SECTION C

SYDNEY TURTLE SURVEY

CHAPTER C1: SURVEY INTRODUCTION

C1.1 Distribution of Turtles in Sydney

As a prelude to pollution studies, a survey was conducted to ascertain the current distribution, abundance, population structure, and species composition of freshwater turtles in the central Sydney area. Surveys also provide important data against which species and population changes can be measured (Lunney 1995). The survey focused on the most urbanised (in terms of population density) region to represent the highest anthropogenic impact situation.

C1.1.1 Local Species

From the collection of the first turtle specimen from the area in 1770, until 1998, *C. longicollis* was the only turtle recorded as native to the Sydney Basin (Cogger 1992, Cann 1998). An unidentifiable turtle with distinctive morphology from the Lane Cove River to the northwest of Sydney's CBD led to the description of a new subspecies of turtle (*Emydura macquarii dharuk*) from the Sydney Basin (Cann 1998). This subspecies has also been reported from the Hawkesbury-Nepean River and Eastlakes (Lachlan) Swamps (Cann 1998).

Although it is possible that a distinct subspecies of *E. macquarii* occurs in Sydney waterways, it is unlikely for several reasons. With the exception of populations on the north coast of NSW, which have variously been referred to as a distinct species, *E. signata*, a single subspecies of *E. macquarii* (*E. m. signata*) or several distinct subspecies of *E. macquarii* (Cann 1998), the range of *E. macquarii* was historically thought not to extend east of the Great Dividing Range, which includes the Blue Mountains to the west of Sydney (Cogger 1962, Goode 1967, Anonymous 1974). While *C. longicollis* was collected in the Sydney area within a few years of European settlement (Shaw, 1794), *E. macquarii* was first collected in 1825 (Legler & Georges 1993) from a location remote from Sydney (possibly the Macquarie River), despite being visually conspicuous during atmospheric and aquatic basking. Hence, it is unlikely that the animals were simply overlooked in the Sydney region as has been suggested (Cann 1998). Sydney surveys between 1945 and 1964 by experienced local amateur herpetologists located *E. macquarii* only in Centennial Park. These were found over two visits in the 1946 to 1948 period – two adults on one occasion and a hatchling with egg tooth on the other (Roy Mackay pers. comm.), suggesting the species was breeding in Sydney, but not widespread at this stage. Although there are now several translocated taxa in Sydney (pers. ob., Craig Latta pers. comm., Steven Emerton pers. comm.), this was unlikely to be the case in the early decades of settlement when *C. longicollis* and *E. macquarii* were both collected and described.

Emydura macquarii has been found within the Sydney region (locations not specified) in the past 20 years (Arthur White pers. comm., Griffiths 1997), and Stephenson (1986) claimed that at least three Sydney parks, including Centennial Park, held *Emydura* species. The register at the Australian Museum (Table C1.1) gives an idea of the temporal trend of lodgements of *C. longicollis* and *E. macquarii*. The register was established in the late 1800s, the first *C. longicollis* was lodged in 1908, and the first *E. macquarii* was lodged in 1980.

Elseya latisternum is not native to the Sydney basin (A.1.5).

C1.1.2 Exotic Species

Concerns have been expressed over several unconfirmed reports of red-eared slider turtles (*Trachemys scripta elegans*) living in Sydney waterways (Anthony Stimson pers. comm., Shelley Burgin pers. comm., Griffiths 1997). There is also a confirmed report of six gravid females being removed from a lagoon (Yeramba) in southern Sydney (Steven Emerton pers. comm.). Transported globally via the pet trade from their native distribution in the Mississippi Basin in North America, these turtles have been found in natural waterways in other countries (Newbery 1984, Nilson & Andrén 1986, Branch 1988, Platt & Fontenot 1992, da Silva & Blasco 1995, Luiselli *et al* 1997, Thomas & Hartnell 2000) where they have established breeding populations (Bertrand & Coste 1994, Ng *et al* 1993), which may result in declines in native populations (Bury 1994).

Species	Number	Location	Registered
C. longicollis	R4281	Smithfield	1908
C. longicollis	R6175	Parramatta River	1913
C. longicollis	R8127-8	Maroubra	1923
C. longicollis	R9380	Wentworthville	1927
C. longicollis	R9689	Wentworthville	1928
C. longicollis	R93451, R93456 R93457, R93458	Liverpool	1965
C. longicollis	R68830-34	Liverpool	1965c
C. longicollis	R25840	Narrabeen	1966
C. longicollis	R25844	Baulkham Hills	1966
C. longicollis	R93452	Fairfield West	1969
C. longicollis	R33120	Londonderry	1972
C. longicollis	R68835, R68836, R68837, R93459, R93455	Canley Heights	1972
C. longicollis	R68847, R93444	Rooty Hill	1974
C. longicollis	R55928	Earlwood, Wolli Ck	1976
C. longicollis	R33116, R33121, R65032-33	Baulkham Hills	1977
C. longicollis	R61591	Towra Point, Botany Bay	1977
E. macquarii	**R96347-48**	**Lane Cove River Park**	**1980**
E. macquarii	**R111887**	**Kuringai Chase NP**	**1984**
C. longicollis	R146246	Rickaby's Ck, Richmond	1994
E. macquarii	**R143556**	**Eastlakes Swamp**	**1994**
C. longicollis	R144659	Vineyard	1996

Table C1.1 All dated records of freshwater turtles with a Sydney region suburb locality from the Reptile Collection Register of the Australian Museum ('R' Register from about 1885) prior to March 2002.

C1.2 Maturity

Male *C. longicollis* from the New England district mature from carapace length (CL) = 150 mm at 6-7 years, while females mature from CL = 170 mm at 9-11 years (Parmenter 1976). Results are similar around Jervis Bay, where the carapace lengths at maturity are 145 mm and 162-168 mm respectively (Kennett & Georges 1990). Growth slows at maturity (Georges 1985), when energy is thought to be redirected to reproduction (Gibbons 1990a). *Emydura macquarii* are larger, with sexual maturity at CL = 200-210mm (Chessman 1978).

C1.3 Aims

The aims of the Sydney Survey are:

- to determine which species of turtle are present in Sydney, while assessing concerns over feral populations (especially of *Trachemys scripta elegans*) in local waterways
- to assess the numbers and distribution of local and translocated turtle species within highly urbanised Sydney
- to assess the effect of baiting fyke nets for use in subsequent studies
- to identify factors indicated as impacting the health and size of urban turtle populations.

Null Hypotheses

1. Each turtle species present in the Sydney region is present in all Sydney waterways and waterbodies.
2. Each turtle species present in the Sydney region is present in equal densities in each waterway and waterbody.
3. The demography of turtle populations in each Sydney waterbody is the same.
4. Baited and unbaited fyke nets give equal catchability of turtles, irrespective of waterbody type or location.

CHAPTER C2: SURVEY METHODS

The survey consisted of two parts, a random survey (Survey A) carried out in November 1998 (NW sites), December 1998 (SW sites), and February 1999 (NE & SE sites), and a non-random survey (Survey B) carried out in March and April 1999.

C2.1 Survey A

C2.1.1 Site Selection

A 1600km^2 area of Sydney, extending 40km inland from the east coast, and 20km north and 20km south of Sydney Harbour was randomly sampled between November 1998 and February 1999. This area was divided into 400km^2 quarters, with sections designated NW, NE, SW and SE. Potential sites were road-accessible, in or adjacent to reserve or parkland, and non-tidal, as Australian turtles do not usually live in brackish water (Cann 1998). Waterways on private land or golf courses were excluded. Sites were identified on an NRMA *Sydney Central and Greater Western Sydney* map (Map 4, Edition 1; July '97-July '98; scale 1: 100 000). Four sites were randomly chosen from 31, 31, and 34 potential sites in the NW, NE and SW sectors respectively, and three from the 15 in the SE sector (Figure B.2). Sites were rejected if they were too shallow for setting nets or if access was impossible or dangerous.

C2.1.2 Trapping

Four unbaited Fyke nets were randomly set at least 10 m apart in a water depth of 50-100 cm for three consecutive 24-hour periods at each survey site. Nets lost through theft or stormwater flow were not replaced (see also Section B.1.1).

C2.1.3 Site Descriptions

Subsequent to the selection process, the following sites were surveyed.

NE sites

Lane Cove River, Macquarie Park (*LCR downstream*) [AMG 328420E 6258900N]
Nets were set at two neighbouring picnic areas (Ironbark Corner & Carter's Creek) accessed from Riverside Drive. Beyond the constructed picnic areas there is dense riparian forest with a mix of native and introduced plants. The river is wide, open and deep, dropping off sharply from the bank. The substrate is soft and bubbly, with lots

of debris, and a rotten or oily smell in places. Lots of water dragons (*Physignathus lesueurii*) were observed.

Lane Cove River, West Pymble (*LCR upstream*) [AMG 326250E 6261400N]
The site is accessed from a very minor path off a more major bush track which is reached by walking down between suburban houses from Gloucester Avenue. Despite the presence of gross pollution, the water appears cleaner than at the downstream site at Macquarie Park, although there is high turbidity due to suspended mud particles. There are shallow areas which are rocky and shaded, and deeper sections with sandy substrate and lots of sunlight. Water levels rise dramatically with heavy rain. The banks are densely vegetated with a high proportion of non-native bushes and vines, although native forest dominates higher up. Water dragons, ducks, and red-bellied black snakes (*Pseudechis porphyriacus*) were observed.

Manly Creek, Manly Vale [AMG 339300E 6260880N]
A small creek running under a major road with playing fields on the approach side which are heavily utilised by school children. There is thick viney scrub and grass on the banks, with a few larger trees such as willows, and on the far side there is thick non-native vegetation rising up to residential housing. Some areas receive full sun, others are fully shaded. Substrate is rocky, interspersed with sandy sections. Shallow rapids run into still water to above waist deep. Gross pollution is low, but oil can be smelt in the water. Lots of water dragons and mosquito fish (*Gambusia* spp) were present. Nets were placed upstream of the heavily trafficked Condamine St, but road runoff enters the creek from neighbouring suburban streets.

Manly Dam, Allambie Heights [AMG 337700E 6261100N]
Manly Dam is the largest freshwater lake in the Sydney metropolitan area. A large open sunny lake, it is used for recreational swimming, boating, and fishing, and there are lots of warm shallows, with deeper water beyond. The area surrounding the trapping site is low native forest. The substrate is very hard and there is little aquatic vegetation, although other areas accessible only by water look more productive, with copious aquatic vegetation and lots of bird life.

NW sites

Breakfast Creek, Marayong [AMG 304500E 6263800N]

This creek is in an open area with only a few metres of low riparian vegetation and a few trees beyond which there is a grassed area (Harvey Park), and then low suburban housing. There are dense clumps of *Typha sp* in the creek, and the substrate is stone or concrete in parts, but is soft over the remainder. A stormwater drain funnels into the creek, so flow is rapid during heavy wet weather, and there is lots of gross pollution. Water birds are plentiful.

Devlin's Creek, North Epping [AMG 322470E 6262900N]

The creek is five to ten minutes' walk from Belinda Crescent down a bush track. Surrounded by tall, thick forest, the creek is 90% shaded. The substrate is mainly stone or gravel. Small sporadic ponds are linked by shallow (< 500 mm deep) stretches, although rubbish high in the trees indicates that the rise in water level during wet weather can be dramatic. Water dragons are present.

Toongabbie Creek, Northmead [AMG 313620E 6259150N]

The approach to the creek to the north of Hammers Rd is down a grass slope. The dense riparian vegetation is scrubby with a high proportion of introduced species. The far western side of the creek is more open, has a sandy bank, and housing on the overlooking ridge. The creek is largely in sunshine. The substrate is sandy, with occasional rocky areas. Water dragons, ducks, carp (*Cyprinus carpio*) and goats are present.

Prospect Creek, Smithfield [AMG 308260E 6253310N]

The site has a lot of gross pollution with rubbish dumped in the car park and surrounding area (Rosford Street Reserve). There are signs of human habitation along the banks (shelters, fires, cans, food scraps). Oil can seen and smelt over much of the creek. The substrate is largely sand, gravel, and refuse, but is a seemingly bottomless pit of microbially-active sludge around a small island and some of the banks. There are lots of reeds and waterbirds around the island. At one point the stream is piped under a grassy knoll, but the stormwater pressure is high here after wet weather, making it unsuitable for trapping downstream, or just upstream of this area. Nets are particularly susceptible to theft at this location.

SE sites

Wolli Creek, Turella [AMG 327770E 6243830N]

A quiet sunny waterway accessed by crossing the footbridge at the end of Henderson St, which is located in a semi-industrial area near Turella train station. The train line runs along the nearside of the creek. On the far side is parkland with a bush track. Woodland and swampland along the creek was severely degraded by the 1940s, and only small remnants of original bushland survive, including some small reserves along the creek (Benson & Howell 1990, Keast 1995). There is lots of introduced vegetation, with willow trees, grass and weedy scrub, although the majority of the creek is open to sunlight. The substrate is soft, microbially active and has an extremely strong smell of oil. Gambusia, ducks, wood ducks, water hens and some egrets were observed.

