure 1.5 Metapopulation Model where the turtle population is divided into a network of subpopulations occupying waterholes of varying persistence, there is no discrimination between permanent and ephemeral waterholes.

trips to the Warrego River sites over the two years. Morphometrics and growth rates were measured, with sex and maturity status also being determined for each turtle that was caught in the study. Through the use of these measurements, this study will enhance the understanding of population dynamics of the Cooper Creek turtle and the traits that enable this species to survive in the 'boom' and 'bust' ecology of dryland rivers. During the field study it became evident that turtles were also under impact by incidental harvesting from illegal netting for fish in waterholes. Therefore, this study also intends to quantify the present and past impact of illegal netting on turtle populations.

1.1.4 Specific Objectives

This thesis augments the literature on geographic variation in *Emydura macquarii* by contrasting the Cooper Creek populations with the Warrego River and other published studies. Specifically I investigate the population dynamics of *Em. macquarii* in Cooper Creek and answer the following questions:

(1) what life-history traits of body size, maturation and growth allow these animals to persist in arid Australia?
(2) what environmental factors and waterhole features enable turtles to persist in arid Australia?
(3) what environmental conditions are more favoured by these turtles populations? The boom or bust time?
(4) what are the impacts of illegal fishing on turtle populations in the Cooper Creek?

1.2 Study Animal – The Cooper Creek Turtle

All freshwater turtles in Australia belong to the family Chelidae, excepting the pig-nosed turtle *Carettochelys insculpta* of the family Carettochelydidae (Georges, 1996). The family Chelidae is considered to be of Gondwanan origin (Burbidge *et al.*, 1974), with no fossil material being found outside their current range of Australia, New Guniea, the island Roti in Indonesia, and South America (Georges and Thomson, 2001). The family Chelidae contains two major lineages in Australia, the long-neck turtles of genus *Chelodina*, and the short-neck turtles of genera *Elseya, Elusor, Emydura, Pseudemydura* and *Rheodytes* (Cann, 1998; Cogger, 2000).

There are four species of *Emydura* classified in Australia: *Em. krefftii, Em. macquarii, Em. subglobosa* and *Em. victoriae* (Cann, 1998). Six subspecies are listed in the *Em. macquarii* complex: *binjing* (Clarence River, NSW), *dharuk* (Sydney Basin, NSW), *gunabarra* (Hunter River, NSW), *dharra* (Macleay and Hastings Rivers, NSW), *macquarii* (Murray-Darling Basin, QLD, NSW, VIC, ACT, SA), and *signata* (Brisbane and Tweed Rivers, QLD, NSW) (Cann, 1998). To complicate matters even more there are three subspecies of *Em. macquarii* yet to be described from Richmond River (NSW), Cooper Creek (QLD) and Bellinger River (NSW) (Cann, 1998).

Emydura macquarii is a widespread species found throughout the Murray and Darling drainage of western New South Wales and inland southern Queensland and with several forms variably distributed throughout eastern-flowing rivers of central and northern coastal New South Wales (Cann, 1998). *Em. macquarii* has an extensive distribution range, from coastal to inland and from Queensland to Victoria, indicating that this species of turtle inhabits a variety of waterbodies from flowing coastal and inland waters, to regulated systems and also disconnected dryland rivers in semi-arid Australia.

This study focuses on the undescribed Cooper Creek turtle, *Emydura sp.* (Cann, 1998), and will be referred to as *Em. macquarii* (A. Georges pers comm.). Little is known of its biology, which attests to the remoteness of south-west Queensland and the distance of the region from established universities (Cann, 1998). The species congregates in permanent waterholes with immigration occurring between ephemeral and semi-permanent waterholes during floods when dispersal is facilitated (Cann, 1998). Because of the isolation of the waterholes and the large distances to permanent waterholes, any turtles that remain in ephemeral waterholes after a flood are unlikely to survive the intervening period. Terrestrial migration of this species is unknown because of the extreme arid environment in which they live. Chessman (1984) found that evaporative water loss was far greatest in *Em. macquarii*, than in *Chelodina expansia* and *C. longicollis*, with the latter being a known migrator and capable of aestivation Cann, 1998; Cogger, 2000). Little is known about aestivation in *Em. macquarii*, but it is unlikely that they would survive long periods in this arid environment without access to free standing water.

The Cooper Creek turtle (Figure 1.6) is a short-necked turtle with a yellow eye-stripe extending back along the lower neck, although the stripe is often faded in adults. Occasionally, a dash of pink occurs in the gular region. Two small barbels are present on the

Figure 1.6 A large female Cooper Creek turtle (photograph by A. Georges).

anterior ventral margin of the jaw. The iris in the eye is large and yellow, with the carapace being a dull or faded olive-green (Cann, 1998). Adult males are easily distinguished from adult females by their longer, thicker tail. Body size can be variable in and between populations. The maximum carapace length measured is 368 mm from the Thomson River, a tributary of the Cooper Creek, recorded by a local pastoralist and naturalist Angus Emmott. This individual is the largest known specimen of any species of *Emydura*. The Cooper Creek turtle becomes extremely large and bulky. Beyond the carapace length of 250 mm they diverge markedly in morphology from other species of *Emydura* (Cann, 1998). They are the only turtle species found throughout the Cooper Creek system, with *C. longicollis* found in the headwaters (A. Georges pers comm.).

Emydura macquarii is typically omnivorous (Spencer *et al.*, 1998) feeding on filamentous algae. It is unknown whether feeding on aquatic macrophytes and invertebrates, terrestrial insects and carrion is random or selective (Chessman, 1978; Georges, 1982; Spencer *et al.*, 1998). The Cooper Creek turtle may lay two clutches per year with a clutch size varying from 10 eggs and up to 20-30 eggs (A. Georges pers com.) and is strongly correlated with maternal body size (Georges, 1983). The hard-shelled eggs measure approximately 42 x 24 mm and weigh around 14 g, being by far the largest known eggs of any *Emydura* species (Cann, 1998). The females ovipost between October to December, with hatchlings appearing from January to March (Georges pers comm., 2002). The hatchlings are approximately 30 mm in carapace length. The sex of the *Em. macquarii* hatchlings is genetically determined (Thompson, 1983; Bull *et al.*, 1985) as opposed to other reptiles including turtles that exhibit TSD (temperature-dependent sex determination). Males mature at smaller sizes than females and reach smaller maximum sizes.

During this study we also caught turtles from the Warrego River, which included three species of turtles: *C. longicollis, C. expansa* and *Em. macquarii*. For this study a focus is on *Em. macquarii* for purposes of comparing the same genera in the Warrego River and the Cooper Creek for evidence of exhibit different life-history and behavioural traits. In this thesis both species of turtles from the different catchments will be referred to as *Em. macquarii*, although the undescribed species from the Cooper Creek is referred to as the Cooper Creek turtle.

1.3 The Study Areas

I investigated the turtle populations of Cooper Creek to better understand their successful suite of life-history or behavioural traits that enhance their survival during the ‘boom’ and ‘bust’ periods. Two catchments were studied in semi-arid Australia. The Cooper Creek catchment in southwest Queensland that floods irregularly, with its floodwaters sometimes reaching Lake Eyre in South Australia. Cooper Creek presently has no water resource development. The Warrego River catchment flows more frequently, has some water resource development, and is southeast of Cooper Creek in southwest Queensland. The Warrego flows into New South Wales and connects with the Darling River. The comparison of climate between catchments is listed in Table 1.1 and location of the Cooper and Warrego catchments in Queensland are depicted in Figure 1.7.

Waterholes were sampled from six locations on the Cooper and four locations on the Warrego. A number of waterholes were then sampled from each location, usually four to six waterholes. These sampled waterholes comprised of one major waterhole with nearby satellite waterholes. A total of 22 waterholes were sampled from the Cooper Creek catchment and 15 waterholes sampled from the Warrego River catchment.

1.3.1 Cooper Creek

The Cooper catchment is part of the Lake Eyre Basin and covers 306 000 km^2 (Walker et al., 1997). It is one of the main rivers on the eastern side of the basin along with the Diamantina-Warburton and Georgina Rivers, which are collectively termed the Channel Country. Precipitation over the eastern basin varies from ~ 450 mm / yr in the headwaters to ~ 120 mm / yr in the Simpson Desert, with most of this area receiving less than 250 mm / yr. Annual pan evaporation varies from ~ 2400 to over 3500 mm / yr (Nanson and Tooth, 1999). A common precipitation pattern in the basin occurs when moist, tropical air spills over the northeastern Great Dividing Range or the northern tablelands during the monsoon (November to March). This leads to intense but erratic rainfall that brings floods to the rivers in most years (Kotwicki, 1986; Nanson and Tooth, 1999), even though major flooding episodes occur only once every twenty years or so and are often associated with La Niña phases of the El Niño Southern Oscillation (Allan, 1988; Nanson and Tooth, 1999). These annual flows do not always connect every waterhole in the system, as the isolated waterholes on the floodplain might be

Table 1.1 *Location and climate of the towns nearest to the study sites in both the Cooper Creek catchment and Warrego River catchment (Bureau of Meterology).*

Catchment	Town	Latitude	Longitude	Altitude (m)	Mean Minimum Temperature (°C)	Mean Maximum Temperature (°C)	Annual Rainfall (mm)
Cooper Creek	Windorah	-25.4228 S	142.6564 E	126.3	15.7	30.3	294.4
Warrego River	Charleville	-26.4131 S	146.2611 E	302.6	13.5	27.9	495.1
Warrego River	Cunnamulla	-28.0706 S	145.6808 E	188.7	14.1	28.0	376.5

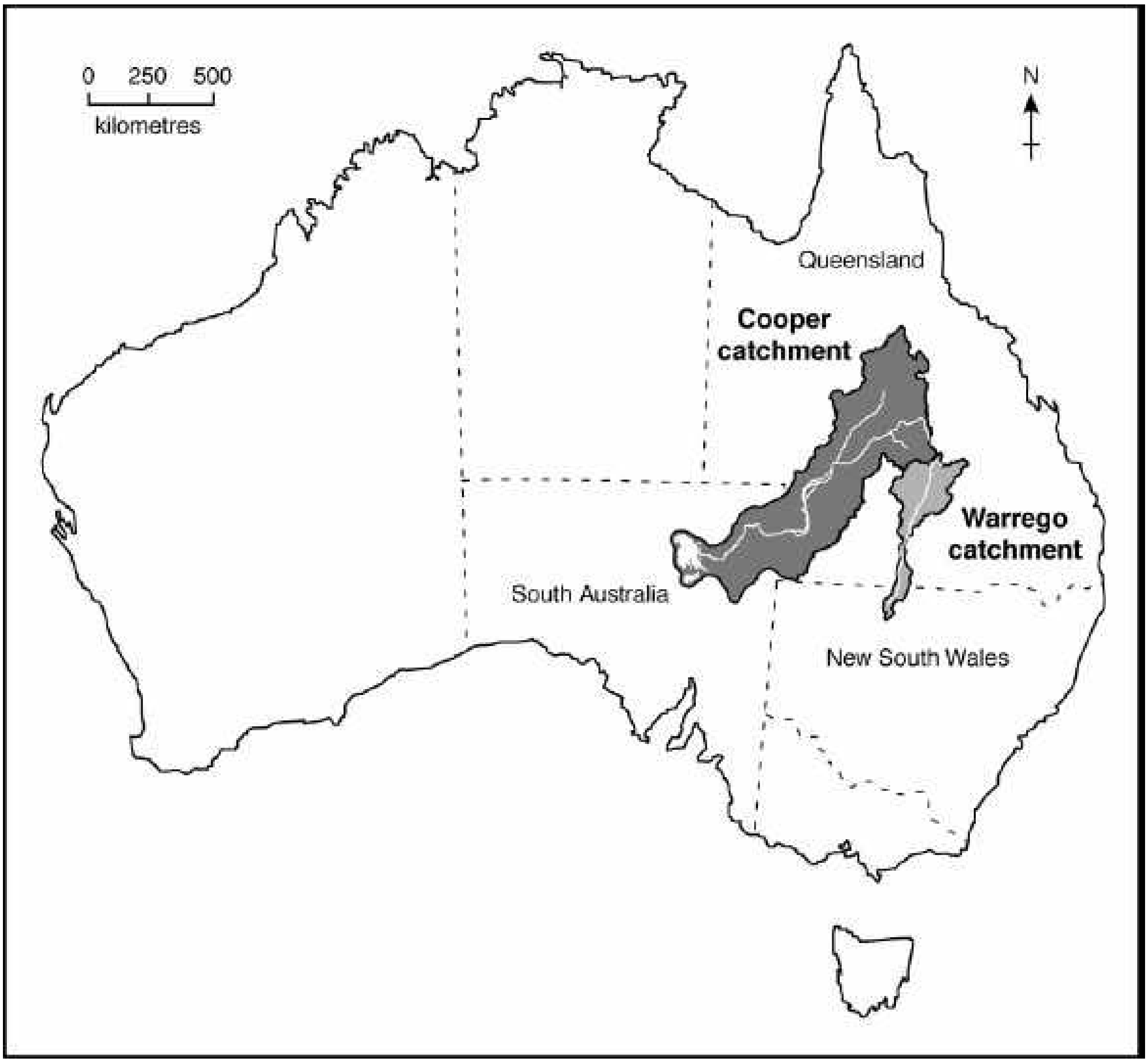


Figure 1.7 Location of study areas, Cooper Creek and Warrego River catchments (Figure from Goodsell 2002).

some distance from the main channel. Hence, some of the waterholes studied for this project may not receive this annual ‘top up’ due to the waterholes’ isolation.

The study sites on the Cooper Creek range from Lochern National Park in the northern part of the catchment, near the junction of the Thomson River and Cooper Creek, to Tanbar Station in the south. Below the township of Windorah, the Cooper channel widens to 70 km across the floodplain, giving this magnificent area its name, the Channel Country (Figure 1.8). We had six locational sites (Figure 1.9) spread along the Cooper, sampling a total of 22 waterholes.

1.3.2 Warrego River

The Warrego catchment has a total area of 78 400 km^2 and receives the tributaries of the Ward, Lango and Nive Rivers, and the distributaries of the Cuttaburra, Noorama and Widgeegoara Creeks (Department of Natural Resources, 2000). From its source in the Carnarvon Range, the Warrego River flows in a southerly direction to its confluence with the Darling River. The headwaters of the Warrego River are the most northerly point of the Murray-Darling Basin, which extends downstream into New South Wales, Victoria and South Australia. The majority of the Warrego Catchment lies in Queensland, with only 16% (some 12 400 km^2) contained in New South Wales (Department of Natural Resources, 2000).

There is considerable variation in rainfall within the catchment, both within any one year and from year to year. At Charleville, annual rainfall has varied from 203 mm (in 1890) to 1,203 mm (in 1899) (Department of Natural Resources, 2000). The rainfall is also seasonal, with the majority of the catchment receiving more than 50% of its annual rainfall in the four month period from December to March, on average 58% of the catchment receives more than 400 mm / yr. Annual pan evaporation ranges from 2 400 to 2 600 mm / yr (Department of Natural Resources, 2000)

Several major floods have occurred in the Warrego Catchment this century with flooding events sometimes occurring simultaneously in the Warrego and Paroo Rivers. The combined floodwaters can cause widespread damage to towns, properties and agriculture in the area but again reminds us of the natural variability of the flow regime in semi-arid Australia with large floods being part of the system for thousands of years.

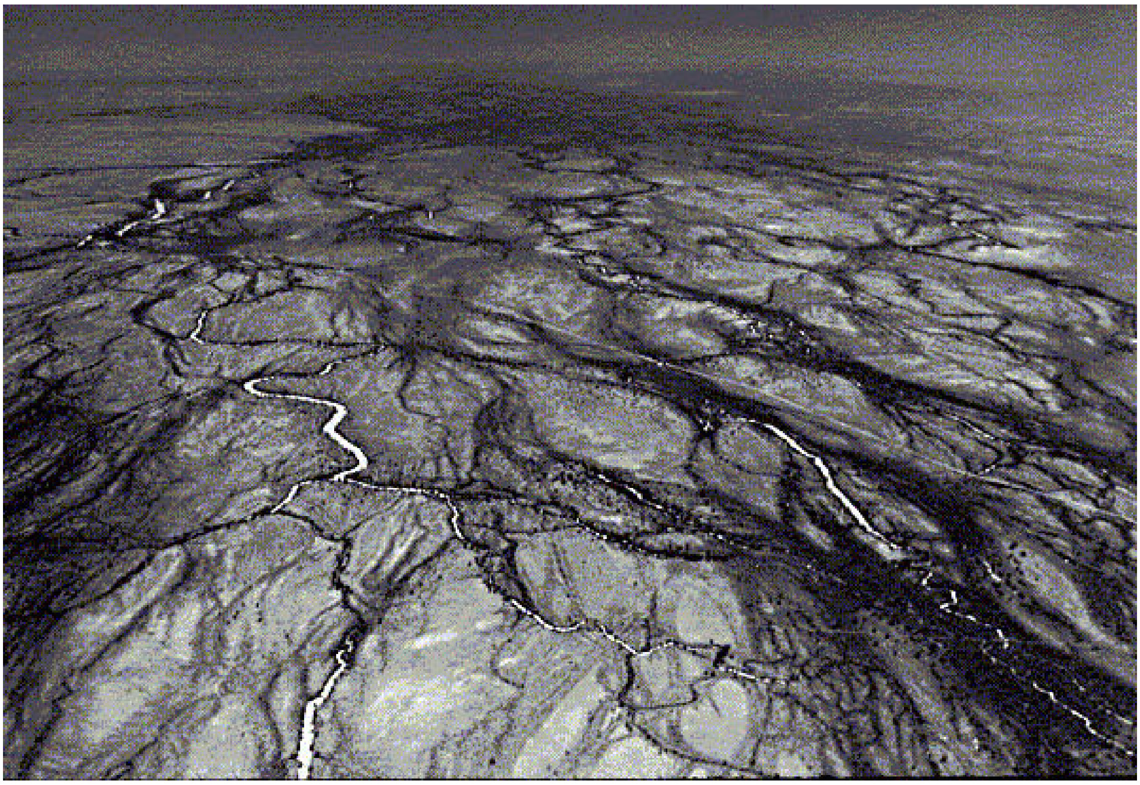


Figure 1.8 The famous Channel Country of the lower Cooper Creek system (photograph, AUSLIG website).

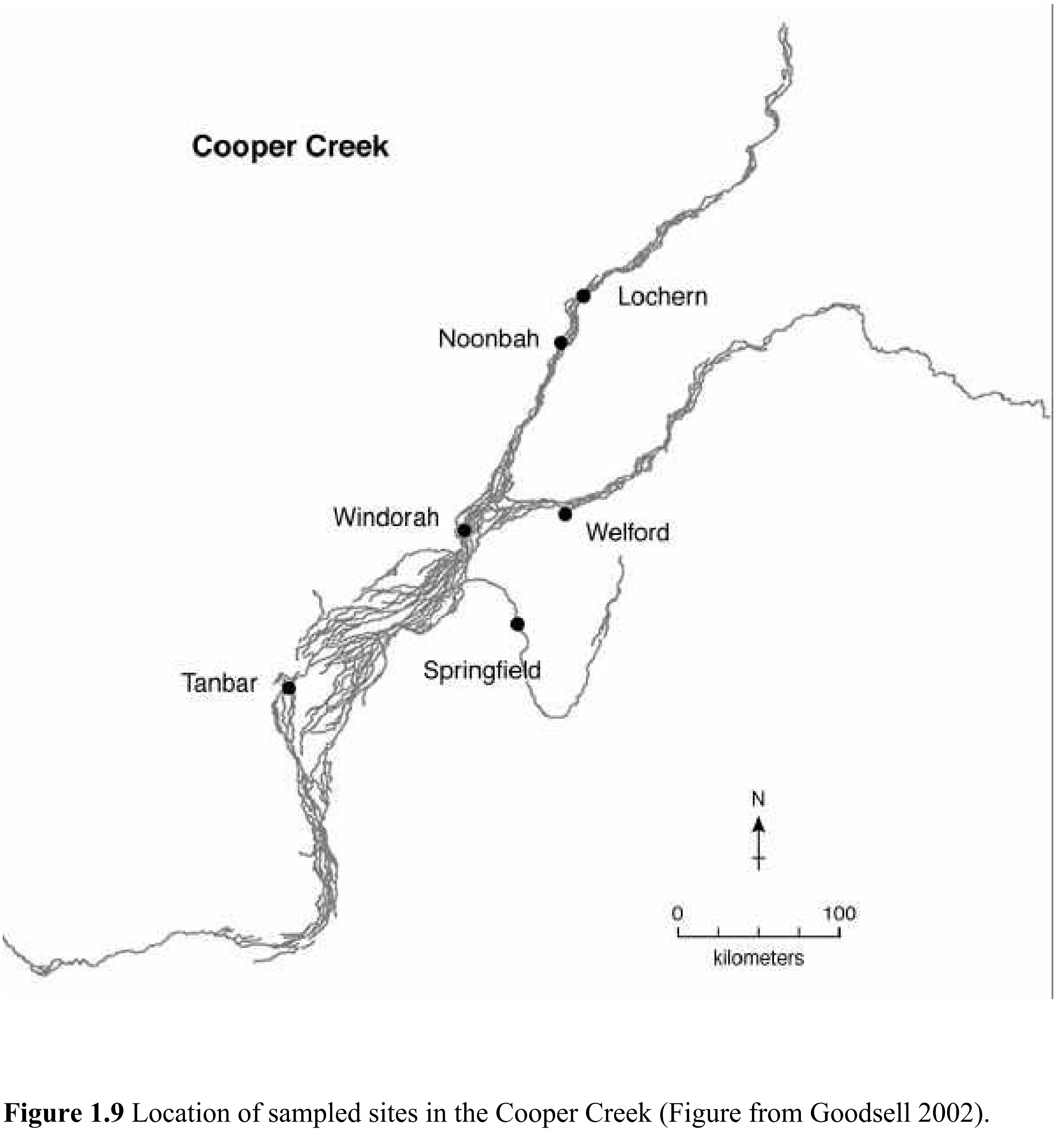


Figure 1.9 Location of sampled sites in the Cooper Creek (Figure from Goodsell 2002).

The study sites on the Warrego River range from Charleville in the northern catchment, to south below Cunnamulla, nearing the New South Wales border (Figure 1.7). We had four locational sites (Figure 1.10) spread along this part of the Warrego River, sampling a total of 15 waterholes.

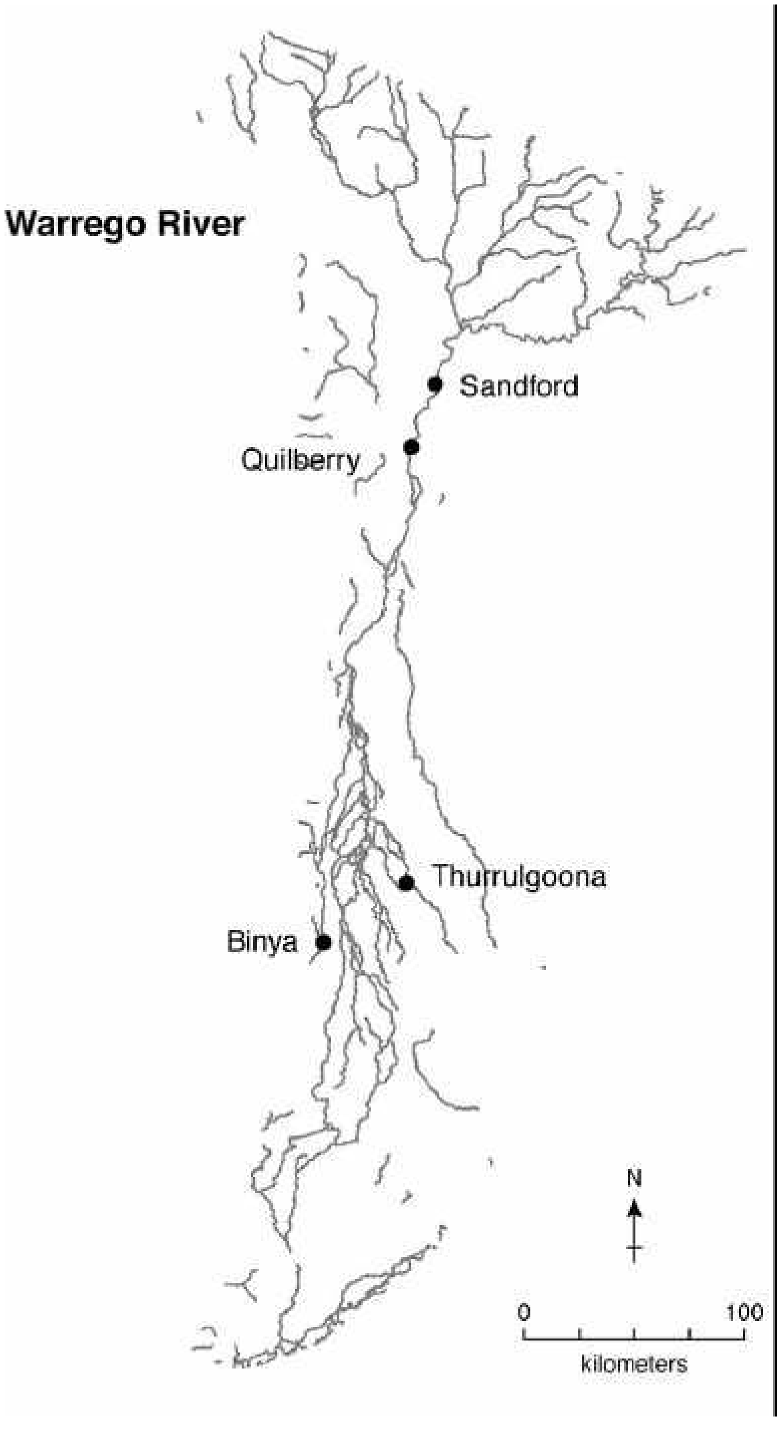


Figure 1.10 Location of sampled sites in the Warrego River (Figure from Goodsell 2002).

CHAPTER TWO

2 MATERIALS AND METHODS

2.1 Period of Fieldwork

Fieldwork was carried out in April and May 2002 to augment data that was collected in April, September and October 2001. Three field trips were to the Cooper Creek catchment (April 2001, September 2001 and April 2002) a total of six weeks sampling. Two field trips were in the Warrego River catchment (October 2001 and May 2002) a total of four weeks sampling. Trips were timed for a metabolically active season of the turtles, as it is more difficult to catch turtles during the cooler months (June to August). The trips were also planned to avoid the hotter months (November to February) as during this period it becomes too hot for *Homo sapiens* to be active in the arid desert temperatures (40°C+).

2.2 Capture

A total of 1,132 turtles (excluding recaptures) were collected from 22 waterholes in the Cooper Creek catchment and 456 turtles (excluding recaptures) were collected from 15 waterholes in the Warrego River catchment. Turtles were caught in rectangular-boxed shaped crab traps (Figure 2.1) called CTL traps made by Tacspo Distributing Pty Ltd (36 Manilla St. East Brisbane 4169). We attached a snorkel extension to some traps (Figure 2.2 and 2.3). The attached snorkel allowed traps to be set overnight and for longer periods during the day, as completely submerged traps needed to be checked within three hours. Snorkel traps were tied to over hanging branches (Figure 2.4) and snags along the shore while the submerged traps had an attached float on a length of rope (3 m), allowing the traps to sit on the substrate of the waterhole. Submerged traps were usually set down the middle of the waterholes and the snorkel traps were set along the shores. The traps were baited with tinned cat-food (fish based), and or other fresh meats depending as available (beef heart, liver or kangaroo).

The traps were largely unbiased in respect to size or sex although hatchlings were seldom taken by the 40 mm mesh size. However, we tested whether turtles could escape from the traps if they were unattended overnight. We placed marked turtles into snorkel traps at dusk and on the morning trap check some turtles had escaped. Since trapping was concentrated

Figure 2.1 A baited box-shaped crab trap will be completely submerged for catching turtles over short catch times (2 – 3 hours) (photograph by A. Quinn).

Figure 2.2 A baited box-shape crab trap with an attached snorkel for catching turtles over longer catch times (from 3 – 24 hours) (photograph by A. Quinn).

during the days, the number of escapee turtles from overnight settings would be limited, with negligible effect on the overall results. It was also observed that turtles were attracted to a trap that already had turtles in it but no formal statistical tests of Poisson distributions were taken. For this study, it was common to have six or more turtles in a trap with this sometimes escalating to 10 – 15 (Figure 2.3) and on one occasion we had 30 turtles in one snorkel trap. Spencer (2001) also noted the activity and movement of feeding in traps attracts other turtles into a trap.

The length of trapping session was an influence upon trapping success. If traps were checked too regularly (i.e. within 2 hrs), trapping success would be reduced as the turtles were disturbed by activity. However, turtles escaped from traps that were checked infrequently and effectiveness of the fresh bait declined over time. The bait was enclosed in bait-bags to discourage consumption. Even so, turtles could pull fragments from the bait-bag to be consumed. The trapping period for the snorkel traps varied. By day the snorkel traps were checked every 3 – 5 hours, and traps were freshly baited at dusk to catch turtles feeding the next morning.

Upon capture, the turtles were put into large mesh capture bags to contain them while in the boat. Turtles were then taken back to camp and transferred into large 200 L tubs for holding. Containers allowed easier and quicker processing and kept the turtles away from ants. After processing, all individuals were released at their respective waterhole of capture.

2.3 Morphometry, Growth Rates and Marking

Maximum carapace length (CL), midline plastron length (PL), and maximum head width (HW) were measured using vernier callipers (to the nearest 0.1 mm). Body weights < 3 kg were measured with an electronic scale (to the nearest g); individuals > 3 kg were measured with a Salter spring balance (to the nearest 10 g). A small piece of webbing was clipped from the edge of turtle’s fifth toe of a rear limb for a DNA sample (for a concurrent genetics study being conducted on the Cooper Creek turtle).

The 95th percentile of adult body size was not calculated to avoid an outlier bias, as there are no unusually large individuals among populations. Sexual size dimorphism index (SD Index) was determined by dividing the maximum carapace length of the larger sex (females) by that

Figure 2.3 Myself checking a successful snorkel trap (snorkel tied to overhanging tree is circled) filled with approximately 10 turtles (photograph by T. Goodsell).

Figure 2.4 A snorkel trap tied to a tree with 30cm of the extension above the water to allow turtles surface and breathe (photograph by M. White).

of the smaller sex (males) (Lovich and Gibbons, 1992). Differences in adult sex ratios were determined by a chi-square analysis against an expected ratio of 1:1 for sample sizes >30; otherwise a Fisher's Exact test was used.

Lack of mark-recapture meant that growth rate was determined using growth rings from the second costal scute. The spacing of growth marks on carapace scutes was measured where marks were clear and recognisable to estimate annual growth rate from scute marks (Germano and Bury, 1998).

In most instances only the bottom part of the growth ring was visible (Figure 2.5). Measurements of growth rings were taken from the same spot on the upper part of the scute (W) therefore a correction factor (x) was applied to equate the actual size of the scute when more than one ring was deposited hence, calculating the initial size of previous scutes. The correction factor was calculated from a few individuals that exhibited a whole growth ring ie. the upper and lower depositions were visible.

Initial size of previous scute when more than one ring was deposited was constructed from the formula:

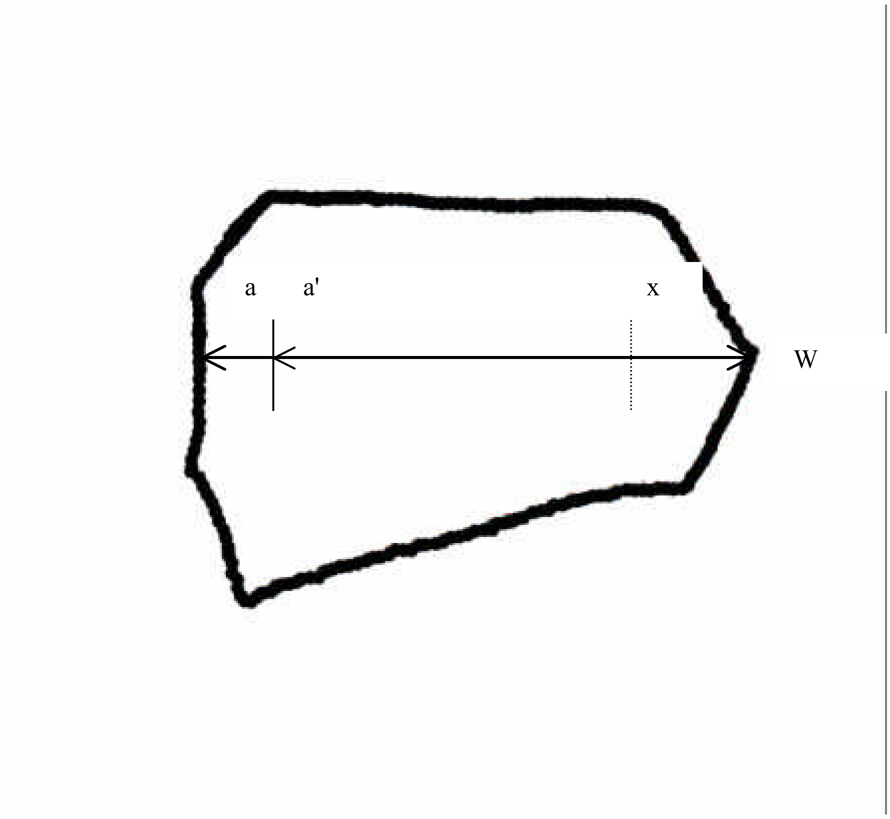
$$k = \frac{a' - x}{a'}$$

where k = initial size of scute empirically determined, a' = length of growth ring measured, and x = correction factor

Growth was then constructed using a linear regression between size of scute and carapace length using the following formula:

$$l' = \quad a'k + \quad o$$

where l' = initial carapace length, = scute length now, a'k = initial scute length, and o = carapace length now.



| represents the visible lower part of the growth ring

┆ represents the faded upper part of a previous growth ring

Figure 2.5 Diagram of a second costal scute showing the measurements of a growth ring for a turtle in this study where, a = length of scute, a' = length of growth ring excluding correction factor, and x = correction factor.

This study assumed that growth rings were deposited annually, as found with *Em. macquarii macquarii* in rivers elsewhere of the Murray Darling Basin (Judge, 2001; Spencer, 2001), but this assumption has yet to be verified for the Cooper Creek turtles. Deposition of growth rings was found across the spectrum of turtle sizes including juveniles and adults, although no rings could be detected on some older individuals. Growth curves were estimated from the last three growing seasons using the last three measured growth rings deposited on the scutes to determine any growth differences in years surrounding a flood.

Von Bertalanffy growth models were fitted to the turtle growth data for each sex separately (Schoener and Schoener, 1978). This approach estimates growth parameters and enables growth rates to be compared between sexes and populations. The growth increment data were fitted using Fabens growth interval model, Fisat II, version 0.2.1 (FAO-ICLARM Fish Stock Assessment Tools, 2002). Fabens (1965) provided a method for fitting von Bertalanffy growth equations specifically with data from animals of unknown ages (Frazer et al., 1990). The model was validated by comparing the predicted asymptotic size with that of maximum adult body size. The asymptotic size should be slightly larger than the maximum adult size for the model to have biological meaning (Frazer et al., 1990).

Fabens rearranged form of the von Bertalanffy equation is:

$$L_r = a - (a - L_c)e^{-kd}$$

where L_r is length at recapture, L_c is length at first capture, d is the time interval between first and last recapture, a is asymptotic length, and k is an intrinsic growth co-efficient.