Kensington Pond, Centennial Park [AMG 336070E 6246950N]

Centennial Park is a large urban park established in 1888, which contains 9 lagoons, is surrounded by dense human settlement, and is heavily used for recreation. Like most of the lagoons, Kensington Pond supports a large bird population. It is 80% grown out with water hyacinth and has an abundance of large carp. The substrate is superficially sandy, but hard underneath. There are areas of planted bush around, but the majority of the area is covered with managed grass.

Model Yacht Pond, Centennial Park [AMG 337300E 6247500N]

Apart from a row of large trees along one edge, there is minimal vegetation around this lagoon, which is enclosed by grassed recreational areas. Within the lagoon there is non-emergent water weed and patches of bullrushes (*Typha* sp.) The substrate is soft. There is a centre island and lots of water birds. This pond was re-filled after draining and dredging several months prior to surveying and one *C. longicollis* and one *E. macquarii* released into it (Jonathan Cartmill pers. comm.). One large stormwater drain empties into the pond.

SW sites

Duck River, Clyde [AMG 316320E 6252250N]

The area is open and grassy, with some large trees and playing fields on either side. In some areas the grass runs to the creek edge, in others there is a mix of some native, but largely exotic, riparian vegetation. Fairly open with some shaded areas. Lots of ducks are present. Substrate is soft and muddy. There is thick water weed in some areas. Pools are joined by shallow stretches, but the water is deeper above a constructed weir.

Yeramba Lagoon, Picnic Point [AMG 315550E 6238350N]
This is a large open water body, which is separated by Henry Lawson Drive from the tidal stretch of the Georges River. It is surrounded by native forest infiltrated by exotic species. Silt accumulating in the lagoon has reduced the water area to a 25-year minimum (NPWS pers. comm.). The substrate is soft and microbially active with the obvious presence of oil and a strong sulfur smell in parts. There are lots of water plants, e.g. the introduced *Alternanthera philoxeroides* and *Elodea canadensis*, and the native *Typha* sp. The water is choked in parts with detritus.

Orphan School Creek, Canley Heights [AMG 307760E 6249520N]
A surfaced path runs along the creek from King Rd, with houses in close proximity on one side. Small sections of surrounding vegetation includes both native and introduced plants. Softer substrate is interspersed between rocky platforms. Lots of gross pollution and some areas of oily black deposit and bubbling substrate. Shopping trolleys litter the creek. Water dragons and ducks are present.

Lake Gillawarna, Georges Hall [AMG 313190E 6246150N]
Gillawarna is an Aboriginal word meaning ‘nesting ground’, and this open lake has island refuges with many birds including ducks, wood ducks, ibis, and water hens. The islands are covered with introduced plants. The water appears very polluted, with lots of floating surface oil as well as black oily deposits. The waterbody receives lots of run-off from the highly trafficked Henry Lawson Drive that runs alongside. The substrate is very soft and in some spots is bubbling with microbial activity. The many carp are sometimes seen gulping at the surface. Most of the water surface is covered with floating water weed. Surrounded by grassed parkland and minimal riparian vegetation. Several stormwater drains empty into the lake. The neighbouring Chipping Norton Lake in the middle reaches of the Georges River is the result of previous sandmining operations (Butlin 1976).

C2.2 Survey B

C2.2.1 Site Selection

Due to concern over the possible presence of *T. s. elegans* in Sydney, an intensive trapping regime was implemented at six additional sites from which *T. s. elegans* had been reported (Anthony Stimson, Steven Emerton pers. comm.).

.

C2.2.2 Trapping

In this additional survey, a comparison was made between unbaited and baited fyke nets, to determine if bait would increase capture rate. *Trachemys. s. elegans* had previously been caught in Yeramba Lagoon using fyke nets baited with pilchards (Steve Emerton pers. comm.), and Parmenter (1976, p141) found that canned sardines were the most effective of baits tested for capturing *C. longicollis*, and tinned fish are also successful when used with north American species (Ernst & Barbour 1989). In this study, four baited (sardine cat food) and four unbaited Fyke nets were randomly set at each location.

C2.2.3 Site Descriptions

Yeramba Lagoon, Picnic Point (re-surveyed)
See description under survey sites.

Lane Cove River, Lindfield (LCR midstream) [AMG 328400E 6259250N]
River access was from two grassed recreational picnic areas in the Lane Cove National Park, ‘Thistlethwaites 36’ and ‘Haynes Flat 35’, which are reached from Max Allen Drive. The site was 350 m upstream of the Survey A site LCR downstream. Between the grassed area and the river is a narrow strip of introduced and native riparian vegetation, although this becomes wider and denser upstream. The river is broad and deep. Lots of water dragons are present.

Blue Gum Creek, Chatswood West [AMG 329410E 6259250N]
A tributary running perpendicular to the Lane Cove River, this is a small shallow creek with a grassed recreational area (Fullers Park) bordering one side of the lower reaches. The remaining area is wooded with a mixture of native and exotic species, including large stands of introduced *Lantana* spp. Mangroves and toados (*Tetractenos hamiltoni*) are in the lower tidal reaches. Soft sandy substrate with sporadic rocky

platforms. Minimal aquatic macrophytes. Varying amounts of sunlight reach the stream.

Harris Creek, Hammondville Park [AMG 311480E 6240700N]
A shallow narrow creek with wider ponds below a small weir, where it is weakly tidal, with mangroves only appearing further downstream. Nets were set above (where it is fairly sunny) and below the weir (more shaded). There is a nearby swamp with a non-biotic green deposit and a very strong smell of sulfur. Substrate is largely sandy, and very soft in parts. Aquatic macrophytes are common along the edges, with riparian vegetation largely introduced. The creek runs along the side of a large sportsfield, with a few residences in the distance, and a sewage works on the other side. Red-bellied black snakes, kingfishers, white-faced herons and other birds are present.

Harris Creek, Holsworthy Barracks [AMG 310840E 6239800N]
Creek access is from Yengo Court at the edge of a new housing area that is currently being constructed within Holsworthy. Upstream of the Hammondville Park Sportsfield site, situated within military grounds, the army barracks runs along one side of the creek. Elsewhere the creek is bordered by native gum forest, with exotics infiltrating into downstream areas. All nets were set upstream of the railway bridge. Substrate soft and sandy, with the occasional rocky platform. Creek very shallow upstream of trapping area. Occasional clumps of aquatic macrophyte. Oil can be smelt and seen in places, and some areas are microbially active.

Busby's Lagoon, Centennial Park [AMG 336250E 6247500N]
Large open pond with two islands and abundant birdlife. Birds nesting on island are predominantly ibis (*Threskiornis molucca*), but there are also swamp hens, moor hens, ducks, geese, crows, darters, and cormorants. European carp are abundant, and Koi are present in smaller numbers. Floating water weed is dense up one end of the lagoon, but the remaining area is fairly clear and open. The substrate is soft and there was a blue-green algal bloom during trapping. Large parts of the bank are open, with grass as the major vegetation, with occasional paperbark trees (*Melaleuca* spp).

C2.3 Turtle Processing

For both surveys, captured turtles were weighed and a series of shell measurements (CL, CCL, CW, PLmax, PLmin, PWa, PWp) taken (Section B.2.2). Due to time limitations only CL and CW were recorded for turtles from Kensington Pond, Model Yacht Pond and Yeramba Lagoon. Captures of carp and eels, the other dominant aquatic vertebrates in the region, were also noted, and daily water temperature taken.

C2.3.1 Sexing

Although hatchlings of some Australian chelids are brightly coloured, the colour does not persist, and most adults are plain and generally show no sexual colour dimorphism (Legler & Georges 1993). There are no other external dimorphisms apparent in juveniles, but after maturity tail length can often be used to distinguish males from females, with the males having larger pre-cloacal tail length (Chessman 1978, Legler & Georges 1993). For both *E. macquarii* (Chessman 1978) and *El. latisternum* (Ernst & Barbour 1989), mature males have longer thicker tails, with the vent posterior to the rear carapacial edge, while the tails of females retain the same appearance as those of juveniles (Thompson 1983b).

The tail of *C. longicollis* has been described as being ‘so extremely short as scarce to deserve the name’ (Shaw 1794), and is a difficult feature to use for sexing (Cann 1998), even though length, thickness, and cloaca to tail tip distance are marginally greater in males (Goode 1967). There are some other morphological trends: by maturity, the shell of females tends to be deeper (Legler & Georges 1993), presumably to aid egg storage, and the plastron of males is often concave (Cann 1998), presumably to facilitate mounting for intercourse. Males of both *Emydura* and *Chelodina* species generally grow more slowly, and to a smaller size than females (Chessman 1978, Georges 1982a, Parmenter 1985). Plastron shape may be useful in sexing mature male *C. longicollis* (Kennett & Georges 1990), but not in all populations (Thompson 1983a).

The sex was recorded for *E. macquarii*, based on tail length, and for *C. longicollis* (Survey B only) based on plastron convexity.

CHAPTER C3: SURVEY RESULTS

C3.1 Sydney Survey A – Specific Comments

The distribution of *Chelodina longicollis* over the 1600km^2 city region was patchy, with no captures at four sites, four sites producing only 1 or 2 turtles, and larger numbers at the remaining seven sites (Table C3.1). *Emydura macquarii* was found at six sites, but at no site exclusively. *Emydura macquarii* was in lower numbers than *C. longicollis*, except at Wolli Creek where it was in similar numbers and at Kensington Pond in Centennial Park, where they were in much greater numbers than *C. longicollis* (Table C3.1). Individuals of both species under 100 mm carapace length (CL) were rarely caught, and those from 100 – 150 mm were only common at two sites (Breakfast Creek for *C. longicollis* and Kensington Pond for *E. macquarii*). One *Elseya latisternum* (adult female, CL = 195 mm), out of its range (Cogger 1992), was captured in Kensington Pond, and no *Trachemys scripta elegans* were caught at any site.

Daytime water temperatures were above 20 ºC at all sites. The three SE sites, and Lane Cove River (LCR) downstream and Manly Dam in the NE sector had higher water temperatures (high-20s – mid-30s ºC) than other sites (low to mid-20s ºC).

C3.2 Sydney Survey B – Specific Comments

Chelodina longicollis was found at all six sites (Table C3.1), but only one individual was captured at Blue Gum Creek, which is tidal in the lower reaches and possibly for the whole trapping area, and only one captured at Harris Creek (Holsworthy). The other four sites had higher captures. *Emydura macquarii* was captured at three of the six sites – in lower numbers than *C. longicollis* at Yeramba Lagoon and LCR midstream, but in much (over 10x) greater numbers at Busby's Lagoon in Centennial Park (Table C3.1). Two *Elseya latisternum* (adult females; CL = 188, 247 mm) were captured Busby's Lagoon, and no *T. scripta elegans* were caught at any site.

Daytime water temperatures were lowest at the Harris Creek sites (Hammondville and Holsworthy), fluctuating from 16-19 ºC. They ranged from 24-27 ºC at Blue Gum Creek and Yeramba Lagoon, and from 27-28 ºC at LCR midstream.

		C. longicollis		*E. macquarii*		*Anguilla spp.*		*C. carpio*	
Survey A	**E**	**n**	**per E**	**n**	**per E**	**n**	**per E**	**n**	**per E**
NE									
LCR downstream	12	13 + 1re	1.08 + 0.08	6	0.50	8	0.67	-	-
LCR upstream	12	-	-	-	-	8	0.67	-	-
Manly Ck	10	2	0.20	-	-	5	0.50	1	0.10
Manly Dam	12	2	0.17	1	0.08	3	0.25	-	-
NW									
Breakfast Ck	9	44 + 3re	4.89 + 0.33re	-	-	40	4.44	-	-
Devlin's Ck	10	-	-	-	-	3	0.30	-	-
Toongabbie Ck	6	1	0.25	-	-	7	1.17	2	0.33
Prospect Ck	6	-	-	-	-	5	0.83	-	-
SE									
Wolli Creek	12	8	0.67	8 + 1re	0.67 + 0.08re	7	0.58	1	0.08
Kensington Pond	12	8	0.67	81	6.75	4	0.33	-	-
Model Yacht Pond	12	10	0.83	-	-	17	1.42	1	0.08
SW									
Duck River	9	-	-	-	-	23	2.56	-	-
Yeramba Lagoon	12	24	2.00	1	0.08	7	0.58	-	-
Orphan School Ck	11	1	0.09	-	-	22	2.00	-	-
Lake Gillawarna	12	8	0.67	1	0.08	5	0.42	18	1.50
Survey B									
Yeramba Lagoon	24	18 + 2re	0.75 + 0.08re	5 + 1re	0.21 + 0.04re	18	0.75	-	-
LCR midstream	24	9 + 3re	0.38 + 0.13re	3	0.13	11	0.46	-	-
Blue Gum Creek	24	1 + 2re	0.04 + 0.08re	-	-	3	0.13	-	-
Harris Ck (Hammondville)	22	6 + 1re	0.27 + 0.05re	-	-	6	0.27	-	-
Harris Ck (Holsworthy)	15	1	0.07	-	-	6	0.40	-	-
Busby's Lagoon	20	14 + 2re	0.70 + 0.10re	128 + 12re	6.40 + 0.60re	2	0.10	2	0.10

Table C3.1 Survey captures of turtles and fish. E = Effort = number of 24-hour fyke net periods. Effort is used as the comparative value, as net numbers varied between sites due to loss from theft or stormwater flows. n = number of turtles captured. Per E = n/E; re = recaptured animals. Recaptures are unknown for turtles at Kensington Pond and Yeramba Lagoon in Survey A, or for fish.