Age may be inferred from the growth models using scute annuli (Germano, 1994; Germano et al., 2000) and mark-recapture (Frazer and Ehrhart, 1985; Lovich et al., 1990; Cox et al., 1991) data. For this study age at maturity was inferred from the growth models as a preliminary estimate; this obviously requires more long-term mark-recapture data to accurately quantify age at maturity. The use of size-based analogues to provide age-based parameter estimates from von Bertalanffy growth functions is criticised as statistically invalid (Francis, 1988; Lutz and Musick, 1996), even though it may serve as a useful approximation.

Each turtle was individually marked by notches cut into the outer carapace scutes with a hacksaw (Figure 2.6). A binomial numbering system was used for notching. For example, a turtle with the ID number 12.91, would have scutes 1 and 2 notched from the top-end of the carapace, plus the 70 and 20 scute (70+20=90) and scute 1 notched from the bottom-end of the carapace. Notches for small juveniles were cut with a sharp blade due the small size of the animal and the softness of their shell.

2.4 Sex Determination and Maturity Status

Sex was determined by external morphology using the following classifications:

Males

Unsexed Juvenile – These animals are small in size and the anterior margin of cloaca lies within the margin of the carapace when the tail is extended. The sex of these animals could not be determined.

Immature Male – The anterior margin of cloaca lies on the margin of the carapace when the tail was extended. Animals in this category were laparoscoped.

Juvenile Male – The anterior margin of cloaca laid outside the margin of the carapace when the tail was extended. The tail extended less than or equal to 3.5 marginal scutes when adpressed and the penis cannot be protruded. Animals in this category were laparoscoped.

Sub-adult Male – The anterior margin of cloaca laid outside the margin of the carapace when the tail was extended. The tail extended less than or equal to 3.5 marginal scutes when adpressed and the penis could be protruded. Animals in this category were laparoscoped.

Mature Male – The anterior margin of cloaca laid outside the margin of the carapace when the tail was extended. The tail extended more than 4 marginal scutes when adpressed and the penis could be protuded. The penis can be protuded when the animal is held on a slight angle with the carapace supported by the cup of one hand, then adpressed the rear feet with the other hand and when the male puts pressure back onto your hand the penis will soon protude.

Females

Unsexed Juvenile – These animals are small in size with anterior margin of cloaca lying within the margin of the carapace when the tail was extended. The sex of these animals could not be determined.

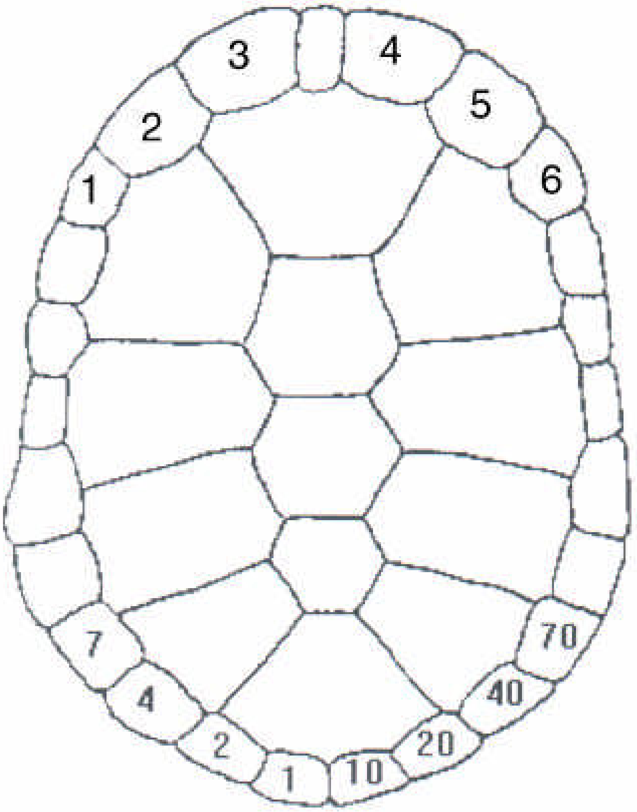


Figure 2.6 The marking system used in this study. Each turtle was given a unique combination of notches to enable further identification. Anterior codes are for hundreds or units, posterior codes are for tens and units.

Sub-adult Female – Equivalent in size to males and showed preliminary development of secondary characteristics (immature, juvenile and sub-adult males), but itself not showing any development. The anterior margin of cloaca laid within the margin of the carapace when the tail was extended. Tail extended less than or equal to 3.5 marginal scutes when adpressed. Animals in this category were laparoscoped.

Mature Female – Larger than the largest mature male yet no development of an enlarged or elongate tail. Gravid during the correct time of year, September to November period. Obvious mature female due to its large and bulky size. Smaller animals in this category were laparoscoped.

To determine maturity status for males and females, turtles were examined by a laparoscope (Wood et al., 1983). Laparoscopy offers the advantages over dissection in that no turtles need to be killed therefore more turtles can be sampled and repeated analysis can occur on the same individual. Turtles were sexed by visual examination of the gonad and associated ducts via a laparoscope (Olympus A7591). Incisions were closed with catgut sutures. Turtles were analysed at camp, and then released back to their respective waterhole, ensuring a full recovery. Surgeries were conducted by Arthur Georges and Scott Thomson, with animal ethics approval of the University of Canberra.

Females were palpated for shelled eggs during the reproductive season (September and October trips) to positively identify reproductive status and size of mature females. The main purpose of conducting the laparoscopy was to determine the size range for female maturity. Tail elongation is a reliable means of confirming male maturity status although some males were laparoscoped as well for confirmation of maturity. Maturity status for males and females was determined as follows:

In the Warrego catchment no laparoscopies were undertaken, but carapace lengths of gravid females allowed an approximation of size at maturity (< 250 mm). For the analysis of adult sex ratios and adult/juvenile ratios, females with a carapace length greater than 250 mm were classified as adults.

Males

Immature Male – Epididymides a translucent straight tube showing no coiling. The translucence implies that the epididymides contains no sperm.

Sub-adult Male – Epididymides a translucent coiled tube.

Mature Male – Epididymides a white, compact, coiled tube. Opacity implies that the tube contains sperm. Previous studies have shown that mature males have sperm in the epididymides in all months of the year (Georges, 1983) with the exception of populations under severe food limitations (Kennett and Georges, 1990).

Females

Immature Female – The ovary is a discrete body, clearly bounded with numerous small yellow follicles equal or sub-equal in size. No follicles were undergoing enlargement, rarely one or two, but not vascularised.

Sub-adult Female – The ovary was a diffuse body whose entire boundary is often difficult to locate in a single view. Numerous small follicles, some of which may have undergone some enlargement. No follicles of pre-ovulatory size (10-15 mm diameter), no corpora lutea, no corpora albucantea (ovarian scars), no eggs in oviducts. Oviducts were simple narrow tubes with little folding. Caution needed as may be mistaken for mature females in non-breeding condition.

Mature Female – The ovary was a diffuse body whose entire boundary is often difficult to locate in a single view. Numerous small follicles, many of which may have undergone some enlargement. Enlarged follicles of pre-ovulatory size (10-15 mm diameter), or if not quite of pre-ovulatory size, are heavily vasculated to indicate vitellogenesis. Corpora lutea may be present regardless of whether eggs are in oviducts, and multiple sets of differing sizes may be present. Corpora albucantea (ovarian scars) indicates previous breeding episodes. Eggs may be present in oviducts. Oviducts were enlarged broad folded tubes.

CHAPTER THREE

3 RESULTS

3.1 Cooper Creek Catchment

The turtles in each waterhole will be treated as individual populations based on population structuring of the turtles as genetically distinct among permanent waterholes (Goodsell, 2002). Only waterholes with >50 turtles captured were analysed in the following sections. All waterholes sampled, permanency of waterhole, and the number of turtles caught is listed in Table 3.1. A total of 1,132 turtles were caught from waterholes in the Cooper system, the permanent waterholes had the highest catch number of turtles. Ephemeral waterholes contained either a few individuals or no turtles at all. Only a total of 16 recaptures have been caught so far. Springfield and Tanbar stations do not allow any netting in the waterholes.

3.1.1 Body Size

Maximum body size of the female Cooper Creek turtle ranged from the 295 mm at the semi-permanent non-netted waterhole of Tanbar, to 366 mm at the permanent non-netted waterhole of Eulbertie. Male maximum body ranged from 265 mm at Tanbar, to 302 mm at the moderately netted permanent waterhole of Currareeva. Females attained larger body sizes than males in all waterholes (Table 3.2). Sexual size dimorphism in the waterholes was relatively similar with females on average 10% larger than males, with SDI ranging from 1.11 at Tanbar to 1.32 at Eulbertie.

3.1.2 Size at Sexual Maturity

Males matured at smaller sizes than females in all waterholes (Table 3.2). However there was substantial variation in the size at maturity, but both sexes matured across the same size range. From laparoscopy, males mature at MCL (maximum carapace length) 177 - 211 mm, whereas females mature at MCL 248 - 268 mm. With so few recaptures to date, age at maturity could not be determined empirically although maturity can be inferred from von Bertalanffy growth curves (see section 3.3.1.4).

Table 3.1. Capture results for waterholes in the Cooper Drainage. Waterhole permanency and rate of illegal netting for fish were defined from landholder information. Catch Per Unit effort (CPU) was calculated by dividing the number of turtles caught by the number of traps set. Permanency of waterholes defined by: P = permanent, SP = semi=permanent, E = ephemeral. Level of illegal netting defined by: 1 = never been netted, 2 = recovery site that hasn't been netted for 10 – 15 years, 3 = moderate netting, 4 = intense netting.

Site Location	Waterhole	Permanency	Level of Netting	CPU	Number of Turtles caught	Number of Recap's.
Lochern N.P	Fish Hole	P	2	2.27	186	4
	Broadwater	P	2	1.07	111	2
Noonbah Station	Top	E		0.09	7	
	Waterloo	P	2	0.57	113	5
	Pelican	E		0	0	
	Bottom	E		0.04	1	
Welford N.P	Little Boomerang	P		0.45	9	
	Trafalgar	P		1.53	23	
Windorah Region	Currareeva	P	3	0.84	151	2
	Murken	P	4	0.20	55	2
	Glen Murken	E		0	0	
	Mayfield	E		0	0	
	Shed Hole	SP	3	0.24	17	
Springfield Station	Homestead	P	1	1.78	190	
	One Mile	E	1	0.04	4	
	Outside	E	1	0	0	
	Warrannee	SP	1	0.38	4	
Tanbar Station	Tanbar	SP	1	0.16	73	1
	Yappi	E	1	0	0	
	Yalungah	E	1	0	0	
	Yoraakah	E	1	0	0	
	Eulbertie	P	1	4.70	188	
				Total	**1,132**	**16**

Table 3.2. Population parameters for *Emydura macquarii* from selected waterholes in the Cooper Creek. Waterholes are arranged from least disturbed to most disturbed. Sexual Diomorphism Index (see methods). CL = maximum carapace length in mm.

		Eulbertie	Springfield	Tanbar	Waterloo	Fish Hole	Broadwater	Currareeva	Murken
No. of turtles		188	190	73	113	186	111	151	55
Maximum CL	M	278.94	272.90	265.50	274.00	282.00	273.40	302.00	257.60
	F	366.9	348.00	295.10	315.30	358.70	327.90	360.00	347.00[d]
CL at Maturity	M	190.8-207.8[$]	177.7-184.6	212.3-230.0[$]	196.3-204.4[$]	194.7-252.4[$]	198.3-211.0	194.1-224.8[$]	185.9-243.6[$]
	F	250.0-264.8	248.7-265.7	243.9-259.7[$]	261.4-273.9	252.9-257.8	249.1-264.3	267.1-268.2	-
Estimated Age at Maturity	M	20	19	7	15	-	-	-	17
	F	15	25	9	19	-	-	-	19
SD Index		1.32	1.28	1.11 : 1	1.15	1.27	1.20	1.19	1.35
χ^2		0.203	0.096	0.563	9.986	9.610	6.605	4.666	1.690
Sex Ratio (Males : Females)		1.45 : 1 ns	0.69 : 1 ns	1.75 : 1 ns	4.16 : 1*	4.1 : 1*	3.57 : 1*	3.16 : 1*	2.3 : 1*
Adult Ratio (Adults : Juveniles)		3.27 : 1	1.71 : 1	0.14 : 1	0.48 : 1	0.39 : 1	0.48 : 1	1.04 : 1	0.22 : 1

[$] maturity was determined from external examination rather than laparoscopy

* $p<0.05$ from chi-square analysis, ns = not significant

[d] represents 3 mature females that were found dead or near death at this waterhole

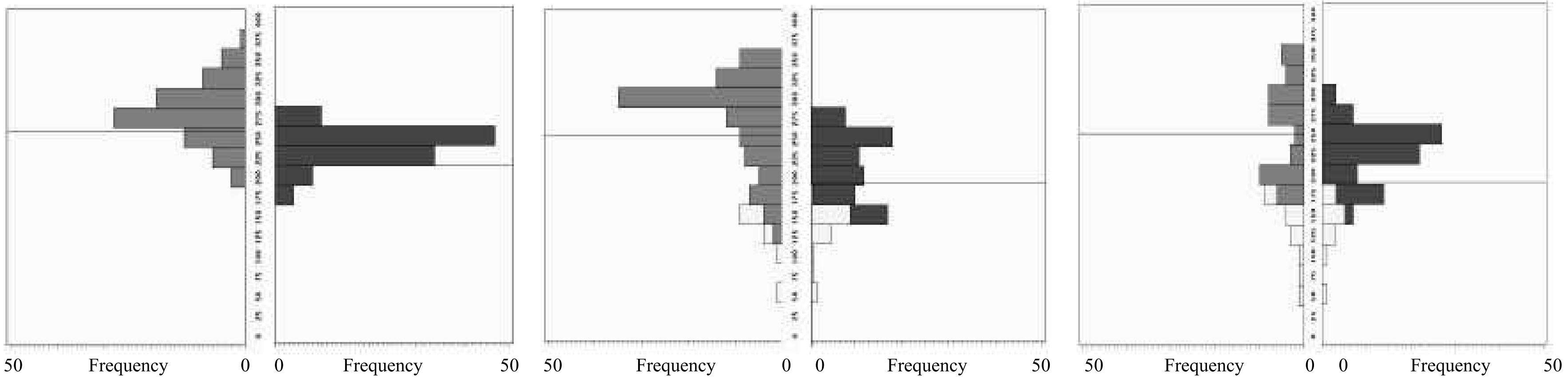
3.1.3 Population Structure

Size distribution varied dramatically among permanently non-netted waterholes to all other waterholes. The demographic profile among waterholes varies from mature adult populations in Eulbertie, Springfield and Currareeva whereas Murken, Tanbar, Broadwater and Fish Hole had a higher frequency of juveniles and sub-adults (Figure 3.1). Eulbertie Waterhole (Fig. 3.1.a) had a high frequency of adult males and females and a low frequency of immature adults. Springfield Waterhole (Fig.3.1.b) also has a high frequency of adults with a low frequency of recruitment (represented by the juveniles). Currareeva Waterhole (Fig.3.1.c) had a high frequency of adult males and a relatively low frequency of juveniles. Tanbar waterhole (Fig. 3.1.e) was dominated by juveniles, where few large individuals were present, this is represented in Murken Waterhole as well (Fig. 3.1.d) where juveniles predominate the population. Three large female carcasses (carapace length 300 – 350 mm) were found on the shore at Murken Waterhole. This shows that adults exist in this waterhole. Waterloo, Fish Hole and Broadwater (Figure 3.1.f - h) all have similar size distributions and were dominated by immature adults and juveniles.

The permanent waterholes Eulbertie, Springfield and Currareeva have an adult to juvenile ratio greater than one (Table 3.2). The proportion of juveniles is greater in all waterholes that are either semi-permanent, intensely illegally netted for fish, or are a recovery population.

Density comparisons among waterholes were not warranted, as mark-recapture data was too sparse from earlier sampling trips. Despite this acknowledged limitation, catch per unit effort data (CPUE) (Figure 3.2) provided some preliminary estimates of turtle density for these waterholes, assuming that capture probabilities were equivalent among waterholes. CPUE suggested that the permanent waterholes of Fish Hole, Springfield Homestead, and Eulbertie waterholes have the highest turtle densities.

(a) Eulbertie Waterhole (b) Springfield Homestead Waterhole (c) Currareeva Waterhole



(d) Murken Waterhole (e) Tanbar Waterhole

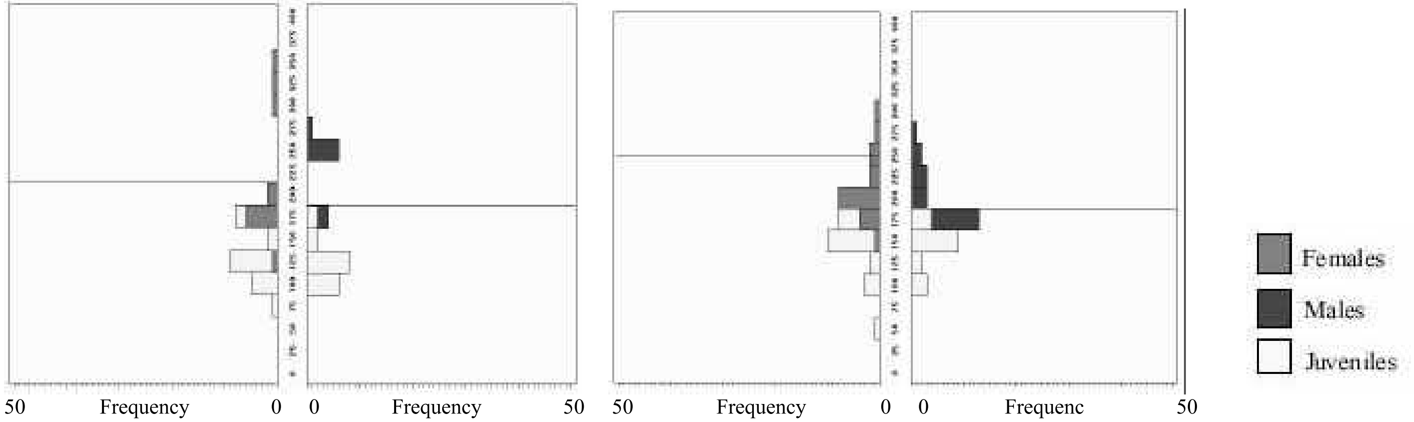


Figure 3.1 Comparison of size distribution among waterholes in the Cooper catchment. Distribution is broken up into males, females and juveniles. Carapace length (mm) categories appear down the centre of each histogram. Size at maturity for each sex is represented by the horizontal line through graph.