C3.3 Sydney Surveys – General Results

C3.3.1 Turtle Morphology

Emydura macquarii from Busby's Lagoon are morphologically diverse. Some (not quantified) are highly domed, others have an extremely flat carapace; carapace colour varies from a pale brown to a dark grey or brown, and some have striated carapacial grooves; there may be small raised pink lumps at the rear of the plastron, and some have a pink tinge to soft tissues such as the underside of the rear legs; the nuchal scute can be large, small or absent; chin barbels are often greatly reduced and even appear absent from some individuals; juveniles often have a ridged central carapace and serrated rear marginals, but this varies within size ranges. Ten percent (n = 13/128) have a yellow post-orbital stripe, which is narrower than usually seen in *E. krefftii* (Cogger 1992), and is probably a variation of *E. macquarii* (John Cann pers. comm.). *Chelodina longicollis* also showed morphological variation, with some distinctly broader across the carapace than others of a similar length.

C3.3.2 Size at Maturity/Sexing

Juvenile *C. longicollis* superficially appear more like mature adult males than females in that the plastron does not show convexity. In contrast, immature *E. macquarii* have the appearance of adult females, due to their small tails. An attempt was made to externally sex *C. longicollis* in Survey B, and using plastron convexity the smallest female *C. longicollis* had CL = 147 mm (n=14), indicating that the sexes may be distinguished at and above this size.

During the Survey, the smallest mature *E. macquarii* males (based on tail size) were from the largest populations, with CLs of 128 mm (250g, Kensington Pond) and 139 mm (290g, Busby's Lagoon). This indicates that size at maturity may vary among populations, but is not common below CL = 140 mm. The large *E. macquarii* populations had sex ratios skewed towards males. The male:female:juvenile ratio was 66:39:21 (plus 2 unknown) at Busby's Lagoon, and 41:30:7 (plus 3 unknown) at Kensington Pond.

C3.3.3 Effect of Baiting

In Survey B, there was no significant difference in the number of turtles captured in baited and unbaited nets for both *C. longicollis* over all sites (two-sample t-test, 5%, 10df), and *E. macquarii* within Busby's Lagoon (two-sample t-test, 5%, 18df). However, *C. longicollis* captures were significantly higher in baited nets within Yeramba Lagoon (two-sample t-test, 5%, 22df). Of the five *E. macquarii* caught at Yeramba Lagoon, all were caught in baited nets.

C3.3.4 Non-Turtle Captures

Beside turtles, the main captures were eels (*Anguilla* spp., all sites) and carp (*Cyprinus carpio*, 6/22 sites) (Table C3.1), with occasional captures of gudgeon (*Gobiomorphus* spp.). The only other captures were a little pied cormorant (*Phalacrocorax melanoleucos*; drowned) at Blue Gum Creek and a duckling (*Anas sp.*) at Breakfast Creek.

Capture rates of turtles and eels were correlated when all data were included in the analysis ($r^2 = 0.299$, F = 8.085, df = 1, 19, p = 0.01). However, the significance is due to a single outlier (Breakfast Creek) with high capture rates for both species. This site had almost twice as many eels and more than twice as many turtles than any other site. When this site is removed the relationship is non-significant ($r^2 = 0.075$, F = 1.450, df = 1, 18, p = 0.244). Although too small for net capture, the introduced eastern mosquito fish (*Gambusia holbrooki*) was noted at most survey sites.

C3.4 Comparison of Turtles over Sites

For analyses, turtle captures from Survey A and Survey B were combined for Lane Cove River (LCR downstream and LCR midstream), and for Yeramba Lagoon. In the following graphs and analyses, turtle numbers may be slightly lower than those shown in raw captures in Table C3.1, due to missing measurements (plastral measurements could not always be taken due to daylight time restraints, and a few turtle mass and length measurements were not included due to shell damage, or absence of measurement).

C3.4.1 Species Distribution

It is not possible to statistically compare raw capture data due to the varying trapping periods for some sites. Additionally, low captures of one or both species at some sites hampers analysis with a χ^2 test. The site with the highest per effort capture rate (Table

C3.1) for *C. longicollis* (Breakfast Creek; 4.89) was 122 times more successful than the site with the lowest capture rate (Blue Gum Creek; 0.04). For *E. macquari*i the site with the highest per effort capture rate (Kensington Pond, 6.75) was 84 times more successful than the site with the lowest capture rate (Lake Gillawarna, 0.08).

At seven sites (Breakfast Creek, Busby's Lagoon, Kensington Ponds, Lane Cove River, Model Yacht Pond, Wolli Creek, Yeramba Lagoon) more than 10 turtles were trapped. The number of *E. macquarii* and *C. longicollis* trapped at these sites were significantly different ($\chi^2 = 220.96$, 6 df, $p < 0.001$).

C3.4.2 Measurement Correlations

Three carapacial measurements (CL, CCL, CW) and four plastral measurements (PWa, PWp, PLmax, PLmin) were taken (Section B.2.2), except when time was limited by high captures. Combining all sites for *C. longicollis* (n = 121), correlation is ≥ 0.90 for all linear measurements, with highest correlations (0.98-1.00) for the four length measurements. Within a single site (Breakfast Creek, n = 43), some width measurements (pWa, CW) also show high correlations (0.97-1.00) with length measurements. Mass (g) correlations with linear measurements are variable (0.89-0.97), but best with length measurements (CL, PLmax, PLmin; 0.97). Mass (g) correlations with linear measurements are over a smaller (0.91-0.96) range when analysis is limited to one site (Breakfast Creek).

Combining all sites for which plastron measurements are available for *E. macquarii* (n = 32 turtles), most measurement correlations are between 0.97 and 1.00, (except PWp vs PLmin/max). The average ratio of CL:PLmax for adult *E. macquarii* is 1.20 (SE 0.007, n = 26) and this can be used as a rough conversion factor between the two parameters. Again, mass (g) correlations with linear measurements are poorer (0.91-0.96). In a comparison between male (n = 47 total, 15 with plastral measurements) and female (n = 34 total, 9 with plastral measurements) *E. macquarii*, correlations are highest (0.98-1.00) for CCL (vs CL, PLmax, PLmin), and PLmax vs PLmin for both sexes. For females only, additional correlations in this high range are CL vs PLmin, and CW vs PWa. Mass (g) correlations with linear measurements improve by analysing the sexes separately, with high (0.98-0.99) correlation between mass and PLmax and PLmin for both sexes and high (1.00) correlation between CCL and mass for females (0.95 for males). CL to mass correlations were 0.97 and 0.96 for females and males respectively.

C3.4.3 Size Distribution

The size distribution (CL) of *C. longicollis* and *E. macquarii* varied over sites (Figure C3.1). For *C. longicollis*, four sites (Breakfast Creek, Busby's Lagoon, Lane Cove River, Yeramba Lagoon) had sufficient captures ($n > 10$) for statistical comparison of size classes. A χ^2 test is not possible using three size classes (juveniles 51-150mm, small adults 151-200mm, large adults >200mm), but using two size classes (juveniles <151mm, adults >150mm) there is a significant difference in turtle size distribution between sites ($\chi^2 = 28.3$, 3 df, $p < 0.001$). Of the sites ($n = 9$) where more than two *C. longicollis* were trapped, individuals with CL = 151-200 mm had the highest relative frequency except at Harris Creek (Hammondville) and Breakfast Creek. At Harris Creek (Hammondville) there were equal frequencies of large juveniles (101-150 mm, $n = 3$) and small adults (151-200 mm, $n = 3$). At Breakfast Creek, large juveniles predominated (101-150 mm, $n = 25$), and this is the only site where a *C. longicollis* of < 100 mm was trapped.

For *E. macquarii*, two sites (Busby's Lagoon, Kensington Pond) had samples sufficient for statistical analysis ($n > 10$). Using the same three size classes as for *C. longicollis*, there is no significant difference ($\chi^2 = 3.601$, 2 df, $p = 0.165$) in the distribution of sizes between these two sites. At all five sites where more than two *E. macquarii* were trapped, small adults (151-200 mm) predominate. Individuals less than 100 mm were captured at four of the seven sites where *E. macquarii* were found, accounting for the only capture at Lake Gillawarna and 9% ($n = 11/123$) of the captures at Busby's Lagoon.

At one site (Busby's Lagoon) there were samples of more than 10 individuals of both species. Using three size categories, a third of the six cells have frequencies less than five, so χ^2 values are suspect. However, the χ^2 value for this (2.914, 2 df) is not significant ($p = 0.233$). For both species small adults (151-200 mm) predominate.

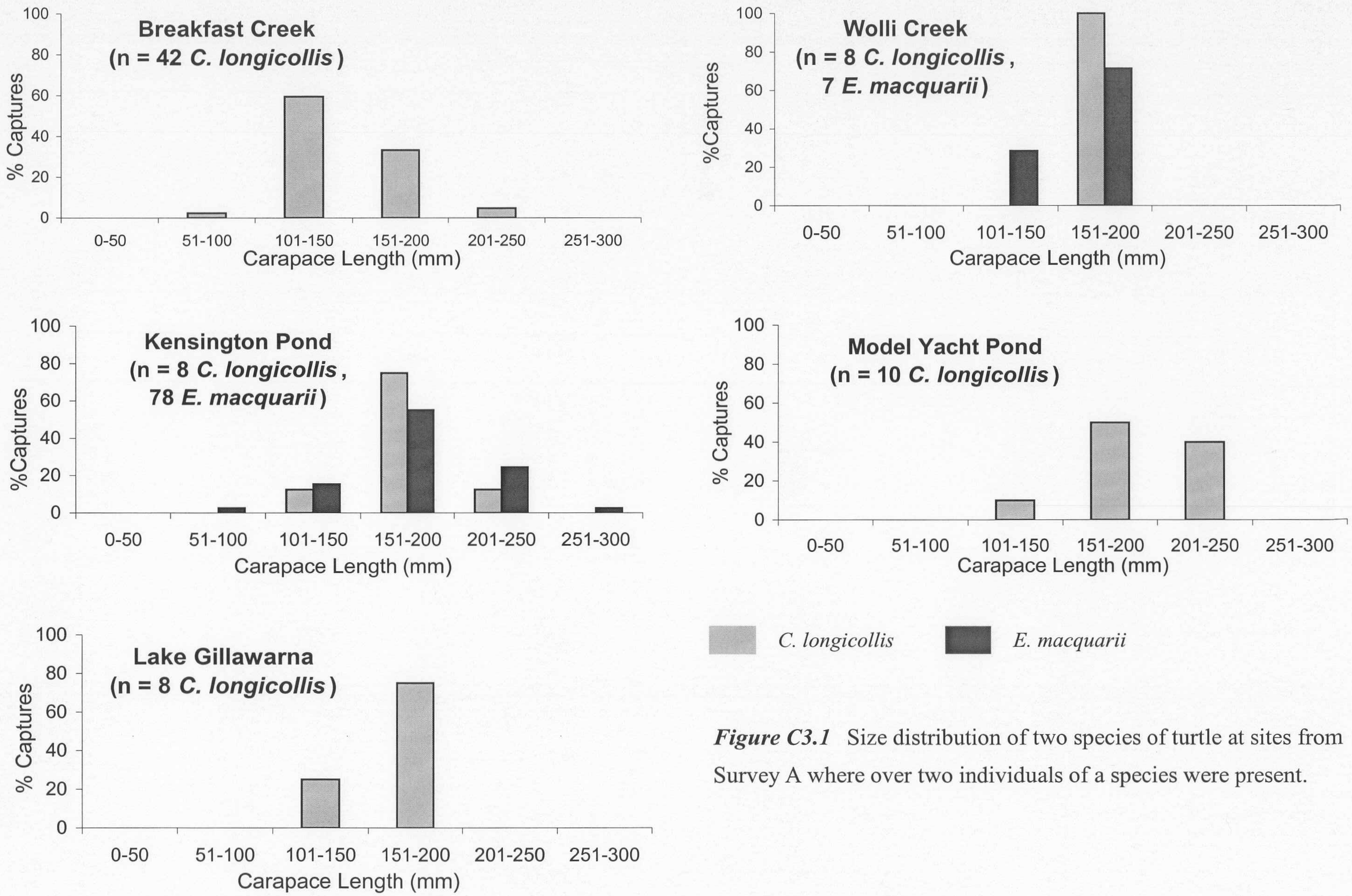


Figure C3.1 Size distribution of two species of turtle at sites from Survey A where over two individuals of a species were present.

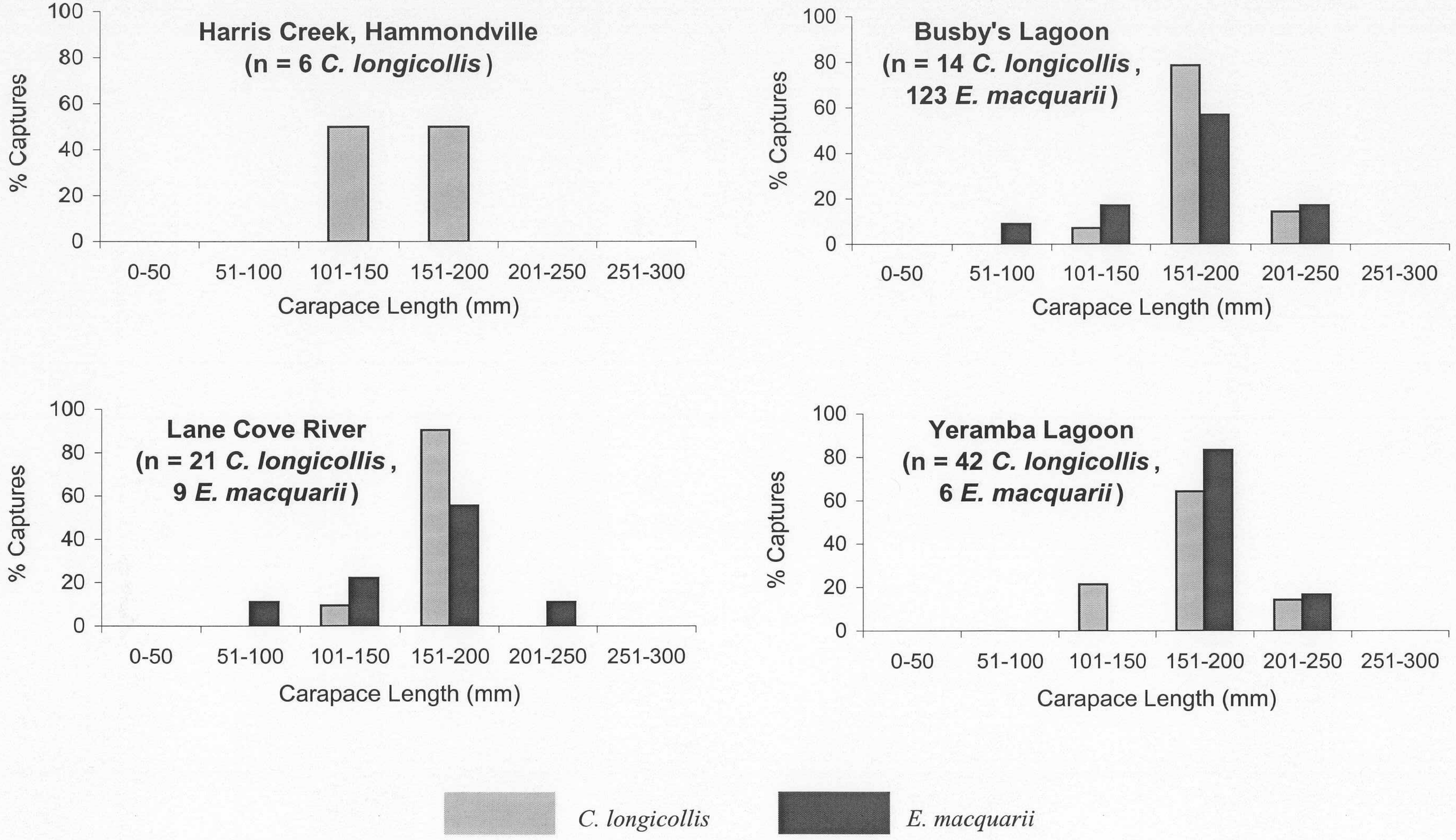


Figure C3.1 cont. Size distribution of two species of turtle at sites from Survey B (Harris Ck and Busby's Lagoon) and combined captures from Survey A + B (Lane Cove River and Yeramba Lagoon) where over two individuals of a species were present.

C3.4.4 Growth Curves & Body Condition

Carapace length (mm) to mass (g) of turtles is compared at the five sites with the largest turtle captures (Breakfast Creek, Yeramba Lagoon, Lane Cove River, Kensington Pond, Busby's Lagoon) (Figure C3.2).

For *C. longicollis*, mass increases in slight negative allometry with CL for Breakfast Creek, Kensington Pond and Busby's Lagoon. However, the relationship is not significantly different from isometry for Lane Cove River or Yeramba Lagoon (Table C3.2). The differences between populations are not simply due to sample size limitations as the two largest samples (Breakfast Creek, Yeramba Lagoon) show different relationships. For *E. macquarii*, only Busby's Lagoon showed a significant difference from isometry (Table C3.3).

There is a statistically significant difference between the five *C. longicollis* populations in the slope of the relationship between ln(mass) and ln(CL) (F = 2.902; 4, 117 df; p = 0.025). For *E. macquarii*, the relationship between ln(mass) and ln(CL) for all four populations falls between those for the two extreme *C. longicollis* populations (Busby's Lagoon, Yeramba Lagoon). There is no significant difference among the four *E. macquarii* populations in the slope of this relationship (F = 0.347; 3, 210 df; p = 0.791), although there is a difference in the intercept of the relationship (F = 4.395; 3, 213 df; p = 0.005).

The difference in mass between different populations of *C. longicollis* is most marked at smaller sizes. At CL = 100 mm the relationship for Yeramba Lagoon *C. longicollis* predicts a mass of 109 g, while the prediction is 1.24x this at Busby's Lagoon (135 g). At CL = 150 mm, a similar mass is predicted for both sites (Yeramba Lagoon 371 g, Busby's Lagoon 384 g). By 200 mm, the mass predicted for Yeramba Lagoon is 1.10 x that of Busby's Lagoon (884 g vs 805 g).

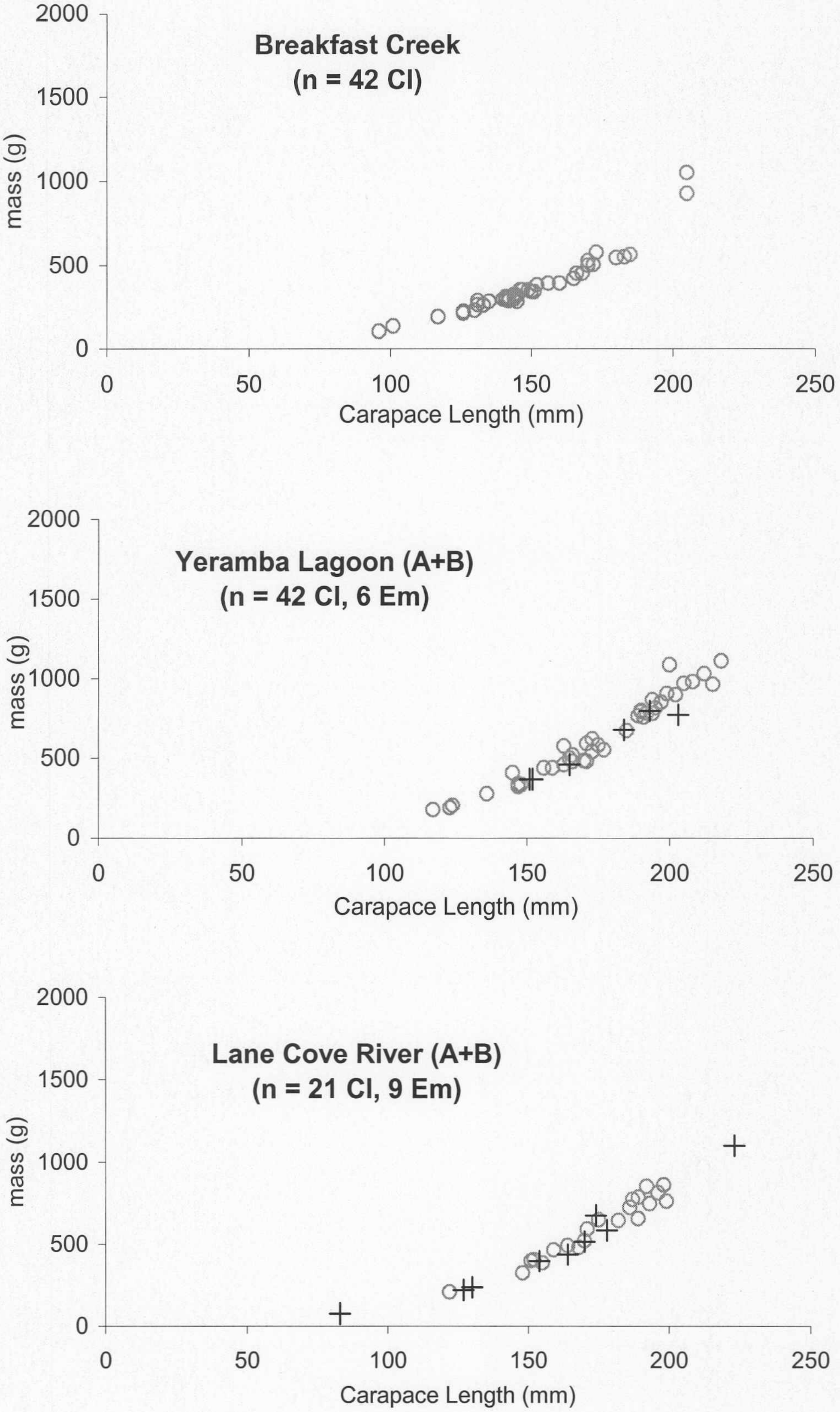
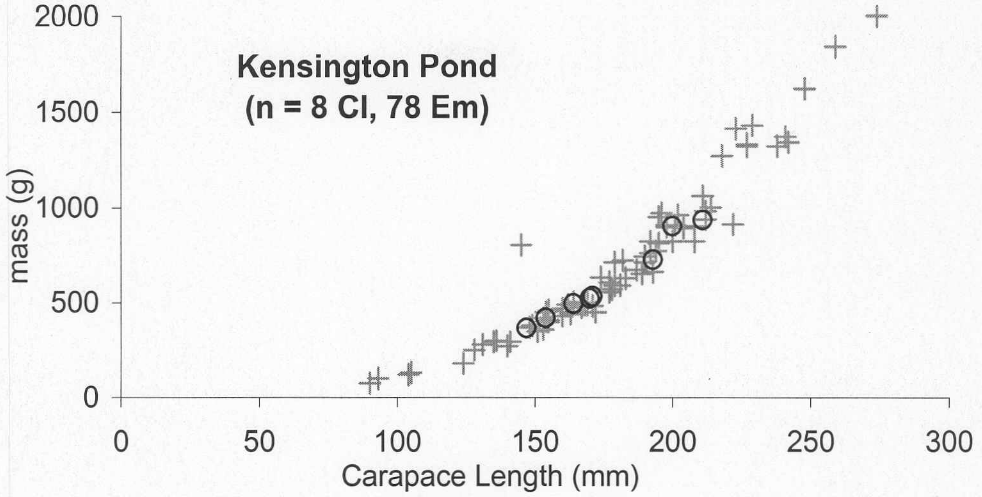


Figure C3.2 Length to mass relationship of turtles from sites with the highest captures. Grey circles = *C. longicollis* (Cl). Black crosses = *E. macquarii* (Em).



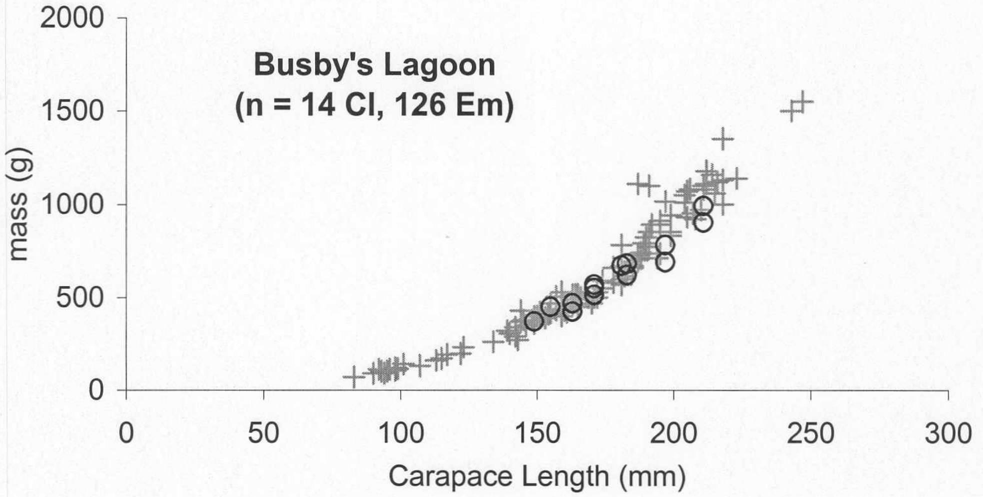


Figure C3.2 cont. Length to mass relationship of turtles from sites with the highest captures. Black circles = *C. longicollis* (Cl). Grey crosses = E. macquarii (Em).

At Busby’s Lagoon, the relationship between ln(mass) and ln(CL) for *E. macquarii* males ($n = 66$) is ln(mass) = 2.715 x ln(CL) – 7.651 with slight negative allometry (SE of slope = 0.092), and for females ($n = 39$) is ln(mass) = 3.089 x ln(CL) – 9.525 with the relationship not significantly different from isometry (SE of slope = 0.128). The slopes of these two relationships are significantly different ($F = 6.018$; 1, 101 df; $p = 0.016$).