(f) Broadwater Waterhole (g) Fish Hole (h) Waterloo Waterhole

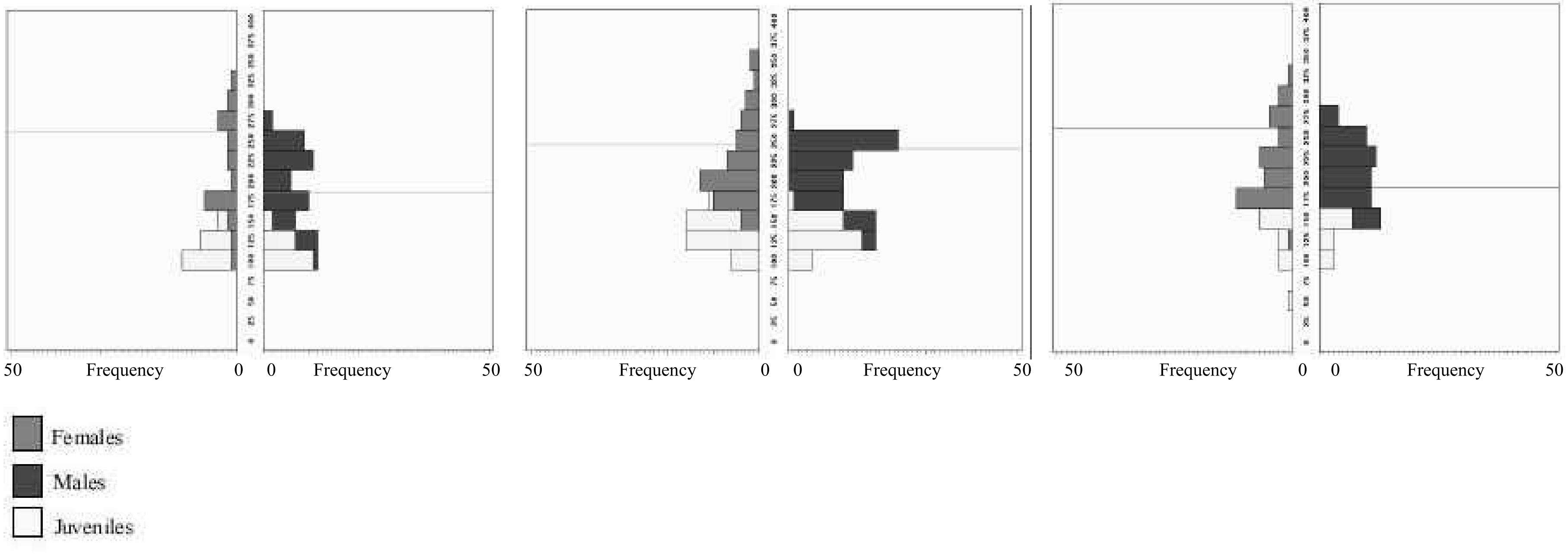


Figure 3.1 cont' Comparison of size distribution among waterholes in the Cooper catchment. Distribution is broken up into males, females and juveniles. Carapace length (mm) categories appear down the centre of each histogram. Size at maturity for each sex is represented by the horizontal line through graph.

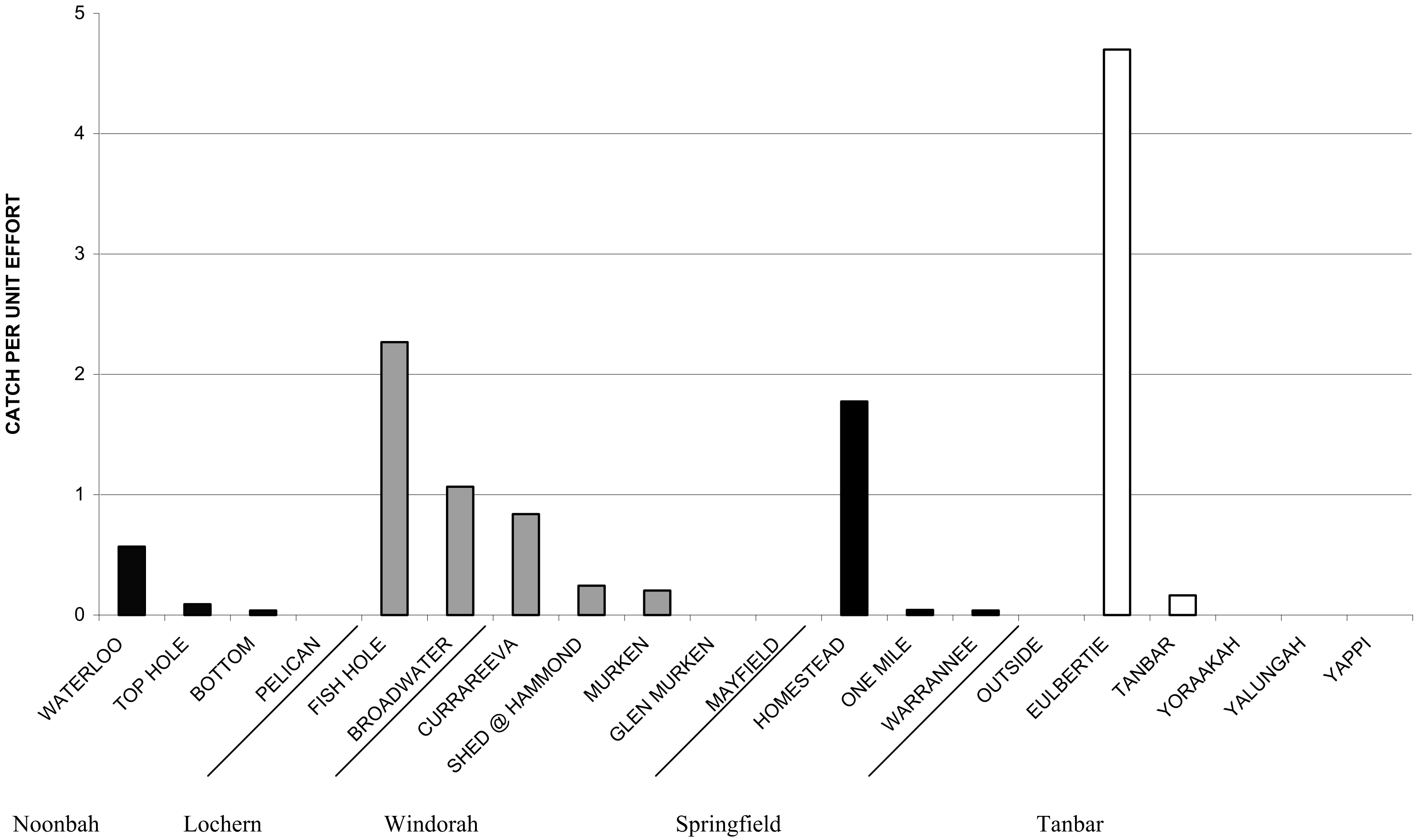


Figure 3.2 Catch per unit effort for all sampled waterholes in the Cooper Creek system.

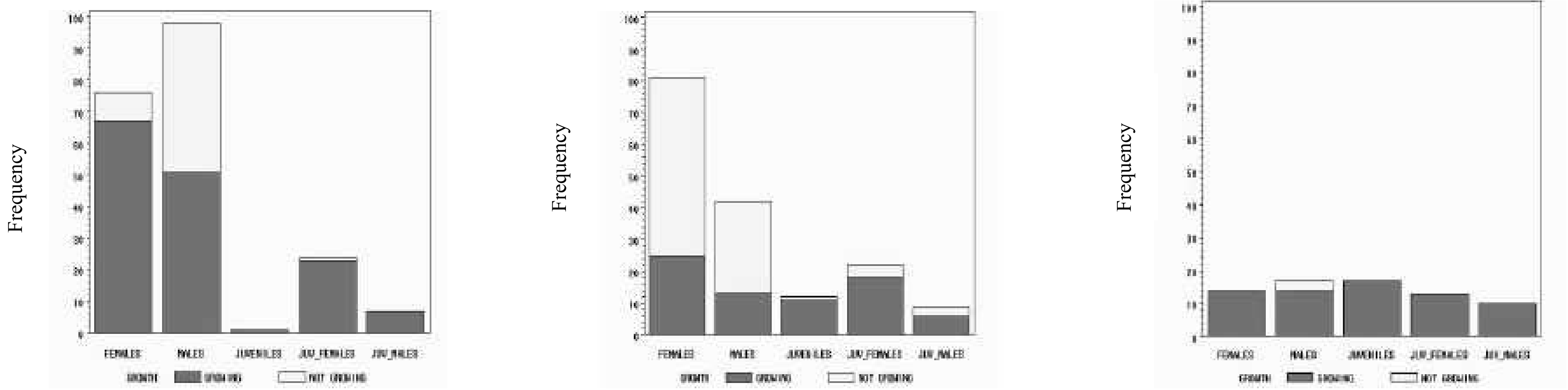
3.1.4 Growth

The proportion of turtles in active growth varies substantially among waterholes (Figure 3.3). The two permanent non-fished waterholes, Eulbertie (Figure 3.3.a) and Springfield (Figure 3.3.b) are the two sites where a substantial amount of animals are not growing when compared to the other waterholes, Tanbar (Figure 3.3.c) and Waterloo (Figure 3.3.e) in particular. Not surprisingly, juveniles are the main growers in all populations, with the major proportion of non-growers in the waterholes being adults.

Von Bertalanffy growth models were estimated from each waterhole population and counts of growth rings for size-at-age data. Table 3.3 presents the results of the growth models for asymptote (a) and growth coefficient (k) for females from the sampled waterholes. The models were validated by the close agreement between asymptotic estimate and maximum adult size (Table 3.3). Growth coefficients of the larger sex (females) were generally higher than the smaller sex (males) (Tables 3.3 and 3.4), sexual differences with growth pattern are consistent with sexual dimorphism in size at maturity. Females in Tanbar Waterhole had a relatively higher growth coefficient than females in most other waterholes (Table 3.3). Broadwater Waterhole also had a high rate of growth in comparison to other waterholes. All other waterholes had an extremely low growth coefficient, with Springfield Homestead having the lowest growth coefficient of all.

Male growth curves (Table 3.4) also showed the same pattern as the females, with the highest growth being achieved at Tanbar and Broadwater and the lowest at Springfield. Estimation of growth coefficients for males at Currareeva was confounded, because so few adults were growing that the asymptote was substantially over-estimated.

There was a decrease in growth coefficients from flood to post-flood seasons for males and females in Eulbertie, Tanbar, Murken, Waterloo and Broadwater (males only) (Table 3.5). Pre-flood to post-flood growth coefficients showed no consistent pattern among all waterholes, but the general trend among Eulbertie, Murken, Waterloo and Broadwater waterholes was for a low growth coefficient before and after the flood.



(a) Eulbertie Waterhole

(b) Springfield Homestead Waterhole

(c) Tanbar Waterhole

(d) Murken Waterhole

(e) Waterloo Waterhole

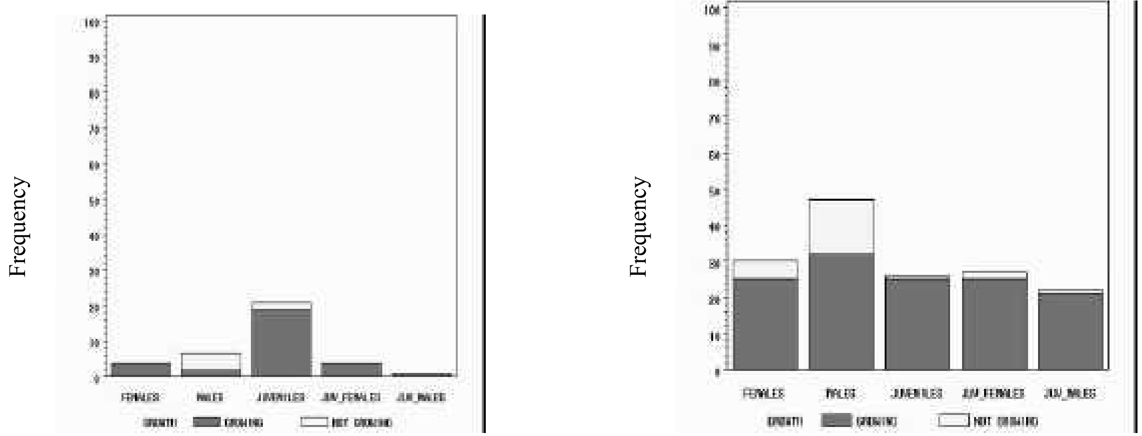


Figure 3.3 Comparison of growers verse non-growers across some waterholes of the Cooper drainage. Categories for adults and juveniles and males and females were determined by laparoscopy.

Table 3.3 Comparison of estimated asymptotic body size (a) and growth coefficient (k) for female *Emydura macquarii* in the Cooper Creek catchment. The asymptote and maximum carapace length (CL) are in mm.

Location	a (mm)	k	95% C.I	Maximum CL (mm)
Eulbertie Waterhole (n=77)	376.96	0.065	0.043 – 0.080	366.90
Springfield Homestead Waterhole (n=98)	368.00	0.039	0.026 – 0.180	348.00
Tanbar Waterhole (n=14)	358.97	0.132	0.083 – 0.163	295.10
Murken Waterhole (n=32)	352.59	0.057	0.034 – 0.066	347.00
Currareeva Waterhole (n=74)	375.58	0.054	0.043 – 0.065	360.00
Waterloo Waterhole (n=57)	354.66	0.063	0.043 – 0.075	315.30
Fish Hole (n=119)	380.82	0.064	0.051 – 0.073	358.70
Broadwater Waterhole (n=24)	352.41	0.096	0.064 – 0.111	327.90

Table 3.4 Comparison of estimated asymptotic body size (a) and growth coefficient (k) for male *Emydura macquarii* in the Cooper Creek catchment. The asymptote and maximum carapace length (CL) are in mm.

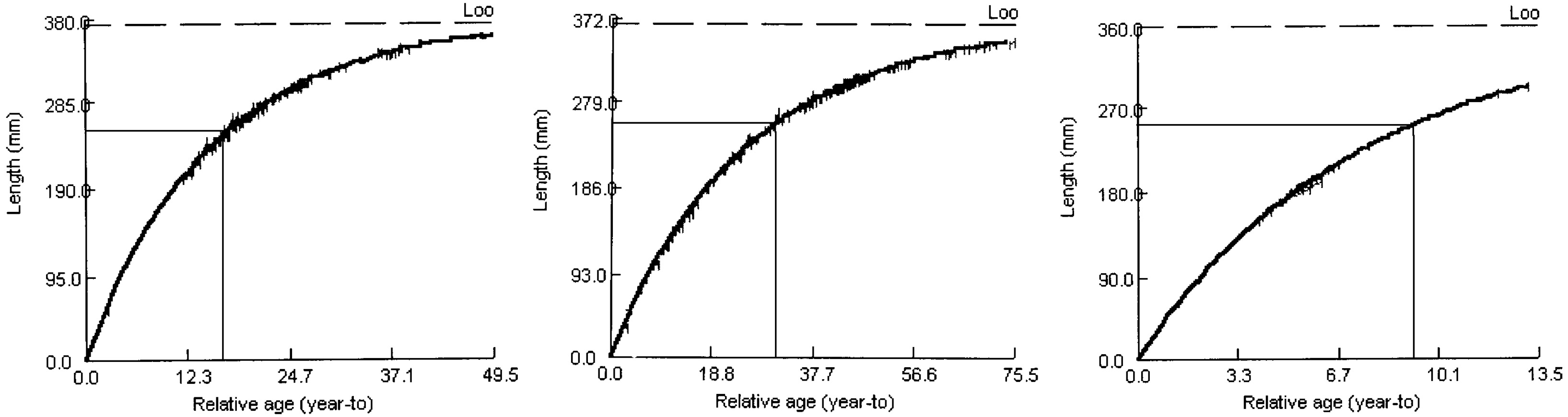
Waterhole	a (mm)	k	95% C.I	Maximum CL (mm)
Eulbertie (n=102)	296.18	0.049	0.024 – 0.048	278.94
Springfield (n=55)	302.00	0.059	0.040 – 0.080	272.90
Tanbar (n=17)	285.00	0.177	0.088 – 0.180	265.50
Murken (n=29)	292.90	0.067	0.035 – 0.067	257.60
Currareeva (n=79)	-	-	-	302.00
Waterloo (n=74)	301.70	0.074	0.055 – 0.099	274.00
Fish Hole (n=137)	284.85	0.096	0.059 – 0.079	282.00
Broadwater (n=50)	307.17	0.081	0.051 – 0.097	273.40

Table 3.5 Comparison of growth coefficient (k) for three seasons, pre-flood 1999/2000, flood 2000/2001, and post-flood 2001/2002 for *Emydura macquarii* in the Cooper Creek catchment.