Site	n	a	b	SE	r^2	Allometry
Lane Cove River	21	2.940	-8.808	0.128	0.965	0
Breakfast Creek	42	2.726	-7.791	0.074	0.971	–
Kensington Pond	8	2.665	-7.399	0.126	0.987	–
Yeramba Lagoon	42	3.021	-9.221	0.078	0.974	0
Busby’s Lagoon	14	2.580	-6.978	0.171	0.950	–

Table C3.2 Relationship between ln(mass) and ln(CL) for *C. longicollis* at five sites. Values a and b solve the equation: ln(mass) = a x ln(CL) +b.
n = sample size; SE = standard error of a; 0 = isometry; – = negative allometry.

Site	n	a	b	SE	r^2	Allometry
Lane Cove River	9	2.794	-8.093	0.109	0.990	0
Kensington Pond	77	2.915	-8.699	0.048	0.980	0
Yeramba Lagoon	6	2.802	-8.149	0.245	0.970	0
Busby’s Lagoon	126	2.909	-8.624	0.036	0.981	–

Table C3.3 Relationship between ln(mass) and ln(CL) for *E. macquarii* at four sites. Values a and b solve the equation: ln(mass) = a x ln(CL) +b.
n = sample size; SE = standard error of a; 0 = isometry; – = negative allometry.

Pooling data for all sites, the relationship between ln(mass)and ln(CL) for *C. longicollis* is ln(mass) = 2.931 x ln(CL) – 8.783. The standard error of the allometric coefficient (2.931) is 0.043. This relationship can be used to produce a mass:length ratio $[(\ln(\text{mass}) + 8.783)/\ln(\text{CL})]$ that is independent of carapace length. A ratio of greater than 2.931 is heavier than average, while a ratio of less than 2.931 is lighter than average. This ratio is used as a measure of body condition for *C. longicollis* in subsequent chapters.

The equivalent relationship for pooled *E. macquarii* was $\ln(\text{mass}) = 2.891 \times \ln(\text{CL}) - 8.552$ (SE of the allometric coefficient = 0.028), giving a mass:length ratio for this species of $(\ln(\text{mass}) + 8.552)/\ln(\text{CL})$ and a mean ratio of 2.891. This ratio is used as a measure of body condition for *E. macquarii* in Section E.

C3.5 Turtle Health

Most captured turtles had no outward appearance of ill-health. Severe injuries (missing limbs, broken shell) were found on apparently healthy turtles, but the prevalence was low (0-2 turtles per site). By far the highest rate of damage was to the plastron at Kensington Pond. Chippping of the marginal scutes of the carapace, or pitting of the surface of the carapace or plastron was not quantified, but was not uncommon, and was the only other outwards sign of damage.

The largest population of *C. longicollis* was at Breakfast Creek. These turtles looked extremely healthy, with many shedding scutes, or having recently shed (as evidenced by no algal growth or staining on shell). This contrasts with turtles at Yeramba Lagoon, the second largest *C. longicollis* population, most of which were heavily covered with algae and had darkly stained plastra.

The largest populations of *E. macquarii* were at Centennial Park (Busby’s Lagoon, Kensington Pond). At Kensington Pond, 14% ($n = 11/81$) of turtles had surface plastral damage, as indicated by the presence of discoloured or abraded patches (Figure C3.3). These turtles were aggressive, and were making uncharacteristic ‘hissing’ sounds. There were no other outward signs of ill-health and the population was large and encompassed a large size range. Many turtles in the nearby Busby’s Lagoon were covered in a brown filamentous alga, but in contrast to the Kensington Pond turtles, they showed virtually no sign of plastral damage and displayed little ‘hissing’ behaviour.

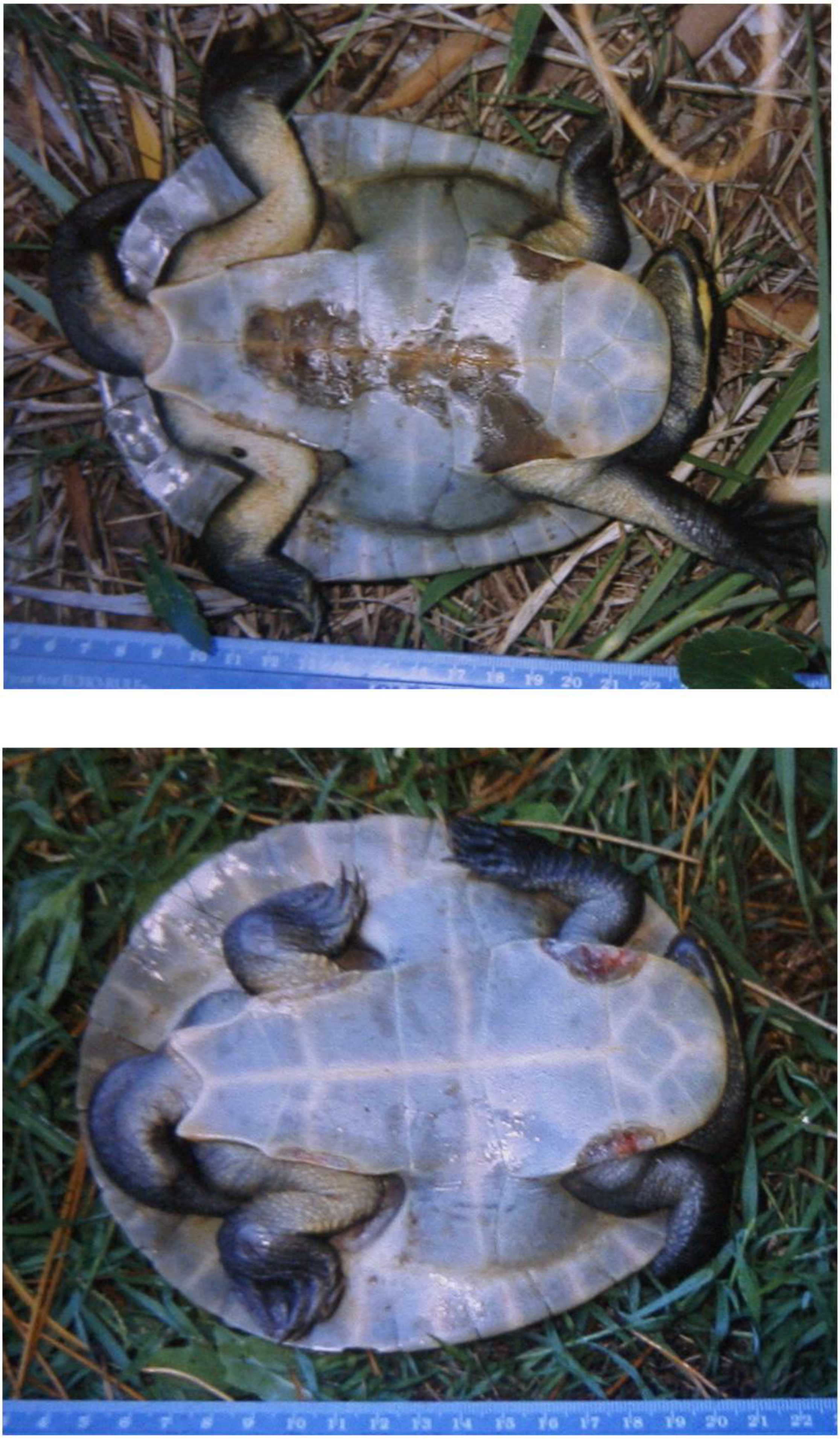


Figure C3.3 Two adult male *E. macquarii* from Kensington Pond showing plastral damage. Similar damage was seen in 14% (n = 11/81) of *E. macquarii* at this site.

CHAPTER C4: SURVEY DISCUSSION

C4.1 Trapping

Differences in capture method, use of different or no bait in traps, position of nets in the water, weather, and water temperature can all affect the size, sex and species of turtles caught in traps (Ream & Ream 1966, Parmenter 1976, Harless & Morlock 1979), including fyke nets (Demuth & Buhlmann 1997). Hoop nets favour *E. macquarii* over *C. longicollis* (Chessman 1988b), although baited hoop traps provide unbiased (size or sex) captures of *E. krefftii* (Georges 1985). Assumptions regarding absolute population characteristics based on trap captures may be invalid, but comparisons among populations using the same trapping regime are justified. The presence of a conspecific turtle in a trap may also affect further captures of that species (Frazer *et al.* 1990), but this is not the case for *C. longicollis* with either conspecific turtles or eels (*Anguilla* spp.) already in traps (Dalem 1988). Eel (*Anguilla* spp.) captures at all survey sites (n = 21) showed nets to be functional.

Up to 24 turtles (23 *E. macquarii* CL = 92-223 mm + 1 *C. longicollis*, Busby's Lagoon) were caught in an individual fyke net, which is more than in other studies (14 turtles, Georges 1982a). Despite sometimes crowded nets and a total of 184 survey captures, only one turtle drowned (*C. longicollis*, LCR midstream). This compares to 21 months of trapping in Victoria, when two *C. longicollis* drowned (n = 272 captures; Beumer *et al.* 1981). No *E. macquarii* died in traps during the survey. The capture of two birds (one drowned) is comparable to the results of nearly 700 trapping days over 21 months in Victoria, where besides fish and turtles, two Eurasian coots and a Pacific black duck (drowned) were captured (Beumer *et al.* 1981).

C4.1.1 Activity

Daytime water temperatures were above 20 ºC at all survey sites, except the Harris Creek sites (Hammondville and Holsworthy) where they were between 16 ºC and 19 ºC. Both *C. longicollis* (Drummond 1967, Parmenter 1976, Chessman 1988a) and *E. macquarii* (Legler 1985) can be active in water at temperatures as low as 8 ºC. In the Murray Valley, however, *C. longicollis*, but not *E. macquarii*, were trapped at water temperatures below 15 ºC and *C. longicollis* were trapped more commonly than *E. macquarii* at 15-20 ºC (Chessman 1988a). Thus, it is possible that, if *E. macquarii* were present at the Harris Creek sites, their capture rate may have been affected by low water temperature. At other sites, diurnal water temperatures were well within activity ranges for both species.

C4.1.2 Baiting

While captures in unbaited nets reflect general activity, captures in baited nets may also reflect specific foraging activity. For the baiting test to be valid, water temperatures must be high enough for feeding activity. The cut off for feeding activity may vary between seasons, with *C. longicollis* caught in baited nets at water temperatures as low as 11.9 ºC in spring but 12.8 ºC in autumn in the Murray Valley (Chessman 1988a). The respective temperatures for *E. macquarii* are 16.3 ºC and 16.9 ºC, putting all survey sites in the feeding range for both species, except the Harris Creek sites (Hammondville and Holsworthy) which are borderline for *E. macquarii*. It must also be recognised that there may be variation between drainages, as *E. macquarii dharra* (Macleay drainage; Cann 1998) can feed all year long in water below 8ºC (Legler 1985).

In Survey B, there was no significant difference in the number of turtles captured in baited and unbaited nets, except for nets within Yeramba Lagoon where captures were higher in baited nets (Section C3.3.3). The positive effect of baiting on captures at Yeramba Lagoon may indicate low food availability within that system. Although baiting fyke nets may increase captures at certain sites, captures will not reflect comparative active turtle numbers over sites if food availabilities vary, so unbaited fyke nets were used in the Immune (Section D) and Reproduction (Section E) studies.

C4.2 Comparison of Turtles over Sites

C4.2.1 Species

The abundance of turtles in the densely populated urban environment studied here varied over sites. Only 0-2 *C. longicollis* were captured at 10 of the survey sites. Captures at the remaining 11 sites were higher, most notably at Breakfast Creek (n = 44). The absence of many large populations of *C. longicollis* within highly urbanised waterways in Sydney contrasts with that found in farm dams in NW Sydney, even though many of those animals die on roadways (Steven Emerton pers. comm.).

Conclusions regarding the effect of anthropogenic factors on capture results is difficult, as natural variations in vertebrate population size can be up to three orders of magnitude, and overall trends are only visible with examination of long-term historical data (Gibbons 1997, Alford *et al*. 2001). Unfortunately, there are virtually no historical data for Sydney populations with which present results can be compared and population trends gauged, although *C. longicollis* is considered common in most freshwaters in the Sydney area (Griffiths 1997), and *C. longicollis* and *E. macquarii* are recorded from Centennial Park (Stephenson 1986). Breakfast Creek was surveyed six times over 26 months (Section D3.1.4) and showed no apparent population decline, but it remains unknown if Sydney turtle populations remain stable over periods greater than this.

Smaller populations may be resulting from non-optimal natural factors such as low levels of sunlight leading to lower water temperatures and basking limitations (Cann 1998; Devlin's Creek, Prospect Creek, variable at Manly Creek, LCR upstream, Blue Gum Creek), rocky substrate with few aquatic plants (Devlin's Creek, variable at Orphan School Creek, Blue Gum Creek), and a tidal nature (Cann 1998; Harris Creek (Hammondville), Blue Gum Creek). Natural population fluctuations, which may include local extinctions, may not recover in urban settings in the way that they would in undisturbed habitat. For instance, movement of a highly migratory species like *C. longicollis* is greatly restricted in a heavily urbanised environment such as Sydney, with impassable barriers such as fences and buildings (Shea *et al*. 2002), and negotiable but dangerous constructions such as road networks (Ehmann & Cogger 1985). This means that declining or extinct local populations may not be replenished by others within the metapopulation.