Waterhole	PRE-FLOOD 1999/2000		FLOOD 2000/2001		POST-FLOOD 2001/2002	
	Males (k)	Females (k)	Males (k)	Females (k)	Males (k)	Females (k)
Eulbertie Waterhole	-	0.054 (n=47)	0.068 (n=55)	0.069 (n=49)	0.048 (n=100)	0.065 (n=77)
Springfield Homestead Waterhole	-	0.037 (n=16)	0.033 (n=44)	0.031 (n=97)	0.059 (n=55)	0.039 (n=98)
Tanbar Waterhole	-	-	0.261 (n=11)	0.199 (n=11)	0.177 (n=17)	0.132 (n=14)
Murken Waterhole	0.046 (n=14)	0.055 (n=12)	0.070 (n=31)	0.060 (n=32)	0.067 (n=29)	0.057 (n=32)
Currareeva Waterhole	-	0.057 (n=28)	-	0.050 (n=74)	-	0.054 (n=74)
Waterloo Waterhole	0.090 (n=31)	0.063 (n=35)	0.083 (n=73)	0.067 (n=58)	0.074 (n=74)	0.063 (n=57)
Fish Hole	0.124 (n=41)	0.067 (n=49)	0.080 (n=133)	0.059 (n=116)	0.096 (n=137)	0.064 (n=119)
Broadwater Waterhole	0.072 (n=35)	0.048 (n=31)	0.094 (n=48)	0.082 (n=22)	0.081 (n=50)	0.096 (n=24)

The female growth curves (Figure 3.4) for five waterholes allowed an estimate of age at sexual maturity to be inferred. These graphs suggested that females were reaching maturity (CL 260 mm) between 9 - 25 years of age. Turtles at the semi-permanent waterhole Tanbar are attaining maturity earlier at 9 years of age, than Eulbertie which where at estimated to mature at 15 years of age (Table 3.2). The male growth curves (Figure 3.5) estimate maturity at an earlier age, between 7 – 20 years (CL 200 mm). It should be re-iterated that these are very preliminary estimates that require more long-term recapture data to accurately quantify age at maturity.

(a) Eulbertie Waterhole (b) Springfield Homestead Waterhole (c) Tanbar Waterhole



(d) Murken Waterhole (e) Waterloo Waterloo

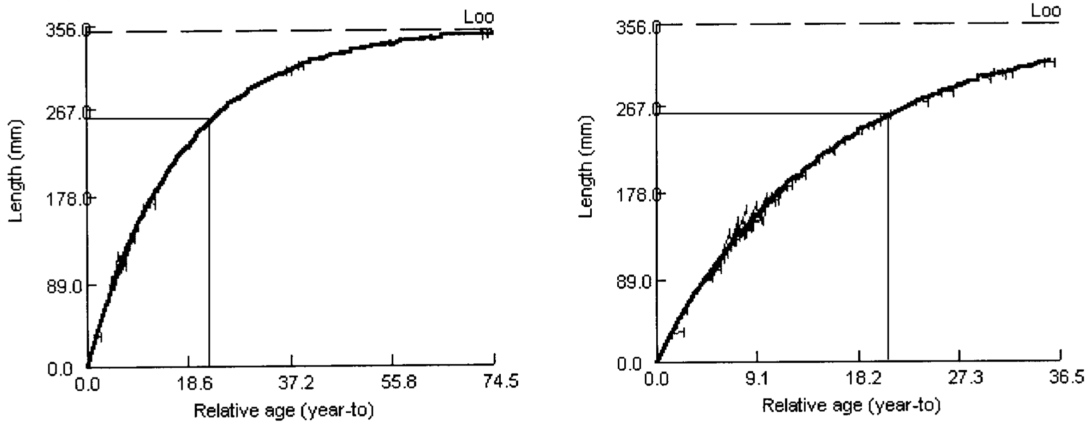
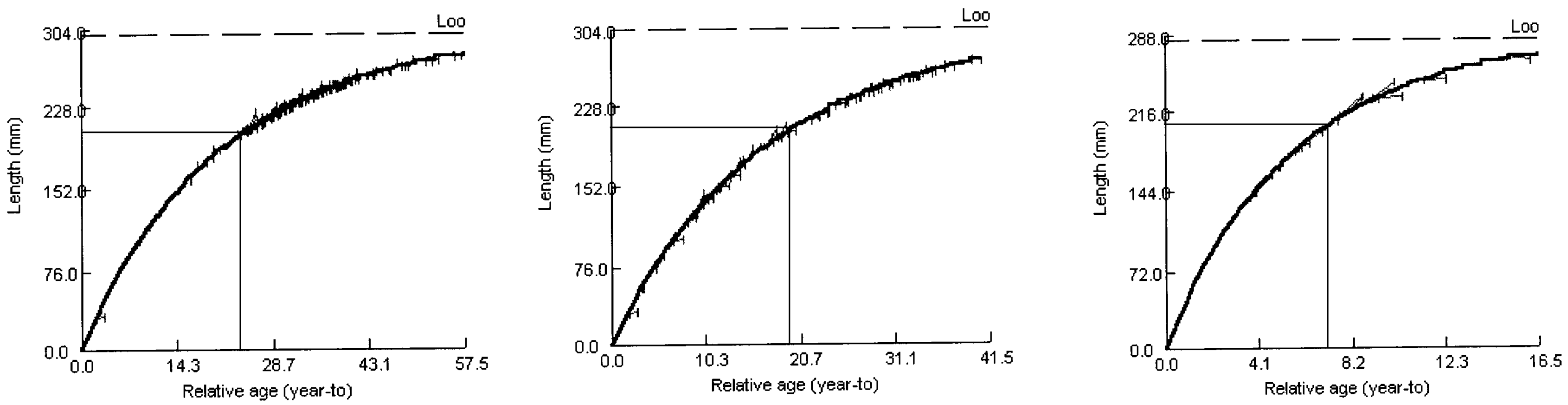


Figure 3.4 Female estimates of *Emydura macquarii* asymptotic length and length-at-age for selected Cooper Creek waterholes as determined from a growth interval model.

(a) Eulbertie Waterhole (b) Springfield Homestead Waterhole (c) Tanbar Waterhole



(d) Murken Waterhole (e) Waterloo Waterhole

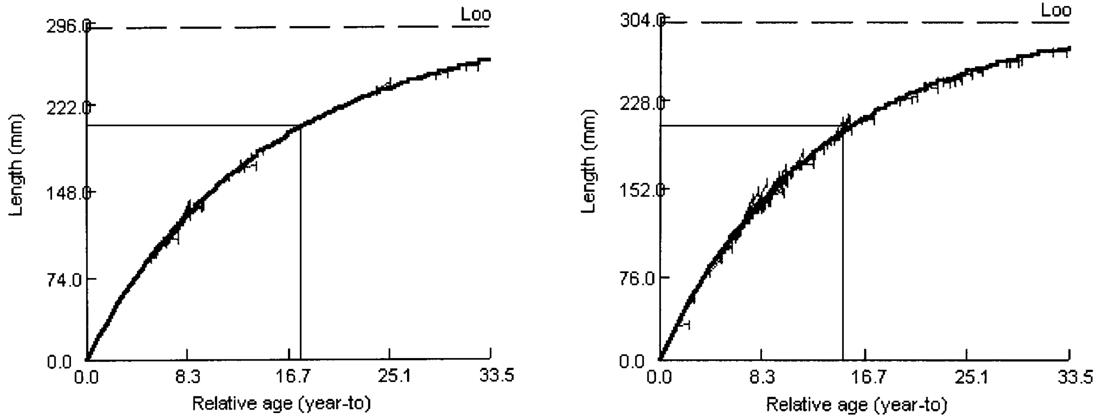


Figure 3.5 Male estimates of *Emydura macquarii* asymptotic length and length-at-age for selected Cooper Creek waterholes as determined from a growth interval model.

3.2 Warrego River Catchment

The turtles from each waterhole were treated as individual populations since population structuring was genetically distinct among waterholes, as was found with the Cooper Creek turtles (Goodsell, 2002).

Two sampling trips were made to the Warrego catchment, and analysis was carried out on waterholes where > 22 turtles were captured. All the waterholes sampled and number of turtles caught is listed in Table 3.6. Highest catch numbers were again recorded in the permanent waterholes.

3.2.1 Body Size

Maximum body size of *Em. macquarii* showed little variation between sexes and among waterholes (Table 3.7). Among waterholes, maximum body size for males ranged from 263.9 – 273.7 mm CL, and for females ranged from 280.4 – 329.2 mm CL. Females attained larger body sizes than males in all waterholes (Table 3.7). Sexual size dimorphism in waterholes was relatively similar with females on average 5% larger than males, with SDI ranging from 1.02 at Quilberry to 1.21 at Sandford Park lagoon (Table 3.7).

3.2.2 Size at Sexual Maturity

Laparoscopies were unable to be undertaken on turtles from the Warrego River due to equipment failure. Thus, there may be bias in classing only the larger females as mature which would confound any comparisons to size classes of adult females in the Cooper. Even so, the size class range of adult females is a close approximation of the carapace lengths of gravid females (Table 3.8) to suggest that females reach maturity at a similar size in the Warrego (< 250 mm) than in the Cooper (248 - 268 mm). The external sexing and maturity status of males was equally reliable for both catchments.

Males on average mature at approximately MCL 200 – 210 mm (Table 3.7). From measurements of gravid females (Table 3.8), the smallest mature gravid female had a MCL of 248.8 mm with other gravid females ranging from 255.1 – 283.0 mm.

Table 3.6 Capture Results in the Warrego drainage. Waterhole permanency and rate of illegal netting for fish were defined from landholder information. Catch per Unit Effort (CPU) was calculated by dividing the number of turtles caught by the number of traps set. Permanency of waterholes defined by: P = permanent, SP = semi-permanent, E = ephemeral. Level of illegal netting defined by: 1 = never been netted, 2 = moderate level of netting, 3 = blasted for fish in the 1950s and 1960s.

Site Location	Waterhole	Permanency	Level of Netting	CPU	Number of Turtles caught	Number of Recap's
Quilberry Region	Sandford Pk. w/h	P	2	0.76	119	
	Sandford Pk Lag.	E		0.78	38	4
	Quilberry	P	2	0.82	150	8
	Clear Lagoon	SP		0.61	22	
Binya Region	Binya	P	2	0.27	43	2
	Red	E		0	0	
	Tinnenburra	E	3	0.15	7	
	Mirage Plains	E		0.01	1	
Glencoe Station	Glencoe	P		0.14	4	
	Rocky	E		0.60	3	
	Key	E		0.40	2	
	Woganora	E		0.07	1	
Thurulgoona Station	Thurulgoona HS	E		0.01	3	
	Thurulgoona w/h	P	1	0.30	63	1
	Noorama	E		0	0	
				Total	**461**	**15**

Table 3.7. Population parameters for *Emydura macquarii* from five selected waterholes in the Warrego River. Waterholes are arranged from upstream to downstream. SD Index (see methods). CL = straight line carapace length in mm. Values in parenthesis represent percentages.

		Sandford Pk W/h	Sandford Pk Lag	Quilberry	Clear Lag.	Binya	Thurulgoona
No. turtles caught		119	38	150	22	43	63
Maximum CL	M	265.7	272.6	273.6	272.0	263.9	272.7
	F	291.0	329.2	280.4	296.5	306.3	302.9
CL at Maturity	M	205.5 – 210.0	233.6 – 239.8	198.4 - 201.4	221.1 - 227.1	208.7 - 253.1	210.0 - 230.2
Estimated Age at Maturity (yrs)	M	12	-	7	-	13	6
	F	16	25	14	-	15	15
SD Index		1.10	1.21	1.02	1.09	1.16	1.11
Sex Ratio (Males:Females)		1.39:1 ns	1.17:1 ns	4.83:1*	1.67:1 ns	0.92:1 ns	1.67:1 ns
Adult Ratio (Adults:Juveniles)		0.57:1	0.52:1	0.30:1	2.67:1	1.39:1	1.03:1

Note: No laparoscopy was undertaken on the Warrego turtles.
* $p<0.005$ from chi-square analysis, ns = not significant

Table 3.8 Carapace length and date of gravid females, *Emydura macquarii* caught in the Warrego River.

Waterhole	Female ID	CL (mm)	Date Gravid
Quilberry	158	248.8	18th Oct 2001
	145	261.3	18th Oct 2001
	156	271.4	18th Oct 2001
Sandford Pk W/h	214	255.1	18th Oct 2001
	90	258.7	17th Oct 2001
	113	259.3	17th Oct 2001
	129	268.1	17th Oct 2001
	103	272.9	17th Oct 2001
Sandford Pk Lagoon	174	276.0	17th Oct 2001
	177	283.0	17th Oct 2001

3.2.3 Population Structure

The size distribution of turtles varies from populations that support mostly adults to populations that support higher numbers of juveniles. The permanent waterhole Thurulgoona (Figure 3.6.f) had a high adult : juvenile ratio whereas, Quilberry (Figure 3.6.a) and Sandford Park (Figure 3.6.d) waterholes have population structures dominated by juveniles. The permanent waterhole Binya (Figure 3.6.c), and the ephemeral waterholes Clear Lagoon (Figure 3.6.b) and Sandford Park Lagoon (Figure 3.6.e) had low frequencies of both adults and juveniles.

There was a significant male bias at Quilberry ($\chi 2=14.669$; d.f.=1; $p<0.005$). There was no significant difference in an adult 1:1 ratio among other waterholes (Table 3.7).

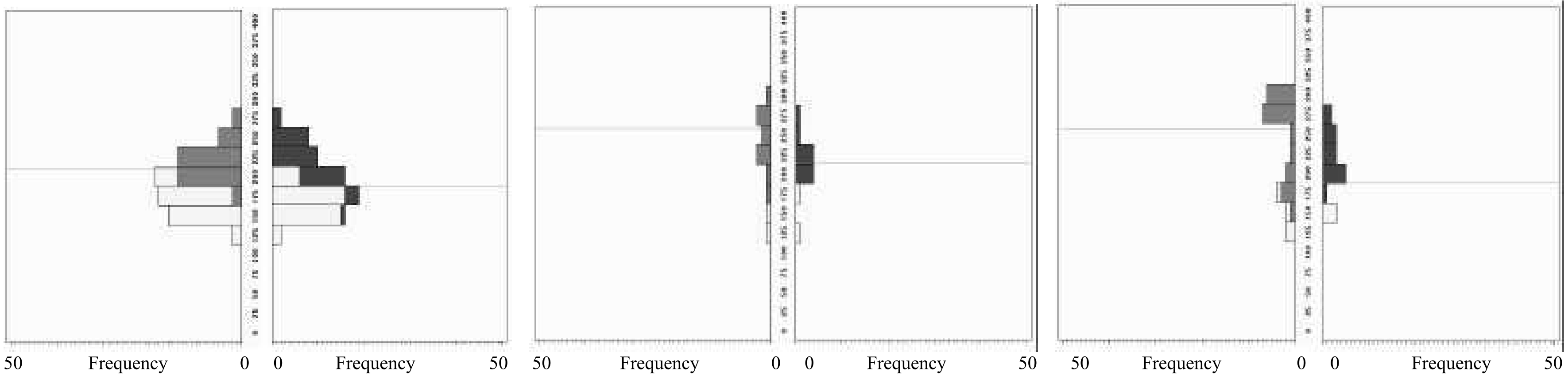
Density comparisons among waterholes were unwarranted as the mark-recapture data was too sparse. CPUE data indicates that Quilberry, Clear Lagoon, Sandford Park and Sandford Park Lagoon had the highest densities of turtles (Figure 3.7).

3.2.4 Growth

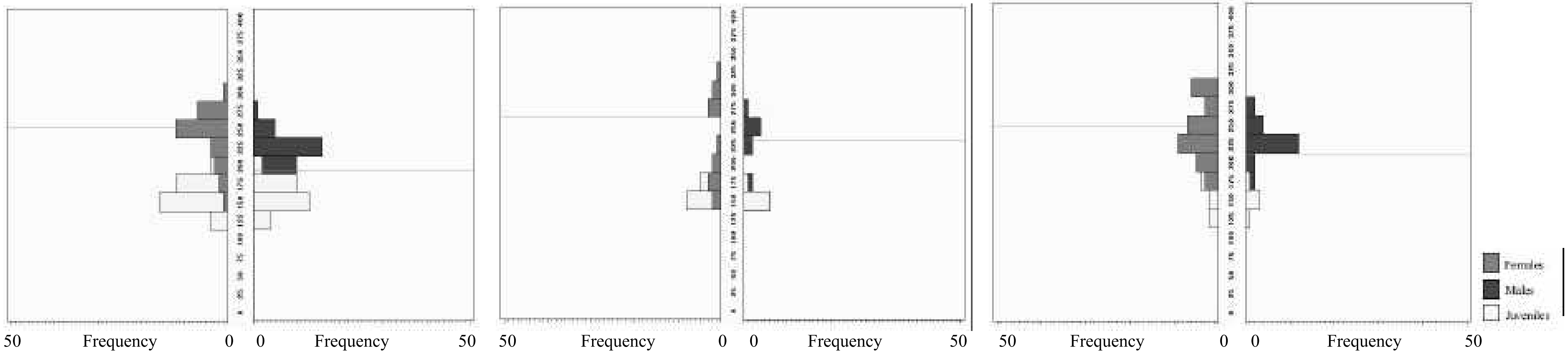
Lack of mark recapture data meant that growth rate was determined solely from growth rings from the second costal scute on the carapace. Table 3.9 and 3.10 presents the parameter estimates for asymptote (a) and growth coefficient (k) for females and males.

Growth coefficients of the larger sex (females) were lower than the smaller sex (males). Female growth coefficient were generally lower (below 0.109), with males exhibiting a higher coefficient of >0.106. Turtles in Quilberry Waterhole have the highest growth coefficient for both sexes compared to all other waterholes. Binya Waterhole has the lowest growth coefficient for both sexes. Females at Sandford Park Lagoon also had a low growth coefficient; too few males were captured to derive an estimated growth coefficient.

Figure 3.8 and 3.9 present female and male growth curves for selected waterholes. An estimate of age at sexual maturity from these graphs suggest that males are reaching sexual maturity between 6 - 13 years of age (CL 200 mm) and females between 14 – 25 years of age (CL 250 mm). These preliminary estimates require empirical validation from long-term mark-recapture studies



(a) Quilberry Waterhole (b) Clear Lagoon (c) Binya Waterhole



(d) Sandford Park Waterhole (e) Sandford Park Lagoon (f) Thurulgoona Waterhole

Figure 3.6 Comparison of size distribution among waterholes in the Warrego catchment. Distribution is broken up into males, females and juveniles. Carapace length (mm) categories appear down the centre of each histogram. Size at maturity for each sex is represented by the horizontal line through graph.

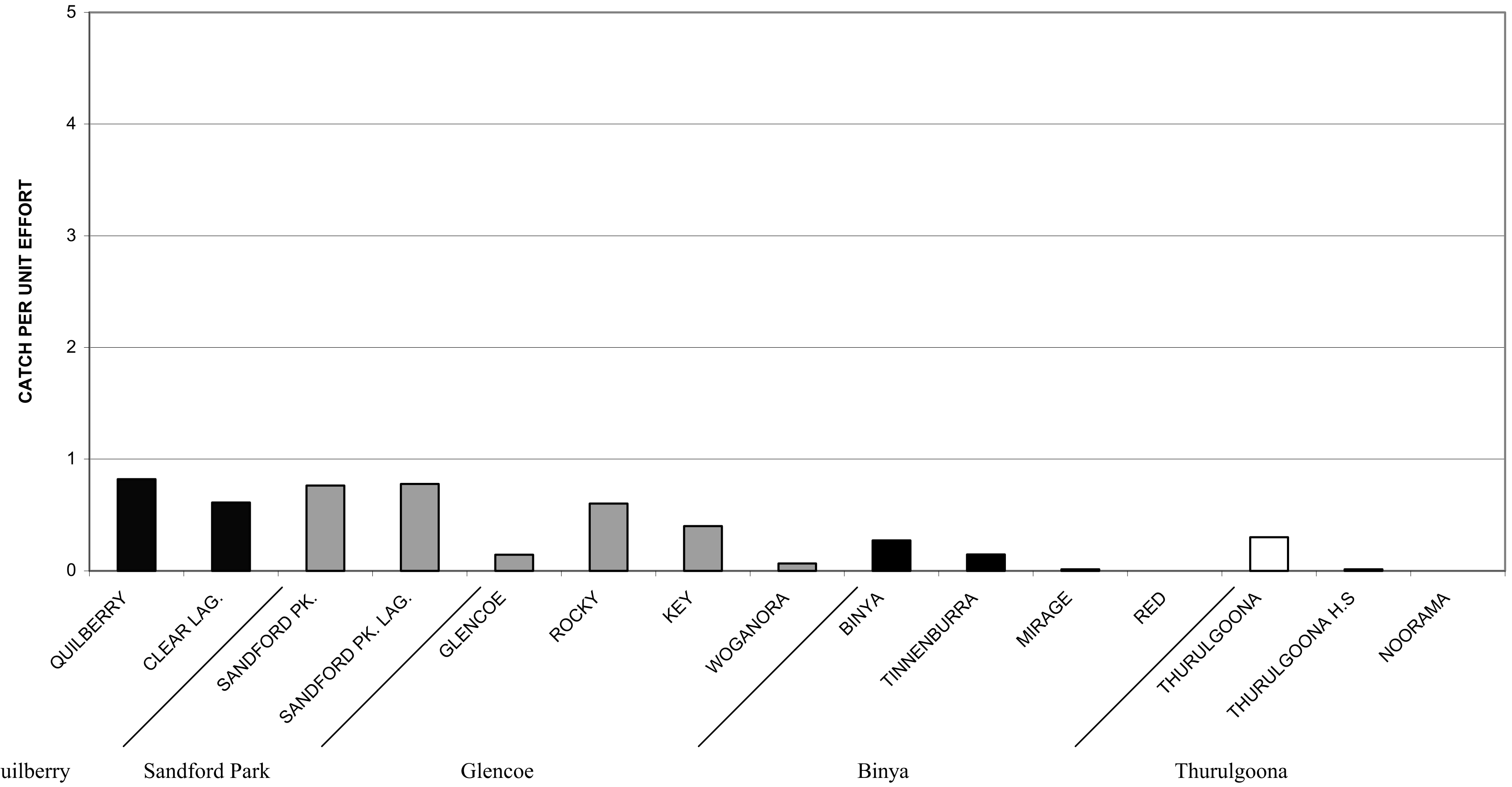


Figure 3.7 Catch per unit effort for all sampled waterholes in the Warrego River system.

Table 3.9 Comparison of estimated asymptotic body size (a) and growth coefficient (k) for female *Emydura macquarii* in the Warrego River catchment. The asymptote and maximum carapace length (CL) are in mm.

Location	a (mm)	k	95% C.I	Maximum CL (mm)
Quilberry Waterhole (n=114)	323.39	0.109	0.042 – 0.091	280.4
Sandford Park Lagoon (n=17)	319.98	0.055	0.023 – 0.063	296.5
Sandford Park Waterhole (n=60)	314.40	0.088	0.053 – 0.086	291.0
Binya Waterhole (n=17)	336.39	0.081	0.038 – 0.111	329.2
Thurulgoona Waterhole (n=26)	326.47	0.089	0.062 – 0.117	306.3

Table 3.10 Comparison of estimated asymptotic body size (a) and growth coefficient (k) for male *Emydura macquarii* in the Warrego River catchment. The asymptote and maximum carapace length (CL) are in mm.

Location	a (mm)	k	95% C.I	Maximum CL (mm)
Quilberry Waterhole	278.12	0.136	0.047 – 0.101	273.6
Sandford Park Lagoon	-	-	-	272.6
Sandford Park Waterhole	270.14	0.115	0.061 – 0.096	265.7
Binya Waterhole	278.61	0.106	0.038 – 0.114	263.9
Thurulgoona Waterhole	317.70	0.151	0.077 – 0.166	272.7

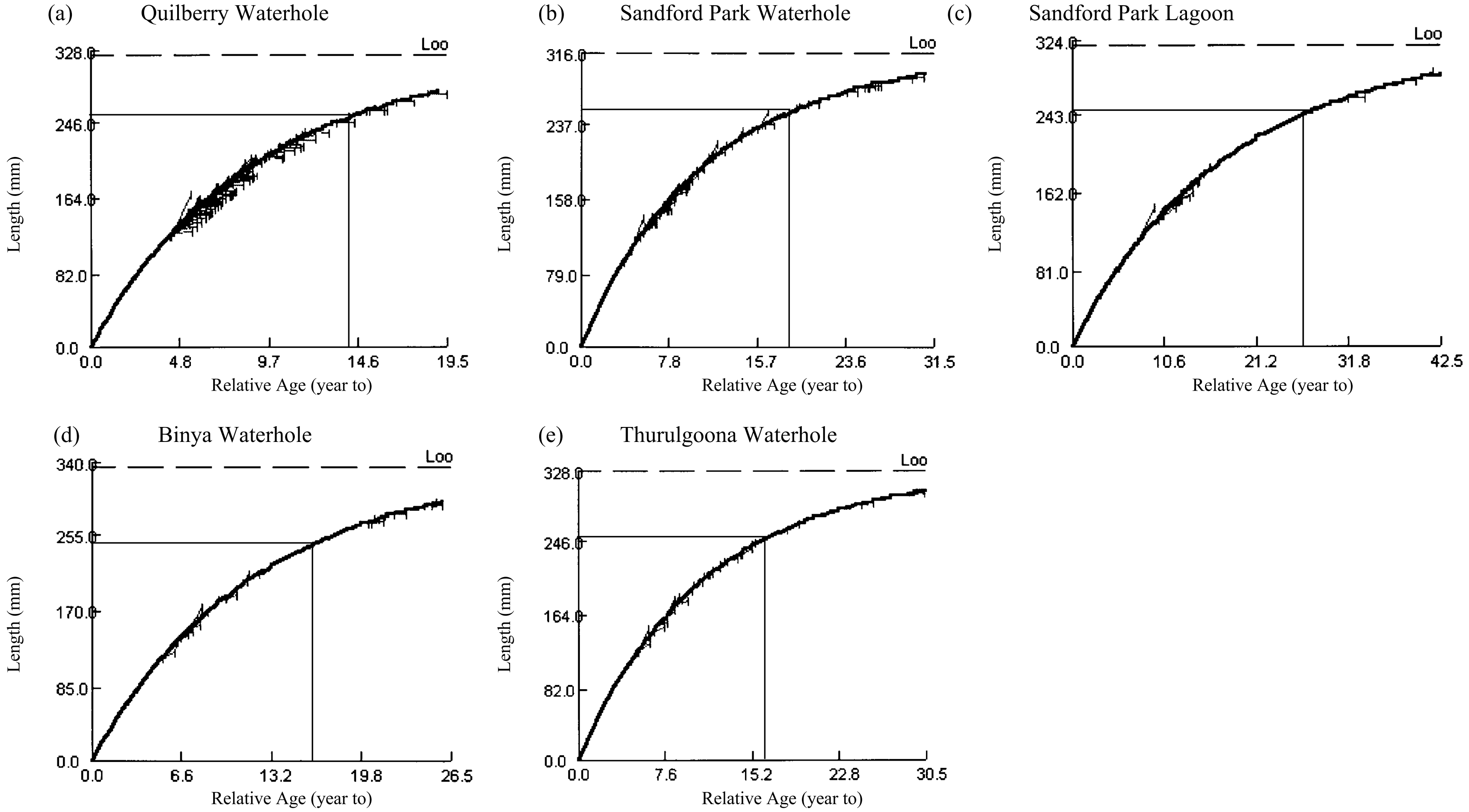
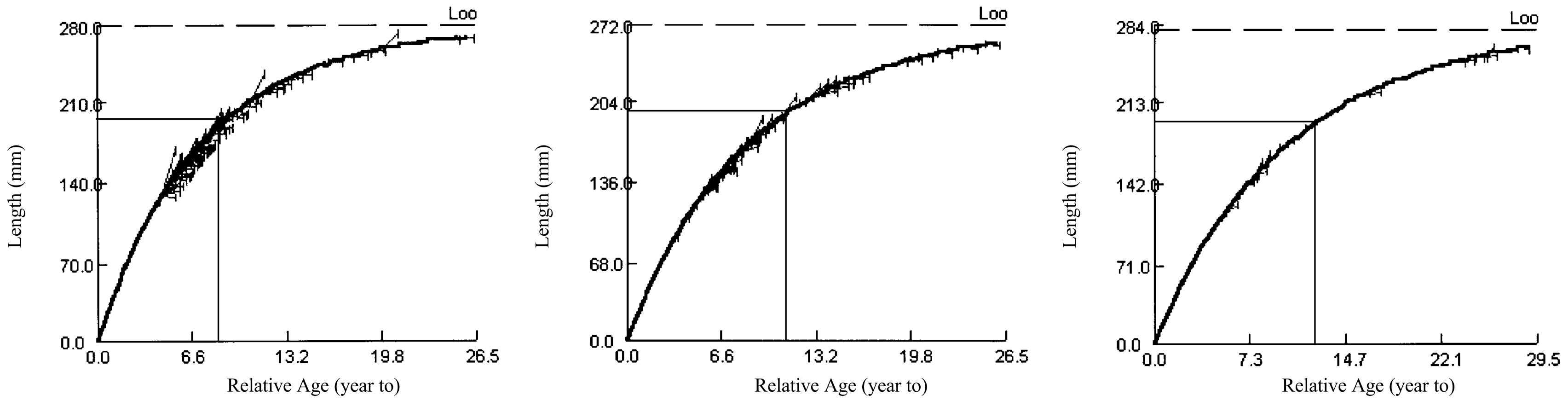


Figure 3.8 Female estimates of *Emydura macquarii* asymptotic length and length-at-age for selected Warrego River waterholes as determined from a growth interval model.
(a) Quilberry Waterhole (b) Sandford Park Waterhole (c) Binya Waterhole



(d) Thurulgoona Waterhole

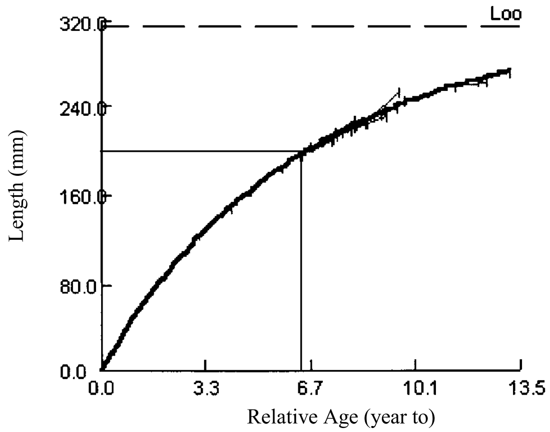


Figure 3.9 Male estimates of *Emydura macquarii* asymptotic length and length-at-age for selected Warrego River waterholes as determined from a growth interval model.

CHAPTER FOUR

4 DISCUSSION

4.1 A framework to explain the persistence of *Emydura* in the Cooper system

4.1.1 Biological Traits

The biological traits of the Cooper Creek turtle *Em. macquarii* in this part of arid Australia include large body size, delaying sexual maturity and indeterminate growth. The maximum body size of *Em. macquarii* is highly variable across drainages although this is poorly documented in the literature. In this study, the maximum female carapace length of the Cooper Creek turtle ranged from 295 mm at the semi-permanent waterhole Tanbar, to 366 mm at the permanent waterhole Eulbertie (Table 3.2). Judge (2001) found maximum female carapace length for *Em. macquarii* in the Macleay, Hunter, Nepean, Brisbane and Murray Rivers to be highly variable ranging from 185 mm in the Macleay River to 303 mm in the Murray River (Table 4.1).

Em. macquarii is sexually dimorphic throughout its range, with females larger than males in all cases (Tables 3.2). This finding supports other studies on aquatic turtles in that females attain larger body sizes than males in most species (Berry and Shine, 1980). In this study, size rather than age was more important in determining maturity in both sexes of *Em. macquarii*. The Cooper Creek turtle matures at CL 248 - 268 mm for females and 177 - 211 mm for males, which is considerably larger than other *Em. macquarii* forms. For example, in the Macleay River, females mature at 136 – 146 mm and males at 105 – 113 mm, yet in the Murray River females mature at 222 – 230 mm and males 172 – 195 mm (Judge, 2001). The positive correlation between body size and reproductive output enables larger turtles to produce larger clutch sizes as well as eggs. Therefore, delayed sexual maturity may increase fecundity and/or increase the survival of offspring (Congdon and Gibbons, 1990). The females of the Cooper Creek turtle demonstrate this capability by having large clutch sizes (20 – 30 eggs), and large eggs (weight approx. 14 g), being by far the largest known eggs of any *Emydura* species (Cann, 1998). A benefit of large clutches and large eggs would

Table 4.1 Comparison of two von Bertalanffy parameters – asymptotic body size (a) and growth coefficient (k) from populations of *Emydura macquarii macquarii* (Judge 2001).

Location	a (mm)		k		Maximum CL (mm)	
	Male	Female	Male	Female	Male	Female
Macleay River	-	163.27	-	0132	153.4	185.4
Hunter River	-	227.84	-	0.125	212.4	242.6
Nepean River	186.12	224.82	0.368	0.268	227.9	260.6
Brisbane River	-	-	-	-	259.2	280.4
Murray River	250.86	264.66	0.201	0.184	278.6	303.5

increase the survival of head-start hatchlings in the arid and sporadic system of the Cooper Creek.

It is extremely difficult to age wild turtles, with the Cooper Creek turtles in particular being difficult, as no previous studies have been done on them. The preliminary estimates of age at maturity for females of the Cooper Creek turtle is 9 - 25 years of age (Table 3.2). Compared to other forms of *Emydura macquarii* in non-arid climates where sexual maturity is attained at 9 – 11 years (Macleay River), 11 – 13 years (Hunter River), 5 – 7 years (Nepean River) and 8 – 10 years in the Murray River (Judge, 2001). Male Cooper Creek turtles attain maturity at 7 – 20 yr of age (Table 3.2) compared to other forms in rivers that attain maturity at 7 – 9 yr (Macleay and Hunter Rivers), 3 – 5 yr (Nepean River) and 6 – 8 yr in the Murray River (Judge, 2001). We predict that size at maturity rather than age at maturity is more important in the Cooper Creek turtle. A trait resulting from the sporadic system whereby large body size favours selection. We also predict that the Cooper Creek turtles may live for a very long time, possible reaching up to 80 yrs.

Cooper Creek turtles exhibited indeterminate growth since, a proportion of adults continue to grow after attaining sexual maturity (Figures 3.3, 3.4 and 3.5). This study assumed that growth rings were deposited annually. This assumption may be confounded in the variable environment of the Cooper Creek and growth rings may be deposited annually, opportunistically or by a combination of these factors driven by the environmental productivity and food availability during and after episodic flood events. In a tropical population of *Trachemys scripta*, it was found that more than one ring developed during a single year (Moll and Legler, 1971), whereas in other turtle species it was found that only one growth ring was deposited annually, as shown with *Chelodina rugosa* and *Elseya denata* (Kennett, 1996), *Pseudemydura umbrina* (Burbidge, 1981) and *Phrynopes rufipes* (Magnusson et al., 1997). Rings of earlier years gradually disappear as a turtle ages, and also growth rates of juveniles exceed that of adults (Congdon and Gibbons, 1990). With all of these factors considered, the growth rates within and among populations undoubtedly varies, as would the age or size at maturity. If the Cooper Creek turtles are maturing at a certain size rather than age, the foregoing factors argue strongly that age should be considered an individual trait.

Temperature is unquestionably a critical factor determining the body size or growth opportunities of turtles. In contrast to North American studies, there appears to be no gradient of body size with latitude in Australia, at least for the *Em. macquarii* complex (Judge, 2001). In Australia, resource availability appears to be limited and less uniform and the seasonal changes in temperature are less extreme than in North American aquatic systems. In Australia any size variation due to temperature is overwhelmed by differences in productivity.