Emydura macquarii is widespread in Sydney, being found from the far southeast (Section E) to the far northwest (captured during preliminary trapping at Riverstone STP set, Section D). Throughout Sydney, *C. longicollis* is present at all sites where *E. macquarii* resides, indicating that the latter does not displace the former in urban environments. At the Survey sites where the two species co-habit (7 sites, combining surveys A & B for Yeramba Lagoon and LCR sites), *C. longicollis* captures were larger, or in one case similar (Wolli Creek), apart from the dramatic exceptions in Busby's Lagoon and Kensington Pond at Centennial Park (128 and 81 *E. macquarii*, and 14 and 8 *C. longicollis* respectively). Historically, *E. macquarii* have only been reported from Centennial Park (Roy Mackay pers. comm.) and two other unidentified Sydney parks (Stephenson 1986).

Large flowing rivers have traditionally been considered the normal habitat preference for *E. macquarii* (Section A.1.4.1). Over all three studies (Sections C, D, E) *E. macquarii* was caught in a variety of habitats, including non-flowing waterbodies (medium-sized and large lagoons), and intermittently-flowing smaller waterways (medium-sized creeks) in addition to the expected large rivers. After introduction into the Sydney area, their reluctance for terrestrial migration (Legler & Georges 1993), coupled with the impediments of urban constructions, may have prevented the migration of those not in large rivers to these preferred habitats. Alternative possiblilities are that *E. macquarii* may not always show a preference for large river habitats (Michael Thompson pers. comm.), or that many urban rivers do not provide the preferred habitat features present in large rivers in non-urban parts of the distribution of the species where previous studies have been undertaken. This is supported by the large *E. macquarii* populations in medium-sized and large lagoons (Centennial Park, Table C3.1; Botany Swamps and Bicentennial Park, Table E3.1), compared to the small populations in the large rivers of Sydney's northwest (pers. ob., South Creek and Eastern Creek, Riverstone STP set, Section D).

Stephenson (1986) found many turtles with tethering holes in the shell (used to secure pet turtles), but only one was found during this survey (*C. longicollis*, LCR downstream). The keeping of pet turtles was generally illegal between 1974 and 1997 (Jeff Hardy pers. comm.). The lack of tethering holes in this survey may reflect a decrease in release of pet turtles into public waterways over this period, and an increase in the progeny of previously released turtles, rendering greater likelihood of exposure to environmental pollutants of turtles from embryo to death.

C4.2.2 Translocated Turtle Species

No exotic turtle species were caught at any location. *Trachemys scripta elegans* was not captured at any Survey site, at any Immune Study site (Section D), or any Reproduction Study site (Section E), despite populations having been reported within Sydney (Griffiths 1997), including all six of the Survey B sites (Anthony Stimson pers. comm., Steven Weir pers. comm.). Reports of 'hundreds' of *T. s. elegans* at Centennial Park (hearsay) suggests that some sightings may be misidentifications of *E. macquarii*, possibly due to the presence in both species of a facial stripe (Ernst & Barbour 1989) and a passion for basking (Webb 1978, Hammond *et al*. 1988). Trapping for seven days a month over fourteen months in the upper Parramatta River catchment yielded 284 *C. longicollis*, 61 *E. macquarii*, and one *T. s. elegans* in 1997-1998 (Jason Ross pers. comm.). Also, six gravid female *T. s. elegans* were removed from Yeramba Lagoon in 1996, but no further specimens were captured in the subsequent year (Steve Emerton pers. comm.) or during the two visits in this survey. So, although individuals are present, concerns over their prevalence in Sydney waterways seem unfounded or exaggerated at this time.

Other historical comparisons may only be made at Centennial Park. In the 15 years to 1986, *C. longicollis* and *E. macquarii* were the two dominant turtle species at the park, with only occasional captures of other species in this period (2 *C. expansa*, 2 *El. latisternum*, 1 *E. krefftii*, 1 undescribed; Stephenson 1986). This same trend continues today, with other species only represented by three *Elseya latisternum.*

C4.2.3 Centennial Park

This study recorded three species of turtle from Centennial Park (*C. longicollis*, *E. macquarii*, *E. latisternum*), with only the first two species commonly trapped. The presence of additional Australian species such as *C. expansa* (Stephenson 1986) and *Elusor macrurus* (Craig Latta pers. comm.) in the park was not confirmed by this study.

Source of Emydura macquarii *population*

The wide morphological variation in *E. macquarii* at Centennial Park (Section C3.3.1) suggests that this population may be derived from multiple geographical origins, as the coastal *E. macquarii* subspecies all show variation in shell characters (e.g. depth, side profile, colour, degree of striation) and other parameters (e.g. presence/size of chin barbels) (Cann 1998). No one parameter is unique to the subspecies described from the Sydney Basin (*E. m. dharuk*), and a range of characteristics should be noted to aid subspecies identification in the future. The presence of a highly varied population supports the view that *E. macquarii* is an introduction to the park, originating from the release of captive animals, which may have come from multiple geographic locations. It also agrees with the occurrence in the park of species that must have been released (*C. expansa, E. latisternum, E. macrurus*) as they do not occur naturally in or close to the Sydney Basin.

Differentiation of the several geographic forms of *E. macquarii* and *E. krefftii* is currently solely based on morphology. Recent genetic studies (Georges & Adams 1996, Georges *et al*. 2002) using allozyme electrophoresis and DNA sequence data respectively were unable to fully distinguish the populations of *E. macquarii* recognised by Cann (1998), nor were they able to distinguish *E. macquarii* from *E. krefftii* (although this result may have been dependent on the choice of genes in the 2002 study). Consequently, on current knowledge, identification of the origin of *E. macquarii* in the Sydney region must be solely based on morphological criteria. The genetic similarity of the two species may, however, explain the presence of a yellow eye stripe on 10% of *E. macquarii*, due to interbreeding with *E. krefftii*.

Georges and Adams (1996) suggested that the abutting but non-overlapping distributions of the morphologically distinguishable forms of shortneck turtles may reflect genetic assimilation of any straying individuals, and the various populations may be in the process of allopatric speciation (Georges *et al*. 1993). However, the situation in Centennial Park, with likely hybridisation of animals from multiple sources, and no one native form dominating the population, is likely to result in a blurring of morphological boundaries, making it difficult to ever identify the origins of the Centennial Park *E. macquarii*. Further, it is possible that if the parental stocks were small, there may have been intensive selection for a distinctive morphology, raising the possibility that the “Sydney subspecies” may have had a hybrid origin. One possible way of identifying whether *E. m. dharuk* is naturally occurring in the Sydney region might be to examine whether it occurs in Aboriginal middens that are older than European settlement (Ken Griffiths pers. comm.)

Source of Chelodina longicollis *population*

The Centennial Park population of *C. longicollis* may also have been affected by introduction of individuals from differing geographic origins to the native population. *Chelodina longicollis* has been translocated to new waterways in Victoria (Beck

1991). The *C. longicollis* trapped in Centennial Park during the present survey showed variation in carapace shape that covers morphology previously attributed to inland and coastal populations (Cann 1998, Beck 1991). However, *C. longicollis* observed in Centennial Park over 15 years to 1986, were of the eastern form (Stephenson 1986). This might suggest that recent releases of inland *C. longicollis* have occurred.

As with the difficulty in genetically distinguishing the populations of *E. macquarii*, Georges *et al*. (2002) were unable to distinguish *C. longicollis* samples from inland and coastal sites, and hence the same problem exists for this species in identifying the original parental sources.

Why does Centennial Park have large populations of E. macquarii*?*

Although *C. longicollis* and *E. macquarii* are sympatric over most of their range (Cogger 1992), the original swamps and the current lagoons of Centennial Park are classic *C. longicollis* habitat, being shallow, remote from rivers, and non-flowing (Chessman 1988b), and *C. longicollis* is considered the only species native to the park (Stephenson 1986). In contrast, *E. macquarii* is rarely found in water bodies less than 2 m deep and prefer permanent, clear, flowing waters, quite unlike those found in the park (Chessman 1988b). It is surprising therefore, that the largest *E. macquarii* populations found in Sydney were at this site, suggesting that a competitive advantage is given by some other factor. Many people feed the large water bird populations in the park (pers. ob.), and oil, manure and fertilisers enter the park's waterbodies in runoff from road, showground, and grassed areas (Jonathan Cartmill, pers. comm.), so there is a huge input of nutrients into the system. *E. macquarii* are not limited by the carnivory of *C. longicollis*, being attracted to (Georges 1985) and consuming (Stephenson 1986) bread, as well as algae (Spencer *et al*. 1998) and macrophytes (Chessman 1986), so their competitive advantage in this highly productive environment could be omnivory. Even in nutrient-poor environments it is thought that the *Emydura* can thrive due to this general omnivorous diet (Georges 1982b, 1985).

Absence of predation has been thought a major factor in the propagation of large turtle populations (Georges 1982a), and a reason for the relative prevalence of juveniles in the Centennial Park population of *E. macquarii* may be that several of the lagoons have islands which protect eggs, and more importantly (Spencer 2001), nesting females, from predators such as foxes (*Vulpes vulpes*), which can destroy over 90% of turtle nests laid (Parmenter 1976, Thompson 1983b, Spencer 2001). Foxes are common throughout Sydney (Andrew Glover pers. comm.) and are present in the park (Jonathan Cartmill pers. comm.). Also, predation pressures on hatchlings are greatly reduced by the time they reach plastron lengths of 100 mm (*E. macquarii*, 2 years old; Spencer 2002), so if hatchlings are growing rapidly due to high levels of resources their survival may be increased due to fewer months of high level predation.

In the Murray Valley, *C. longicollis* is uncommon in the stable water bodies where *Emydura* are present, preferring smaller lagoons (Chessman 1988b), and this situation is reflected within the confines of Centennial Park. In the 15 years to 1986, *C. longicollis* was most common in the shallow swampy areas, and was the only turtle species in Model Yacht Pond (Stephenson 1986). In this study, again, *C. longicollis* was the only turtle species captured in Model Yacht Pond, which contrasts with the large lagoons which are dominated by *E. macquarii*. The smaller lagoons may provide a less competitive environment for maintaining the *C. longicollis* metapopulation of the park.

Emydura macquarii of all sizes bask atmospherically in all seasons, usually at air temperatures upwards of 25ºC (Chessman 1987). In contrast to *E. macquarii* and *El. latisternum*, *C. longicollis* bask only occasionally (Webb 1978, Ernst & Barbour 1989). The presence of basking perches safe from eutherian predators may be an advantage at Centennial Park, as they were rarely present at other survey sites. During appropriate conditions, however, basking sites are crowded and optimum basking may be prevented.

C4.2.4 Measurement Correlations

Of shell measurements (Section C3.4.2), CL was chosen as the preferred measure of turtle size for subsequent studies due to its high correlation with other linear measurements, its ease of measurement compared to a curved measurement (CCL), and its common use as a descriptor of size in other studies (e.g., Parmenter 1976, Chessman 1978, Kennett 1994, Kennett & Georges 1990). Plastron length is also commonly used as a size descriptor in turtle studies (e.g., Hart 1983, Thompson 1983, Spencer 2002), and, for comparison, the conversion relationship CL:PLmax = 1.20 (adult *E. macquarii*) can be used to estimate PL from CL in this study. Mass is an important measure, but correlations are poorer, as animal weights will vary with extraneous factors such as algae on the shell, stomach contents, and water in the bladder and cloaca, as well as the ‘domedness’ of females (Section C3.4.2).

Age:size relationships are inconsistent for adult turtles due to the irregular growth of mature individuals (Kennett 1996, Spencer 2002), yet length remains the best indicator of comparative age in this study. For pollution studies, size (length or weight) may even be as important as age in representing assimilation, and hence uptake of contaminant-carrying dietary items.

C4.2.5 Size

Only one *C. longicollis* of CL < 100 mm was caught during the survey (96 mm, Breakfast Creek), suggesting that this size range is not well assessed by fyke net trapping. Although it is normal for adults to be more common in populations (Georges 1985), it is likely that the survey results reflect an extreme capture bias, as CL < 100 mm is the only size range missing in the larger populations. The result is not surprising, however, as hatchlings are cryptic (Cann 1998), may spend their first few years secreted in macrophytes (Anonymous 1974), and are rarely seen in nature until they have reached approximately 100 mm carapace length (estimated as 3-years-old; Beck 1991). With minimal captures of small juveniles, it is hard to gauge ongoing hatchling recruitment to the population. Freshwater turtles are long-lived (Gibbons 1987), so in populations where mainly larger adults were caught there may not be adequate juvenile recruitment for the continuation of the population.

In the smaller populations in this study, captured *C. longicollis* were usually adults (CL > 150 mm), but in the larger populations large juveniles (CL = 100-150 mm) were common, confirming that turtles of this size are catchable. Hence, absence of captures probably represents absence of individuals, but the possibility that the lack of juvenile captures reflects a true lack of juvenile recruitment within rapidly diminishing populations must also be considered. Population structures are highly variable, and age structures have not been determined for any Australian species (Georges *et al.* 1993), so juvenile numbers may in reality be low in these long-lived vertebrates. However, the fact that small juveniles are rarely caught, even in populations with numerous large juveniles (e.g. Breakfast Creek, this study; Spencer 2002) makes the latter explanation highly unlikely.