Turtles in a more productive habitat will exhibit faster growth, larger size, and higher reproductive output compared to less productive habitats (Brown et al., 1994). In the Cooper system, 'boom' times of productivity occur during a flood and the period following a flood. During these 'boom' times turtles acquire and allocate energy toward growth and reproduction. During a flood, turtles in the Cooper Creek disperse across the floodplain and return to the waterholes with the receding floodwaters. The most recent flood in the Cooper system was January 2000 and since then opportunities for growth and reproduction are limited. Turtles at Springfield Homestead exhibit the slowest growth compared to all other waterholes (Table 3.3 and 3.4). Springfield is located on Kyabra Creek, a creek that did not receive the 2000 flood. Kyabra Creek's last major flood was in 1989 (Landholder; B. Morish, pers com.). Primary productivity data confirm that Springfield Homestead has very low mean gross primary production (GPP) of 0.08 $gCm^{-2}day^{-1}$ in April 2001, compared to other sampled waterholes that had a GPP ranging from 0.1 – 0.77 $gCm^{-2}day^{-1}$ (Appendix 1). Such low productivity may partly explain why Springfield turtles have the lowest growth among our sampled populations.

In contrast, turtles from Tanbar Waterhole have the highest growth rate (Table 3.3 and 3.4). Tanbar Waterhole is a semi-permanent waterhole that dried completely during the 1980 – 1983 drought (Landholder; G. Scott, pers com.) but has since recolonised with turtles. The low density of turtles in Tanbar (Figure 3.2) may enable higher per capita food availability. The waterhole productivity at Tanbar was also relatively high in comparison to other waterholes, having a GPP of 0.50 $gCm^{-2}day^{-1}$, in April 2001 (Appendix 1).

In comparison to other freshwater turtles, Cooper Creek turtles have a low growth coefficient. Judge (2001) found female growth rates of *Em. macquarii macquarii* in the Macleay, Hunter, Nepean and Murray Rivers ranged from 0.125 in the Hunter River to 0.268 in the Nepean River (Table 4.1), which is higher than *Em. macquarii* females from the Cooper Creek. The fastest growing turtles in the Cooper Creek (at Tanbar) were still slow in comparison to Judge (2001) and other studies done on freshwater turtle growth (Table 4.2).

A comparison of growth coefficients over 2000 – 2002 in relation to flood pulses presented a trend that pre-flood season in some waterholes the turtles had a slower growth rate than during the flood season. Low growth coefficient was again exhibited in the post-flood season (Table 3.5). The low growth coefficient during pre and post flood events was found in Eulbertie, Tanbar and Murken waterholes. Pre-flood, the waterholes would expect to have low productivity and high competition for available resources. During a flood there would be an increase in resource availability, enabling turtles to put energy towards growth and reproduction, hence the rise in growth. Post-flood, it is expected that productivity and resource availability would again decrease causing a lower growth rate. Springfield Homestead waterhole did not receive the 2000 flood and its turtles exhibited a lower growth coefficient over the last three seasons compared to all other waterholes. Waterloo, Fish Hole and Broadwater also do not exhibit this pre-flood, flood and post-flood trend, no clear pattern in these waterholes is perhaps due to their location. Waterloo, Fish Hole and Broadwater are all located on the Thomson River and in the same channel reach, with Fish Hole and Waterloo separated by approximately 30 km of channel. The Thomson River is in the upper region of the Cooper catchment, which receives more in-channel flows from monsoon rain falling in northern Australia. In contrast, the lower catchment mainly feed on floodwaters that go through the whole Cooper system. Waterholes in the upper part of the catchment may receive more regular flow and are believed to have higher productivity, which relates to an increase in growth coefficients of turtles in these waterholes across all seasons, rather than just in a flood.

4.1.2 Waterhole Persistence and Population Structure

Cooper Creek has developed an extensive system of anastomosing channels, a distinctive feature of which is the preponderance of waterholes (Knighton and Nanson, 1994). Current waterholes of the Cooper system are long-lived, stable features of the environment, as indicated by the surrounding trees (G. Nanson, pers comm.). Waterholes may be relict features of the Pleistocene climatic conditions, however recent work has shown the channels to be largely contemporary (Knighton and Nanson, 1994).

The Cooper Creek turtle has life-history traits that enable it to persist in a variable environment. Turtles are most abundant in the permanent waterholes, with only small

Table 4.2 Comparison of two von Bertalanffy parameters – asymtotic body size (a) and growth rate (k) between species of turtles. *Chelodina expansa, Chelodina longicollis, Elseya latisternum, Elseya sp., Rheodytes leukops, Elusor macrurus, Emydura krefftii* (Tucker, 2000), *Chelodina rugosa* (Kennett 1994), *Sternotherus minor* (Cox et al., 1991), *Chrysemys picta* (Frazer et al., 1991), *Trachemys scripta* (Frazer et al., 1990).

Species (Location)	a (mm)		k	
	Male	Female	Male	Female
Chelodina expansa (South-east Queensland)	255.5	293.5	0.34	0.26
Chelodina longicollis (South-east Queensland)	167.7	174.5	0.31	0.36
Elseya latisternum (South-east Queensland)	203.9	290.1	0.23	0.12
Elseya sp. (South-east Queensland)	377.4	327.5	0.04	0.11
Rheodytes leukops (South-east Queensland)	257.1	271.8	0.21	0.19
Elusor macrurus (South-east Queensland)	337.3	327.5	0.11	0.11
Emydura krefftii (South-east Queensland)	168.7	184.5	0.42	0.32
Chelodina rugosa (Darwin, N.T)	175.5	246.2	0.41	0.29
Sterotherus minor (North Florida, USA)	112.8	110.4	0.10	0.14
Chrysemy picta (South-west Michigan, USA)	111.8	152.2	0.18	0.13
Trachemys scripta (South Carolina, USA)	-	202.7	-	0.20

numbers collected from semi-permanent waterholes and few, if any turtles collected from the ephemeral waterholes (Table 3.1). The Cooper Creek turtles have high site fidelity with the permanent waterholes having strong genetic structure among populations (Goodsell, 2002). This study suggests turtles are strongly associated with the attributes of permanent waterholes. The permanent waterholes are characteristically large in size, an incised channel (rather than a clay-pan on the floodplain), have overhanging vegetation, and contain deep pools within the waterhole itself (Figures 4.1 – 4.3).

The permanent waterholes (Eulbertie and Springfield Homestead) all featured a relatively high proportion of adult turtles compared to all other waterholes (Figure 3.1.b). Eulbertie is a very large permanent waterhole that has not dried up in European history (Landholder; G. Scott pers comm.). Eulbertie is recognised as a unique waterhole in the Cooper system for both its size and permanency (G. Nanson pers comm., J. Reid pers comm.) and relative pristine condition, as it has never been netted for fish (G. Scott pers comm.). The turtle population in Eulbertie also is unique in containing a high proportion of adults and sub-adults, as only two unsexed juveniles were caught among the 186 turtles collected. Juveniles in Eulbertie were possibly in low numbers due to high adult density (Figure 3.1.a) and hence competition for resources, or the adults are foregoing reproduction to minimise energy expenditure due to the reduction in available resources from competition. It is not possible to find another replicate for Eulbertie to better understand these qualities. Other waterholes similar in size and permanency exist in the lower Cooper, but these waterholes are located near Innaminka and are intensely netted for fish, which has a demonstrated impact on turtle structure. This point is discussed further in the next section, but larger sized turtles are also caught and drowned in gill and drum nets. Therefore, Eulbertie waterhole supports a turtle population in climax-state and is exhibiting a compensatory density-dependent response, in relation to less recruitment due to competition for resources.

Springfield Homestead Waterhole is also a permanent waterhole that has never been netted for fish (Landholder; B. Morish pers comm.). During the early 1980s drought this waterhole dried to a 500m pool only 1.5 meters deep. Such a large reduction in waterhole size would impact the turtle population by decreasing the population size due to less available aquatic habitat. It is expected that large adults would compete for the remaining waterhole habitat, with juveniles decimating. After the drought broke and floodwaters replenished Springfield Homestead, the population recovered as recruitment resumed, as demonstrated by the size distribution graph (Figure 3.1.b).

Figure 4.1 The permanent Broadwater Waterhole, located on the Thomson River in Lochern National Park in the upper Cooper catchment. This is a large deep waterhole with lots of overhanging vegetation.

Figure 4.2 The permanent Fish Hole Waterhole, located on the Thomson River in the border of Lochern National Park in the upper Cooper catchment. This is a large deep waterhole with steep banks in some parts and lots of overhanging vegetation.

Figure 4.3 The ephemeral waterhole Top Hole, located on the Thomson River on the Noonbah property in the upper Cooper catchment. This is ephemeral has steep bank with fringing vegetation located high on the top of the banks.

Tanbar waterhole is a semi-permanent waterhole that dried completely for three years during the early 1980s drought. All turtles in the waterhole were decimated although the waterhole was recolonised (possibly from Eulbertie located 30 km away across the floodplain) with the following flood. The turtle density at Tanbar is relatively low (Figure 3.2) and consists of juveniles with only 15% of the population being mature adults (Table 3.2). Migrants to the waterhole would probably be a mix of adults, sub-adults and locally recruited juveniles. These few adults would be reproducing and adding the highly dominated juvenile structure of the waterhole (Figure 3.1.e). Tanbar waterhole is in a dis-equilibrium state responding through enhanced recruitment regarded as a density-dependent response.

During the field collections, we observed microhabitat preferences for turtles of different sizes, as adult turtles were more often caught in traps within the deeper pools of the waterholes. Juvenile turtles were collected at edges of the waterholes among the shelter from overhanging trees or snags. It is unclear whether larger animals from the deep pools are displacing juveniles. As our anecdotal observations were not tested statistically nor experimentally, the refugia potential of deep pools would become most relevant during a drought when the permanent waterholes persist longer during the 'bust' times and enhance the chance of turtles survival. Nevertheless, a trade-off exists because turtle densities are higher in permanent waterholes, which creates a potential for depletion through competition for available resources. As resource availability declines during a 'bust' period we speculate that the turtles adopt a loss-minimising strategy by foregoing reproduction, as exhibited by no recruitment at Eulbertie Waterhole. Whereas during 'boom' periods the turtles redirect energy to growth and reproduction. Other turtle species put energy into growth until reaching maturity, thereafter, directing energy into reproduction. Therefore, because the Cooper Creek turtle receives sporadic times of increased productivity they attain large body sizes and delayed sexual maturity.

A trade-off occurs between permanent and ephemeral waterholes. Ephemeral waterholes, on a semi-permanent time scale ie. Tanbar, have low turtle densities, high productivity and high growth rate but risk mortality if the waterhole dries out before the next flood. Permanent waterholes ie. Eulbertie, have high densities, low resource availability but increased survival due to the permanency of the waterhole. Therefore during a 'bust' time ie. a drought, the turtles in the permanent waterholes may be experiencing a bust demonstrated by low growth and recruitment whereas the semi-permanent waterholes may be experiencing a boom demonstrated by high growth and reproduction.

I eliminate the habitat specialisation model because turtle populations exist in both permanent and ephemeral waterholes enabling turtles to utilise a range of available habitats, therefore the turtles are not specialists to permanent waterholes. I also eliminate the source-sink model because turtles in the ephemeral waterholes are able to recruit and contribute to the regional gene pool, therefore the permanent waterholes are not the source populations because during bust periods if a permanent waterhole is in climax state then main contribution the regional gene pool would be from the ephemeral waterhole on a time scale to the turtles reproductive potential. The pulse model was also eliminated because the ephemeral waterholes are not the main contribution to the regional gene pool.

I consider a focal area model as a representation for the population dynamics of the Cooper Creek turtle (Figure 4.4). Whereby during floods turtles will disperse and occupy a range of permanent and ephemeral waterholes. Turtles strongly select the permanent waterholes using cues from waterhole attributes such as morphology and riparian vegetation. Waterholes are not groundwater fed (Geomorphologist: G. Nanson pers comm.) therefore excluding this feature as a cue. The turtles also use the same mechanisms to select the ephemeral (semi-permanent) waterholes but at a lesser extent. The main contribution to the regional gene pool would be from the turtle populations occupying the permanent waterholes due to their increased chance of survival, these populations would recruit during the boom times. Depending on the frequency of drying of the ephemeral waterholes, waterholes that dry over a relatively long time scale and match the turtles reproductive potential, for example Tanbar, which may dry every 15 – 20 yrs, will contribute to the regional gene pool. The cost involved is that the ephemeral turtle populations will decimate if a flood doesn’t pass through the system allowing the turtles to disperse. Thus both permanent and ephemeral waterholes are occupied under this model, with the main contribution to the future gene pool being made from the permanent waterholes with secondary contribution being made from the ephemeral waterholes.

Over a geomorphological time scale, we predict that the turtle populations exist under the metapopulation model due to the waterholes being contemporary features of the landscape. The Cooper Creek turtles trait of occupying both permanent and semi-permanent waterholes would enable their success over geological time with the changing permanency of the waterholes. Therefore the turtles current strategy enables them to switch between waterholes of varying permanency enhancing their future success.

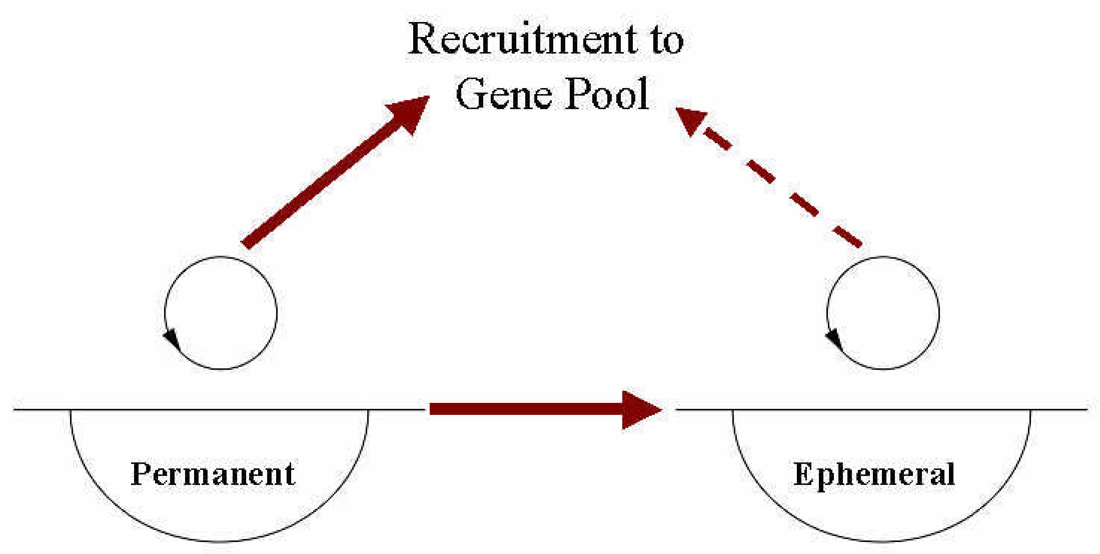


Figure 4.4 Focal area model where the main recruitment to the future gene pool is coming from the permanent waterholes, with the semi-permanent waterholes only contributing to the future gene pool if the waterhole does not dry before the next flood.

4.2 Effects of Harvest on Turtle Populations

During this study it became an additional factor affected turtle population structure in the permanent waterholes where a high abundance of turtles was expected. For example Murken Waterhole was a permanent waterhole yet had a low abundance and unusual population structure (Figure 3.1.d) with few adults. After much deliberation and consultation with landholders and the obvious evidence of a drum trap, we soon concluded that illegal netting for fish was an impact affecting stock structure of turtle populations in the Cooper Creek.

In some waterholes of southwest Queensland and South Australia, fishermen net for fish using either gill nets or drum nets. These nets catch the much sought after yellow-belly, *Macquaria ambigua* but also trap and drown turtles. Size selective mortality affects the population structure of turtles in the netted waterholes.

Murken Waterhole is near the town of Windorah and was formerly used for the towns' water supply, but the town has since changed to Currareeva waterhole. During conversations with local people and landholders, we found that waterholes with road access or close to towns are more intensely illegally netted for fish. There is also variation between landholders that either allow their station-hands or other people onto their properties to net for fish, or were strict in not allowing any netting to be done. There is also a prejudice against the turtles from the drop-line fisherman, as turtles will take bait and in doing so swallow the hooks. Some fishermen will cut the line while others will cut the turtles throat to reclaim their hook.

Murken Waterhole is intensely netted for fish. During fieldwork in October 2001 we found a drum net similar to the one in Figure 4.5, on the bank with turtle bones in the bottom of the net. On this same trip we found three dead or near dead females on the shore with their craniums smashed. We speculate that these large females were probably in a gill net still alive, subsequently the fisherman delivered a blunt traumatic blow to the cranium to further prevent these turtles from tangling their nets. These three dead females were the only mature females collected at this waterhole. On the most recent trip to this waterhole, four males in the size class range of 250 mm were collected. From the size distribution graph (Figure 3.1d), the net mesh of gill nets seem to be net selective, aiming to capture large sized fish but also incidentally netting large size turtles over CL 225 mm. The smaller sized turtles are surviving for the time being, but for how much longer? With it taking at approximately 15 years for

Figure 4.5 Angus Emmott, landholder of Noonbah station found the evidence of illegal fishing in a waterhole near his station. He is holding a drum net (left) for yellow belly and a small boat (right) used to lay a gill net across the waterhole just below water level. The boat is normally hidden in bushes along the bank.

females to reach maturity, the future of the Murken Waterhole turtle population indeed looks bleak.