The largest *C. longicollis* captured in this survey were CL = 217 and 218 mm (Model Yacht Pond and Yeramba Lagoon, both 1110 g), which is smaller than those in the Murray Valley, which reach 254 mm (Goode 1967). The maximum mass is also lower, with those in the Murray reaching 1600 g (Chessman 1984b). Elsewhere in Australia, the maximum is CL = 238 mm and mass of 1470 g (Cann 1998). Although the lower mass of Sydney *C. longicollis* may reflect increased competition or reduced resources, it may also reflect different genetic populations, with some populations, such as those from Gippsland, generally smaller than others (Goode 1967).

The largest *C. longicollis* from Busby's Lagoon and Kensington Pond were both CL = 211 mm. As this approaches the maximum size found over the survey, it suggests that coexistence with *E. macquarii* at these sites does not affect maximum attainable size, although conclusions are confounded by the possibility that these turtles were released into the system as adults.

The largest *E. macquarii* were in the Centennial Park populations (274 mm male, 259 mm female) and are smaller than those in the Murray Valley which range up to 2500 g (Chessman 1984b), or over 4 kg (Michael Thompson pers. comm), and smaller than those previously found in the park, which range to CL = 385 mm (Stephenson 1986). Growth rates may be reduced in these large populations, or animals may not live as long as in natural populations, leading to smaller maximum size. Alternatively, early onset of maturity (see below) may affect maximum size, as there is reduced growth following sexual maturity (Kennett 1994, Spencer 2002).

There was a significant difference between the distribution of juvenile (≤ 150 mm) and adult (>150 mm) *C. longicollis* over four well-sampled sites, with adults predominating at all but Breakfast Creek. A similar predominance of adults was seen at other sites with smaller samples not amenable to statistical analysis. In contrast, there was no difference in size distribution of *E. macquarii* at the two sites where comparison was possible, with small adults (151-200 mm) dominating at both; small numbers of small juveniles (< 100 mm) were captured at four of the seven *E. macquarii* sites. At previously studied mainland sites, adult *E. macquarii* are always in equal or greater numbers than juveniles (reviewed in Georges 1985).

C4.2.6 Growth Curves & Body Condition

Size measurements from turtle recapture studies can be fitted to models which can then produce age-size curves. However, growth models, and thus estimates of age, are severely distorted if growth data from all size classes are not included in the analyses (Spencer 2002). As *C. longicollis* and *E. macquarii* individuals < 100 mm are hard to capture, the following results must be interpreted with caution.

For *C. longicollis*, carapace length (mm) to mass (g) ratio of turtles showed negative allometry at Breakfast Creek, Kensington Pond, and Busby's Lagoon. At the remaining two sites, no statistically significant departure from isometry was found, although at Lane Cove River, the trend was towards negative allometry, and the lack of significance may be due to small sample size and large standard error. Only at Yeramba Lagoon was the allometric coefficient (slope) more than 3.0, and then not significantly so. This result was not a statistical artefact, as the sample was large. When data were pooled across sites, the allometric coefficient was 2.931, again slightly, but not significantly, below isometry (3.0). For the four populations of *E. macquarii*, the allometric coefficient in each case was below 3.0, although only for Busby's Lagoon was the value significantly different from isometry. However, the coefficient for two of the remaining populations was even further below 3.0, and the small samples and consequently the large standard error may have affected this result. The remaining population (Kensington Ponds) had a large sample, and hence the result is likely to be real, but the coefficient (2.915) was only slightly greater than for Busby's Lagoon. At none of the four sites was the allometric coefficient 3.0 or greater, and when data were pooled across sites, the allometric coefficient (2.891) was significantly less than 3.0.

Together, these data suggest that the general trend is for slight negative allometry or isometry in the relationship between mass and carapace length, and that positive allometry should be considered as a deviation from normality. The trend towards heavy animals at apparently less productive sites (e.g. Yeramba Lagoon), and lighter animals at more productive sites (Breakfast Creek, Kensington Pond, Busby's Lagoon), may mean that slower growing animals have more muscle (heavier) and less fat (lighter), or have greater calcification of the shell (Section D4.2). Mature adult chelids show irregular growth (Parmenter 1976, Chessman 1978, Bury 1979, Georges 1982a), and animals of the same length will be younger at productive sites than at less productive sites, if growth is faster overall at productive sites. Also, due to the varying shapes of the carapace of the *E. macquarii* subspecies (Cann 1998), a mixed population will show greater mass variation over carapace length.

The slope of the relationship between ln(mass) and ln(CL) is different between the five *C. longicollis* populations analysed (Section C3.3.4), indicating body condition varies over sites. For *E. macquarii* populations (n = 4), there was no significant difference in the slope of this relationship, and the relationships were encompassed by the outermost *C. longicollis* populations (Busby's Lagoon, Yeramba Lagoon). There was, however, a significant difference in the intercept of the relationship for *E. macquarii* (Section C3.3.4), with Kensington Pond and Busby's lagoon turtles at larger sizes lighter than Yeramba Lagoon and Lane Cove River turtles of the same length. Stomach flushing of turtles from different sites could be used to see if growth parameters were related to amount and type of food, and if this varied between the two species. Other factors (not assessed) which will affect weight are shell thickness, the amount of food, water and faeces held within the gastrointestinal tract and bladder (Jacobson *et al*. 1993), and the amount of shell algae.

The difference in mass between different populations is most marked at smaller sizes (Section C3.4.4), although more comprehensive trapping would be required to confirm this relationship due to the low captures of juvenile turtles (Spencer 2002). The fact that the turtles at Yeramba Lagoon are comparatively lighter when juveniles, have few large juveniles, don't shed very frequently (Section C3.5), prefer baited nets, yet have the second largest *C. longicollis* population, may indicate a once thriving but now dwindling, resource-poor population.

The relationship between ln(mass) and ln(CL) is significantly different for male (slight negative allometry) and female (isometry) *E. macquarii* (Busby's Lagoon). Although the rate of growth of adults is not correlated with or sex (or size) (*C.*

longicollis; Kennett & Georges 1990), the difference between the sexes is not surprising as Australian chelid females tend to have more voluminous shells than males (Legler & Georges 1993), and it is likely that the difference will apply to *C. longicollis* as well. Mass:length will also vary between gravid and non-gravid females (Jacobson *et al.* 1993). If the male:female:gravid female ratio is different over sites, this may explain differences among populations in the mass/length relationship. The low capture rates at some sites, and the lack of sexing of *C. longicollis* in Survey A, mean this cannot be assessed for these populations. There have been few other studies of sexual dimorphism in mass:length ratios in chelids, and those few studies use a variety of methods that make direct comparisons difficult. In a population of *E. m. krefftii* from Queensland, females have significantly broader carapaces when the effects of body mass are removed (Trembath *et al.* 2004), although no statistical comparisons of regression lines of log(carapace length)/log(mass) were presented. In a different population of the same subspecies (Tucker *et al.* 2002), there was no difference between sexes in the relationship between log(mass) and log(carapace length) (incorrectly stated as snout-vent length on some occasions), although no statistical test was presented to support this claim. Kennett and Georges (1990) used the relationship between log(mass) and log(carapace length) as a body condition index to compare *C. longicollis* at different sites near Jervis Bay, but did not present the relationship, and assumed there was no difference between sexes. No study explored the potential for differences between gravid and non-gravid females.

A mass:length relationship independent of CL (Section C3.4.4) will be used as an estimate of ‘body condition’ in the following chapters. This may be confounded by other factors (Section D4.2), and assumptions that the heavier of same-length turtles would have better ‘body condition’, and that this is dependent on food availability (Kennett & Georges 1990), could be false (Section D4.2.1), so future interpretations should be made with caution.

C4.3 Other Turtle Aspects

C4.3.1 Maturity

Adult *C. longicollis* were sexed during Survey B. In adult female *C. longicollis*, the posterior lobe of the plastron is convex, whereas in males it is concave or irregular

(Chessman 1978). Internal examination of the gonads is used for confirming sexual maturity (Chessman 1978, Kennett & Georges 1990), but mature gonads may not correspond to the appearance of external sexual characteristics (Chessman 1978). So although sexing *C. longicollis* on plastron shape is 100% reliable for mature turtles in some populations (Kennett & Georges 1990), it may be especially difficult in other populations (e.g. Thompson 1983a). In this study, the possibility that populations have mixed genetic origin complicates the outcome. In the future, both mature and immature turtles can be sexed using laparoscopy or hormonal assays (Work & Balazs 1999).

Although there will be individual and population variation (Gibbons *et al*. 1981), and possible differences between the sexes (Congdon & Gibbons 1990a), most turtles mature once they attain a certain size rather than a certain age (Gibbons 1982). Sexual maturity of *C. longicollis* occurs from CL = 145 mm for males and between CL = 162 and 168 mm for females at Jervis Bay, NSW (Kennett & Georges 1990). This is comparable to the New England tableland where most male *C. longicollis* mature at a carapace length of 150 mm, after the seventh winter of life, and females at 170 mm after their tenth or eleventh winter (Parmenter 1976), but contrasts to the Murray Valley where male *C. longicollis* mature at CL = 180-190 mm and females at 210 mm (Chessman 1978). In the present study the sexes could be distinguished from CL = 147 mm (the size of the smallest sexable female), although gonadal examination was not carried out to determine that this corresponded to the onset of maturity. Assuming that a similar degree of sexual dimorphism in size at maturity occurs in the Sydney area as in other parts of the range of the species, the Sydney population probably reaches maturity at a similar size or a little smaller than for other east coast and range populations.

The smallest mature *E. macquarii* males (based on tail size) were from the largest populations, with carapace lengths of 128 mm (250g, Kensington Pond) and 139 mm (290g, Busby's Lagoon). No mature males of CL < 140 mm were found at other sites, indicating that size at maturity may vary among populations, and that energy may be able to be invested in reproductive effort at an earlier time (smaller size) if resources are not limiting for growth. This may not be the case for females, as slow growth after maturity (Spencer 2002) means maturity at smaller sizes will be limiting for egg-carrying capacity, which is closely related to maternal body size (Georges 1985).

Widely distributed species like *E. macquarii* show considerable differences in growth rates and maturity over different populations and between the sexes (St Claire *et al.* 1994). Male *E. macquarii* sexual maturity in Sydney falls in the mid-range of that found in populations from other locations. Sydney turtles contrast greatly to those from one study in the Murray Valley where males matured at 200-210 mm (females possibly at 210 mm; Chessman 1978). The age at maturity for Murray Valley animals was estimated at 8 years, but age was determined using growth rings and may not have been accurate due to a lack of previous evaluation of the technique in that population (Spencer 2002). In a second study from the Murray Valley, male *E. macquarii* showed tail elongation from an average PL = 147 mm (maturity at 5-6 years for males and 9-12 years for females; Spencer 2002), which corresponds approximately to CL = 176 (Section C3.4.2). In contrast, *E. krefftii* on Fraser Island mature at smaller sizes than Sydney *E. macquarii*: CL = 110-117 mm for males and CL = 150-155 mm for females (Georges 1985).

A reduction in turtle population density may also lead to an increase in growth rate, and consequent reduction in the age at maturity (Kennett 1994). Although age was unknown, in the productive yet high density populations at Centennial Park, maturity occurs at a smaller size and it is possible that resource availability may also influence time to maturity. Additionally, although ‘body condition’ for juveniles can be high in these large populations, older animals are generally lighter than those found in less productive habitats (Section C4.2.6). This could represent an unusually high survival of juveniles in a protected (Section C4.2.3) and resource-rich environment, with a resultant over-population of adults with high levels of competition.

Sex Ratios

Emydura macquarii from Lake Bonney, South Australia, had a male:female:juvenile ratio of 69:125:11 (n = 205, Thompson 1988). The adult sex ratio was significantly different from unity, yet eggs from the same population produced a 1:1 sex ratio (Thompson 1988), which is usual for chelid turtles with their genotypic sex determination (Georges *et al.* 1993).

The two largest *E. macquarii* populations from the current study showed male:female:juvenile ratios of 66:39:21 (plus 2 unknown; Busby's Lagoon) and 41:30:7 (plus 3 unknown; Kensington Pond). These ratios are unusual, as it is a predominance of females that is more commonly found in natural populations (reviewed in Thompson 1988), although this will vary with season and year of capture (Gibbons 1990). Capture bias has long been considered a risk to skewed sex ratio captures (Ream & Ream 1966), and this cannot be discounted as both these populations show the same trend.

If, however, the capture ratio is a true reflection of the animals present, there are several possible explanations for the greater proportion of males. Centennial Park has resident terrestrial feral predators (foxes and cats), and as females must leave the water to nest they will have increased vulnerabilty to terrestrial predation during this period (Spencer 2001), if their choice of nesting site is not on a protected island. It is doubtful that differential immigration or emigration would be relevant in the restricted area of this suburban park, at least regarding the metapopulation; instead, this and similar isolated urban habitats may limit the natural tendency (Dalem 1998) for high dispersal of small males from large populations. The primary cause, however, of biased adult sex ratios in natural populations is difference in age at maturity between males and females (Gibbons 1990b). If males mature first, as is the case with *E. macquarii* (Spencer 2002), then there will be more mature males than mature females in a population which has a 1:1 sex ratio of hatchlings (Lovich & Gibbons 1990). Counting immature animals above the size of maturity for males as females should remove this problem (Gibbons 1990).