Currareeva waterhole is another waterhole subject to illegal netting, but the impact is not yet as severe. The size of Currareeva Waterhole is 12 km long, which diffuses the impact of fishing on the turtle population structure. Evenso, there are fewer large females in Currareeva compared to other permanent waterholes that are not netted (Eulbertie and Springfield waterholes, Figure 3.1) which suggests that large turtles are subject to incidental mortality from the size selectivity of the illegal netting.

Broadwater, Waterloo and Fish Hole were categorised as turtle populations in recovery as these waterholes were all netted for fish in the past. Netting stopped in Broadwater and Fish Hole 10 years ago when the property was turned into a National Park. Although Fish Hole lies at the park boundary evidence of traps (Figure 4.5) has been found. Fish Hole is still being netted but not as intensely. The property owner of Waterloo stopped netting on his property 15 years ago. Therefore, there are three replicates of recovery turtle populations in permanent waterholes that feature similar population structures (Figure 3.1 f-h). There are few adults but a large proportion of sub-adults and juveniles which will eventually increase the future adult population. The turtle populations in these three waterholes are on the up-swing and are expected to attain a stable population state in the years to come. This study has shown that after a population has been reduced it may recover over a long time period of more than 15 years.

Examples of turtle’s vulnerability to exploitation have been documented for land tortoises, freshwater turtles and sea turtles. Diamondback terrapins (*Malaclemys terrapin*) were abundant and exploited commercially in the 1920s in the United States but recent localised population declines have been linked to incidental capture by crab-pot fisheries, resulting in terrapin capture and subsequent drowning (Tucker et al., 2001). Male and juvenile female terrapins are the size classes most frequently captured in crab-pots (Roosenburg, 1991; Hoyle, 1997; Tucker et al., 2001). Turtles in these life-history stages are sensitive to exploitation and the impact of low adult survivorship on population dynamics is severe (Brooks et al., 1991; Congdon et al., 1994; Heppell, 1998; Tucker et al., 2001). Other studies have shown increases in human-induced harvesting of adults from the wild may result in sharp decreases in population size. For example, Congdon et al. (1994) showed that a harvesting pressure as low as 10% per year could result in a 50% reduction in adult snapping turtles (*Chelydra* *serpentina*) within 15 years. Futhermore, Brooks et al. (1991) found that juvenile snapping turtles showed no compensatory response to increased adult mortality. Close and Seigel (1997), found that populations of sliders (*Trachemys scripta elegans*) from protected sites were larger than turtles from harvested sites with incidental by-catch (fisherman who set out traps to catch bait-fish and accidentally catch and drown turtles) being suggestive as the major factor responsible for declining turtle populations. The pancake tortoise (*Malacohersus tornieri*), in Tanzania is also exploited for commercial harvesting. Isolation of suitable habitats (rock-crevices), coupled with this species' limited dispersal abilities and low recruitment rates make recovery of depleted populations unlikely (Klemens and Moll, 1995).

Turtle life histories make them particularly prone to overexploitation if adults suffer increased mortality, primarily because the low probability of reproductive success each year demands extreme iteroparity (Heppell, 1998). A study on the sudden increase in the natural mortality of adults of the common snapping turtle (*Chelydra serpentina*) agreed with the view that populations of species with high, stochastic juvenile mortality and long adult life spans may be decimated quickly by increased mortality of adult animals, particularly if numbers of juveniles and immigrants are low. Recovery of such populations should be very slow because of lack of effective density-dependent response in reproduction and recruitment (Brooks et al., 1991). Implications for conservation and management of long-lived organisms need to be carefully managed. Successful programs will be those that recognise all life stages, without protection of adults and older juveniles, programs that protect nests and headstart hatchlings have a low probability of success (Congdon et al., 1994).

4.3 Warrego River Catchment

4.3.1 Biological Traits

The *Emydura macquarii* form in the Warrego River attained smaller maximum carapace length than the Cooper Creek form. The largest female collected from the Warrego measured 329 mm carapace length whereas the largest female collected in the Cooper was 366 mm. The same was true for the males, with the largest male collected in the Warrego being 272 mm whereas in the Cooper the largest male was 302 mm. Size at sexual maturity was similar between catchments. The smallest gravid female was 248 mm in the Warrego River and the Cooper Creek female determined by laparoscope was also 248 mm. The males in the Warrego and Cooper matured at a similar size of 177 – 211 mm. The difference in maximum sizes for males and females suggest there may be a difference among the life-history traits of the turtles in the Warrego and the Cooper that may be influenced by the different environmental and climatic conditions in each catchment with selection favouring large maternal body size in the Cooper Creek due to the aridity. The Cooper Creek is part of the Lake Eyre Basin and receives less rainfall and more episodic floods than the Warrego River (see Chapter One, General Introduction), which is part of the Murray Darling Basin. Also, the Warrego has three species of turtles including the *Emydura macquarii* form, *Chelodina longicollis* and *Chelodina expansa*. The additional two species is circumstantial evidence that the Warrego River is under different climatic and water regime conditions compared to the Cooper.

Growth coefficients of the *Emydura macquarii* form in the Warrego River were less variable but not necessarily higher than the Cooper Creek turtle. This may be attributed to different water regimes of the Warrego evenly sustained flows that enhance productivity of waterholes. The mean gross primary production of Warrego sites ranged from 0.08 $gCm^{-2}day^{-1}$ at Thurulgoona to 0.11 $gCm^{-2}day^{-1}$ at Quilberry waterhole, during October 2001 (Appendix 1). Female turtles at Thurulgoona waterhole had a low growth coefficient of 0.08, while the females at Quilberry had a relatively higher growth coefficient of 0.11 (Table 3.9). The association of high GPP with increased growth did not hold for the ephemeral waterhole of Sandford Park lagoon. Here females exhibited the lowest growth coefficient but a high mean GPP (Appendix 1) was found of 0.11 $gCm^{-2}day^{-1}$. It remains counterintuitive why an ephemeral waterbody would have consistently higher readings of GPP yet limited growth unless turtles in Sandford Park lagoon haven't been there long enough to reap the rewards of a high GPP. A related point of interest is that several *Chelodina longicollis* were caught in the ephemeral waterholes. As mentioned earlier *C. longicollis* prefer the high productive waterbodies before migrating overland back to the permanent waterholes during droughts as found at Jervis Bay (Kennett and Georges, 1990).

4.3.2 Waterhole Persistence and Population Structure

The Warrego River has several water resource developments pending for the catchment apart from the existing weir at Cunnamulla. Landholders use the permanent waterholes as a main water supply for irrigation or stock needs Floodwater is diverted to the permanent waterholes through the use of levee banks (Figure 4.6). Also some landholders pump water from permanent waterholes to ephemeral waterholes to maintain stock water during dry periods.

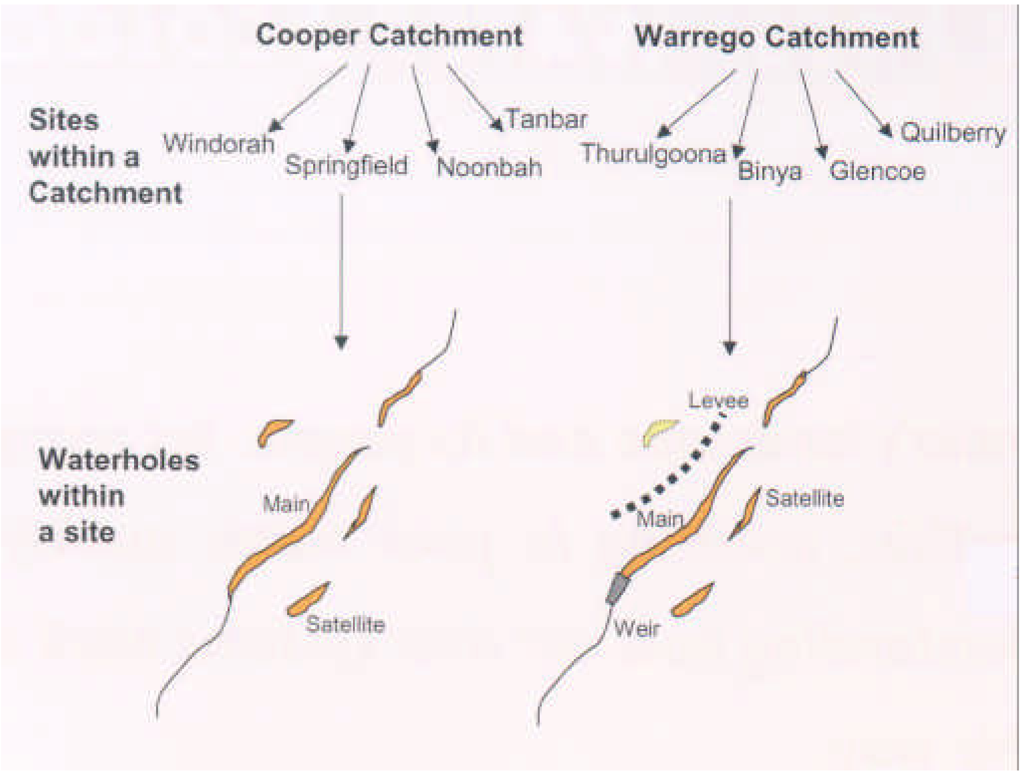


Figure 4.6 Comparison of waterholes between the Cooper Creek and Warrego River. The Warrego River has some resource development, either diverting or containing water within the waterholes (Figure from Dryland Refugia Newsletter, Issue One, CRC for Freshwater Ecology).

Permanent waterholes host a similar population structure pattern in both the Warrego and Cooper waterholes. The permanent waterholes (Quilberry, Sandford Park w/h, Binya and Thurulgoona Waterholes) have a greater abundance of turtles than the semi-permanent and ephemeral waterholes (Table 3.6). Quilberry and Sandford Park Waterholes have population structures consisting of low adult : juvenile ratios whereas the Thurulgoona population had high adult : juvenile ratio (Table 3.7). The low abundance of adults in Quilberry and Sandford Park waterhole is possibly a result of illegal netting. Quilberry Waterhole has convenient public access via a travelling stock route and Sandford Park waterhole has access from the road. Landholders on both of these properties have no idea of the frequency of netting in these waterholes, but acknowledge that it happens. During a field trip in May 2002, at Quilberry Waterhole we observed fishermen set a submerged gill net down through the waterhole. We have no quantitative basis for direct comparison, but a subjective impression is that the rate of illegal fishing in the Warrego River does not seem as intense as it is in the Cooper Creek. Station hands at Thurulgoona were doubtful that any netting has been done at Thurulgoona Waterhole, which corroborates with our data showing the higher proportion of adults in the waterhole population structure. Binya Waterhole is a permanent waterhole that dried down severely in the late 1950s drought that would have caused a reduction in the population. During fieldwork at Binya we were catching a high proportion of carp (*Cyprinus carpio*) in the turtle traps. The low captures of turtles in Binya may be a consequence that turtles were not going into traps because carp were scaring them away.

Clear and Sandford Park lagoons are both semi-permanent waterholes. Clear Lagoon dried up in 1965 and again in the early 1980s (Landholder B. Fisher pers comm.). Sandford Park lagoon dried up in the late 1950s and again 1965 (Landholder; C. Adcock pers comm.). Both of these waterholes have low turtle abundance, but turtles are represented across all size class ranges to indicate successful local reproduction and recruitment. Sandford Park Lagoon has low adult : juvenile ratios, which may be attributed to the ephemerality of the waterhole.

4.4 Conclusion

This study investigated the ability of freshwater turtles to persist in the dryland river Cooper Creek, in arid Australia. The central findings of this project revealed that the *Emydura macquarii* complex from the Cooper Creek has life-history traits that enable its persistence in the harsh ‘boom and bust’ environment. Biological features of the Cooper Creek turtle include; large body size, delaying sexual maturity and indeterminate growth. The turtles biological features combined with the their ability to seek out refuge in the permanent waterholes during ‘bust’ periods ultimately enhances survival.

The research demonstrated that permanent waterholes are consistently dominated by adults, have a have density of turtles, and a low growth coefficient. Whereas, semi-permanent waterholes are predominated by juveniles, turtles are in low density and exhibit a high growth coefficient. The ephemeral waterholes on a different time scale to the turtles life history and reproductive potential contain no turtle populations.

A trade-off exists during a drought (the bust period) between permanent and semi-permanent waterholes. High turtle density in the permanent waterholes causes competition for decreasing food resources and availability. During the bust, turtles in permanent waterholes exhibit a type of shutdown mode, where energy is no longer being directed into reproduction (minimal or no recruitment) and growth (low growth coefficients). Therefore, the turtle population at Eulbertie Waterhole are in climax state and are exhibiting a compensatory density-dependent response in relation to less recruitment and low growth due to adults competing for resources.

Whereas, the semi-permanent waterholes are exhibiting a boom time during the drought period. Due to low turtle density there is less competition for resources allowing turtles to direct energy into reproduction and growth. Therefore, the turtle population at Tanbar Waterhole is in dis-equilibrium state responding through enhanced recruitment and growth regarded as a density-dependent response. A trade-off exists, in that the semi-permanent waterhole may dry before the next flood therefore decreasing the turtles survival in the waterhole, compared to the permanent waterholes where the turtles’ survival are enhanced. The population dynamics of the Cooper Creek turtle persist under the focal area model.

The research from this study also demonstrated that the impact of illegal netting for fish in waterholes in southwest Queensland has a detrimental effect on the population structure of the Cooper Creek turtle. Illegal fishing is net selective removing not only the large sized fish but also the large size turtles (< 225 mm). The decrease in adults at Murken Waterhole is markedly effecting the future turtle population. Due to the life-history strategies of the Cooper Creek turtle in delaying sexual maturity until attainment of a large body size (248 - 268 mm for females and 177 - 211 mm for males), if Murken Waterhole is continually intensely netted, than the future turtle population may not recover. Although, recovery of turtle populations from illegal netting is possible, demonstrated from Waterloo, Broadwater and

Fish Hole waterholes. These adult populations are now increasing with the population on the up-swing due to the netting being stopped 10 – 15 years ago. These three turtle populations are an example that they can recover but taking a long period of time to do so.

4.5 Conservation and Management Issues

The Cooper Creek turtle has successful suite of co-evolved adaptive strategies to persist in the highly variable environment of the Cooper Creek. Prospects have been voiced for irrigation development to be undertaken on this dryland river in arid Australia. Floodplain habitats rely on natural patterns of hydrological connection to sustain resident biota and ecosystems processes (Junk et al., 1989; Sheldon et al., 2002). Even if irrigation is technically feasible in the region, it would cause catastrophic changes to the environment (Walker et al., 1997). For turtles alone, with the permanent waterholes targeted for water extraction and changes in flow regime pose critical problems for floodplain connectivity. Turtles exhibit high site fidelity between permanent waterholes (Goodsell, 2002), water extractions from these permanent waterholes could decimate genetically diverse populations. Changes in floodplain connectivity would have a marked effect on the flows to waterholes consequently causing a change in resource availability, which the turtle populations depend upon for reproduction and growth. Therefore, changing the natural aspects of floodplain connection and frequency in dryland rivers will have significant impacts on the diversity and population dynamics of biota.

The current conservation concern for turtles is the impact that illegal netting is having on turtle population structure in some waterholes. This study demonstrated that turtle populations are able to recover from intense netting (Fish Hole in particular) over a long time period. The main challenge is community awareness on the conservation value of these unique freshwater turtles in the Cooper Creek. It is also important to create awareness on how all biota interact to maintain ecosystem health. Ideally, for illegal netting to be stopped now would greatly influence the future sustainability of the turtle populations but in reality it is not possible to change peoples views, ideas and attitudes overnight. Through education, such as the Dryland River Refugia Newsletter that the refugium project sends out twice annually, we hope to create awareness both to the community and landholders of the impact that illegal netting is having on turtle populations and hence encourage landholders in taking action to reduce or stop netting.

4.6 Future Research

This project is part of an on-going research project with the CRC for freshwater Ecology. The refugium project is only in Phase One of data collection before going into Phase Two, focusing on management issues to predict the consequences of water resource development on physical and biological processes and biodiversity in dryland rivers. The next step for the turtle research is to sample the Border Rivers catchment as defined from the project, to link and compare turtle populations across the three catchments that under different impacts of water resource development, with ongoing sampling of the Cooper Creek and Warrego River.

In the Cooper Creek, the next stage for turtle research is to gather more recapture data to determine the density of turtles in the waterholes and also to determine if growth rings are being deposited annually. We would also like to gain a better understanding of the turtle processes between the permanent waterhole, Eulbertie and the semi-permanent waterhole, Tanbar. Thus, incorporating dietary make-up of the turtles among waterholes and flow of carbon through the system by using isotope analysis.

Another main focus is to sample the Diamantina River, west of the Cooper Creek, as anecdotal information infers that turtles (*Em. Macquarii*) may be persisting in this dryland river. By sampling the Diamantina, we would be able to compare the genetic structure, population dynamics and biological features of turtles between these two arid catchments in the Lake Eyre Basin.

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Appendix I

Mean GGP from September 2001 Cooper Creek Trip (unpublish. Fellows and Bunn 2001).

Waterhole	GPP (gCmm^{-2}day^{-1})
Bottom	0.29
Glen Murken	0.46
Springfield Homestead	0.08
Mayfield	0.77
Murken	0.31
One Mile	0.08
Pelican	0.52
Shed @ Hammond D.	0.08
Tanbar	0.50
Top	0.18
Warrannee	0.20
Waterloo	0.28
Yalungah	0.10
Yappi	0.64
Yorakah	0.44

Appendix I cont'

Mean GGP from October 2001 Warrego River Trip (unpublish. Fellows and Bunn 2001).

Waterhole	GPP (gCmm^{-2}day^{-1})
Binya	0.12
Clear Lagoon	0.12
Glencoe	0.25
Key	0.22
Mirage Plains	0.19
Noorama	0.05
Quilberry	0.11
Red	0.29
Rocky	0.20
Sandford Park Lagoon	0.11
Sandford Park W/h	0.11
Thurulgoona	0.08
Thurulgoona Homestead	0.07
Tinnenburra	0.14
Woganora	0.31