C4.3.2 Turtle Health

Most captured turtles had no outward appearance of ill-health. This may reflect high death rate of infected individuals, selection of resilient individuals, no outward signs of internal disorders, the cryptic nature of sick reptiles (Crawshaw 2000), or simply a healthy population with low levels of disease. The highest level of outwardly visible injury or infection was at Kensington Ponds (below). At other sites, damage to the carapace was most common, followed by limb injury, and damage to the plastron, but these gross injuries had a low prevalence (0-2 turtles/site). Broken shells could be ascribed to vehicular injuries (Ehmann & Cogger 1985), and injured or missing limbs to predation (suspected for *E. macquarii* and *C. longicollis* by Thompson 1983a).

The largest population of *C. longicollis* was at Breakfast Creek, and animals appeared extremely healthy. The prevalence of shedding, or recently shed turtles at Breakfast Creek compared to turtles at other sites in the same period, suggests rapidly growing turtles (Parmenter 1976, Dalem 1998), and hence a ready food supply. The contrast with the lack of shedding on turtles at Yeramba Lagoon, suggests that individuals in this population may not be growing rapidly, possibly due to a poor food supply as suggested by their attraction to baited nets (Section C4.1.2).

Plastral Damage

Surface plastral damage was prevalent (14%; n = 81) in the large *E. macquarii* population at Kensington Pond, but not in other survey populations, including the nearby Busby's Lagoon (520 m away). This demarcation may represent a low level of exchange of individuals between neighbouring *E. macquarii* populations. The reluctance of *E. macquarii* to migrate, even the short distance between waterbodies in the park, was demonstrated during the draining of one of the other large lagoons (Duck Pond, 100 m from Busby's Lagoon) when 64 *E. macquarii* (but no *C. longicollis*) were trapped over 30 hours in the remaining 10 m diameter pool (unreported results, animals not sexed). It is also possible that migrating *E. macquarii* recover in neighbouring ponds once removed from some predisposing condition at Kensington Pond, although no scarring was visible on turtles from Busby's Lagoon.

Very little is known about shell disease in wild turtles (Garner *et al.* 1997), although it can be associated with high mortality rates (*Gopherus agassizii*; Jacobson *et al.* 1994). Shell disease may be associated with infectious (e.g. bacteria, fungi, parasites) or non-infectious (e.g. nutritional deficiency) conditions (Crawshaw 2000). In one instance, the rate of shell damage (erosion or pitting), although high (33%), did not differ between turtles from non-impacted and impacted sites in populations of flattened musk turtles (*Sternotherus depressus*) (Bailey & Guyer 1998), although the cause of the shell damage was not determined. In captive turtles shell infections are usually mycotic (Hunt 1957, Frye 1991a,b), occur more frequently on the plastron than carapace (Hunt 1957), and are likely to occur secondarily to previous shell damage, or infect animals already weakened by some other predisposing factor (Austwick & Keymer 1981). One predisposing factor could be acidity resulting from the draining of acid sulfate soils which causes skin damage, and subsequent invasion by pathogenic fungi in fish (EPA 1996), and another influence could be the high level of metal contamination in the ponds (Vesk & Allaway 1997). Also, the substrate at Kensington Pond is hard and impenetrable underneath an overlying layer of sand, and this could have caused abrasion with subsequent infection, as occurs with captive turtles housed on concrete (Weigel 1989). Finally, overcrowding may be a contributing factor as disease emergence is often found after an increase in the density of host animals following habitat modification (Daszak *et al*. 2001).

In a lake in Georgia, USA, eight turtle species were examined for the presence of shell necrosis, but it was only found in river cooters (*Pseudemys concinna*; 74%) and yellow-bellied sliders (*Trachemys scripta*; 35%) (Lovich *et al.* 1996), although these turtles were otherwise normal on external examination (Garner *et al.* 1997). All symptomatic turtles examined (2 *P. concinna*, 2 *T. scripta*) had *Bacteroides* sp. in the blood, but the primary pathogen could not be determined, and it was thought that the lesions were probably indicative of an underlying visceral disorder, as internal lesions were also widespread (Garner *et al.* 1997). Unfortunately asymptomatic individuals were not examined.

The diseased turtles were two of only three prolific aerial basking species in the Georgian lake, and are also the most herbivorous of the turtle species present, and it thought that such ecological factors could be related to the etiology of the shell disease (Lovich *et al.* 1996). The infection of semi-aquatic omnivorous turtles, but not the highly aquatic carnivorous turtles, may have been related to the different dietary habits, the level of exposure to ultraviolet radiation, or an unknown factor (Lovich *et al.* 1996). The ecological differences are similar to that between *E. macquarii*, which bask and are omnivorous, and *C. longicollis* which rarely bask and are carnivorous (Sections A.1.3.3, A.1.4.2, C4.2.3).

As in Centennial Park, the infected Georgian turtles were located within a single lake in the larger Lake Blackshear area (Garner *et al.* 1997). The authors thought this may indicate environmental factors in the etiopathogenesis of the lesions (Garner *et al.*

1997), such as toxic or immunosuppressive chemicals (Lovich *et al.* 1996). An ulcerative skin disease has also been found in a population of *E. m. krefftii* from a location that may receive surface runoff and atmospheric fallout from a nearby coal-fired power plant, but not in turtles from the surrounding catchments (Tucker *et al.* 2002). Exposure to sublethal levels of various organic and inorganic substances can suppress nonspecific disease resistance factors and lead to disease from saprophytic or opportunistic organisms (Overstreet 1993). If the 'hissing' behaviour noted for turtles in Kensington Pond results from a pulmonary infection, the combination of this plus plastral infections could indicate immunocompromisation in these turtles, possibly as the result of exposure to pollutants (Tangredi & Evans 1997). Both diet and population dynamics can have a dramatic effect on immunocompetency (Kollias 1984), as can stress or overcrowding (Crawshaw 2000), and these may well also be contributing factors in this large population.

C4.3.3 Fish

The diet of *C. longicollis* and *E. macquarii* overlap considerably, despite the obligate carnivory in *C. longicollis* (Chessman 1984a) and the prevalence of algae and plant consumption in *E. macquarii* (Chessman 1986, Spencer *et al.* 1998). For dietary generalists, an environmental abundance of a food item can lead to its dominance in the diet, such as at Jervis Bay, where caddis fly larvae occur in the stomachs of 99.8% of all *C. longicollis* (Georges *et al.* 1986). Captures of eels (*Anguilla* spp.) at all sites, and carp (*Cyprinus carpio*) at six sites (Table C3.1), suggest that these species are the other main vertebrates in the turtles' habitat, and due to their often large biomass, they may be an important food source for turtles.

The diet of turtles often includes fish (Georges *et al.* 1986) and carrion (Chessman 1984a, Chessman 1986), which is often the remains of the introduced European carp (*Cyprinus carpio*) for both *C. longicollis* (Chessman 1984a) and *E. macquarii* (Spencer *et al.* 1998). This carrion is highly selected for by *E. macquarii* (in 26% of stomachs despite low availability), which is not surprising, as less than 1% of the energy is assimilated from a plant diet compared to a fish diet (Spencer *et al.* 1998). Presence of carp is important, as intake of animal tissue may also be required to maintain *E. macquarii* in positive energy balance, and thus capable of growth and reproduction (Spencer *et al.* 1998).

One ton of carp, with an estimated two tons remaining, were removed from Busby's Lagoon during a regular 6-monthly electroshocking cull within a month prior to this survey (professional carp killers pers. comm.). The presence of a large carp population in conjunction with the relatively high proportion of juvenile *E. macquarii* turtles at this site is contrary to a previous study finding few or no *C. longicollis* hatchlings in waterbodies containing carp (Chessman 1978). The huge biomass of carp represents a plentiful food source for both *C. longicollis* and *E. macquarii*, and may also be a factor driving the large population, as food availability influences turtle abundance (Allanson & Georges 1999). Carp is highly migratory, spreading rapidly under good conditions (Harris 1996), and it is likely to be present in most of Sydney's permanent freshwaters, possibly aiding chelid survival in urban areas.

Apart from turtles, the main captures in nets in the survey were eels (*Anguilla* spp.), which were caught at all survey sites (n = 21). Although eels may eat hatchling and juvenile turtles (Cann 1998), and as carnivores (Lake 1978) with a similar diet (caddis flies and other insect larvae, beetles, worms, molluscs, crustaceans, fish; Merrick & Schmida 1984) will compete for food, they will also provide food themselves in the form of carrion. Survey captures of eels and turtles are correlated, but this was dependent on inclusion of the large Breakfast Creek site, and the effect of the presence of *Anguilla* spp. on Sydney turtle populations remains unknown.

The eastern mosquito fish (*Gambusia holbrooki*) was noted at most survey sites and all Immune Study sites and is known as an excellent food item for captive *C. longicollis* (Craig Latta pers. comm.), and, where present, is thought to be a major part of *C. longicollis* diet in wild populations (Mackay 1949). This gives *C. longicollis* a competitive advantage at cohabited sites, as *E. macquarii* are unable to capture these small fast fishes (Georges *et al.* 1986, Spencer *et al.* 1998), rarely obtaining vertebrate material other than carrion (Chessman 1986). The benefit to *C. longicollis* may be increased in urban areas, where natural dietary items may be reduced (e.g. macroinvertebrate species, Chessman 1995, Walsh *et al*. 2001; native fish, Faragher & Harris 1994), and the turtles may be restricted in their habit of migrating to productive ephemeral ponds (Section A.1.3.4). Interestingly, gudgeon, the third fish family captured (Section C3.2), are also fond of gambusia (McDowall

1996). Another thing to note about gudgeons is that they are tolerant of acidic waters (some down to pH 4) where there may be no other fish present (EPA 1996). Turtles are also found in waters down to pH 4 (*E. krefftii*, Georges 1985), and tolerance of a wide range of pH may aid survial in urban waters where the pH is unnaturally altered.

Like *C. longicollis* and *E. macquarii* (Section E), *G. holbrooki* accumulate anthropogenic metals, and can be used for biomonitoring these elements (Kearns *et al*. 2003). Future work on pollution effects on Australian freshwater turtles could involve examination of food chain transmission of metals, and could encorporate gambusia, carp, and other dietary items such as insects.

The fish and turtles found in Sydney's waterways during this study have in common a lack of specialised requirements for food, habitat structure, or waterflow, and tolerate cold waters and can rapidly colonise new waterways (Lake 1978, Harris 1996). Carp cause widespread degradation of aquatic habitats, with often devastating effects on local plants and animals (Harris 1996). Turtles may be unusual in having an extremely high tolerance to such disruption.

C4.4 Summary

There have been occasional published comments on the turtles of Sydney but the extent and size of populations has not been described before.

The species of turtle found in this study are not present in all waterways and waterbodies (rejecting Hypothesis 1, Section C1.3), and are not present in equal densities in the waterbodies in which they are present (rejecting Hypothesis 2). The demography of populations varies across sites (rejecting Hypothesis 3). Trappability of turtles in baited vs. unbaited nets shows some variation between species and sites in an inconsistent manner (rejecting Hypothesis 4) and hence studies of turtle populations that aim to compare sites should use a consistent method. Baiting nets did not have any consistent effect in increasing turtle captures.

Of the two dominant species of turtle in the Sydney region, *C. longicollis* is the more widespread (n = 17/21 survey sites), although population size varies over sites (captures per effort = 0-4.89, Table C3.1). In contrast, *E. macquarii* is found at fewer sites (n = 9/21 survey sites), but populations reach larger sizes (captures per effort = 0-6.75). The presence of *E. macquarii* in large numbers at some cohabited sites may suggest a dietary advantage due to its omnivory (compared to the obligate carnivory of *C. longicollis*). Introduced fish, such as carp and gambusia, which adversely affect many aquatic plants and animals, may actually benefit Australian freshwater turtles in degraded urban waterways, where native dietary items may be reduced. Concerns over rampant populations of exotic turtles appear exaggerated.

The relationship between mass and carapace length varies across sites for *C. longicollis*, with the relationship for *E. macquarii* encompassed by the range of variation for *C. longicollis*. A body condition index that does not change with increasing turtle length was derived for Sydney populations of these two species, which will allow assessment of changes in the body condition of local turtle populations in future studies.

A lack of adequate dietary items does not generally appear problematic for *C. longicollis* and *E. macquarii* in these highly urbanised Sydney environments (Sections A.1.3.3, A.1.4.2, C4.2.3). Thus, other factors must be influencing the variation in turtle numbers and age distributions at different sites. Possible factors include reproductive problems, such as pollution effects on fertility (Section E), nest or adult predation by introduced eutherians (Thompson 1983b, Parmenter 1985, Spencer 2001) and a scarcity of nesting sites. Pollution-induced immune compromisation may also be the factor underlying the *E. macquarii* shell disease at Kensington Pond, and may also be a factor in populations without obvious signs of external disease (Section D). Poor reproductive capacity or increased mortality due to pollutant effects are of greater concern in urban areas where recruitment from the wider metapopulation may be limited or non-existant due to the presence of impassable or dangerous constructions such as buildings and roads.