APPENDIX O5

Australian Giant Cuttlefish

O5 AUSTRALIAN GIANT CUTTLEFISH

This appendix provides a detailed natural history and discusses the potential impact of the proposed desalination plant discharges on the Australian Giant Cuttlefish, *Sepia apama*, to supplement the material provided in Chapter 16, Marine Environment. It also presents the results of surveys of Giant Cuttlefish habitat and population.

O5.1 NATURAL HISTORY OF THE AUSTRALIAN GIANT CUTTLEFISH

The Giant Cuttlefish, *Sepia apama*, is the largest cuttlefish species in the world, with males reaching 1 m in length (cuttlebone to 52 cm), and weighing up to 6.2 kg (Gales et al. 1993). Knowledge of the biology of the Australian Giant Cuttlefish is largely limited to winter when they migrate inshore to spawn (Lu 1998a). Cuttlefish are carnivorous, opportunistic and voracious predators (Lee et al. 1998). They feed predominantly on crustaceans and fish.

Giant Cuttlefish are demersal animals that live in close association with (and frequently rest on) the seafloor. They use a range of behaviours to avoid predation, including complex camouflage and hiding within algae or the reef substrate.

The species as it is currently understood occurs across the temperate waters of southern Australia from southern Queensland to the mid-coast of Western Australian (Lu 1998b). Recent work, however, has shown that the population that spawns at Point Lowly is one of five genetically different populations existing in southern Australia (B Gillanders, University of Adelaide and S Donnellan, South Australian Museum, pers. comm., 11 December 2007). It has minimal interbreeding with the nearest population just north of Wallaroo. These two populations show some of the hallmarks of separate species, such as genetic separation, separate but adjacent distributions, differences in the morphology that may indicate ecological differentiation and different patterns of sexual dimorphism (B Gillanders, University of Adelaide and S Donnellan, South Australian Museum, pers. comm., 11 December 2007).

They grow rapidly but are short lived and appear to be semelparous (die after reproducing only once) (Hall et al. 2007). In Upper Spencer Gulf the population appears to comprise two year classes of both males and females, with some individuals growing very rapidly and maturing within one year, whilst others do not return to spawn until their second year when they are much larger (Hall et al. 2007).

Throughout most of its range, Giant Cuttlefish breed as pairs or in small groups, on rocky reef habitats where suitable caves and crevices provide egg-laying shelter (Hall & Fowler 2003). Typical breeding behaviour for Giant Cuttlefish throughout their geographic range consists of males competing for and defending optimal egg-laying caves (Rowlings 1994). Loose aggregations of cuttlefish can form but rarely exceed 10 animals at one location at one time.

As the majority of Spencer Gulf has a soft sediment seafloor, there are limited areas of emerged rock where female cuttlefish can lay their eggs. Furthermore, the geology of the Point Lowly reef is such that broken slabs of old seafloor sandstone produce a mosaic of flat rocks perfect for laying cuttlefish eggs on the undersides (Gostin et al. 1984). As a consequence, tens-of-thousands to hundreds-of-thousands of cuttlefish, potentially from a large area, aggregate to mate and breed on a narrow strip of rocky reef close to shore, between 2 and 5 metres in depth, from Whyalla to Point Lowly, covering approximately 61 ha (Hall & Fowler 2003) (see Figure 16.9 in Chapter 16, Marine Environment of the Draft EIS). At Black Point near Port Bonython, densities of over 105 cuttlefish per 100 m^2 have been recorded at the peak of the season (Hall and Hanlon 2002). Furthermore, a catch of 250 tonnes of cuttlefish was removed from Point Lowly alone in just 3 months during 1997 (Hall and Fowler 2003).

The breeding aggregation at Point Lowly is seasonal and cuttlefish are not resident year-round. In mid to late May cuttlefish start arriving at the Point Lowly reefs to spawn, with peak numbers occurring in late May and June (Hall & Fowler 2003). By July, numbers start to decline (as cuttlefish either die or move away from the area), however some mating and spawning activity continues through to September.

Although migratory routes to the breeding grounds have not been determined, it is likely to occur through adjacent deeper waters, since cuttlefish primarily associate with the seafloor. In these areas lower light levels, seagrasses and benthic invertebrate communities may provide cover from visual predators such as fish and dolphins. Spawning and post-spawning cuttlefish are a rich food source for many marine predators including pods of the Bottlenose Dolphin *Tursiops aduncus*, resident during the cuttlefish breeding season at Point Lowly.

During the spawning period, the sex ratio is highly skewed towards males, requiring them to compete for females with elaborate visual displays (Hall and Hanlon 2002). Detailed field studies of the mating system of *Sepia apama* have observed complex behavioural interactions among small (approx. 12 months old) and large (approx. 18 months old) males and females, which are critical for normal fertilisation and egg laying (Hall and Hanlon 2002), and have provided insights into the sexual selection of cephalopods (Hall and Hanlon 2002, Naud et al. 2004 and 2005, Hanlon et al. 2005).

Copulation involves the transfer of a packet of sperm to the female, which is stored in a pouch below the mouth (Hall and Hanlon 2002). During egg laying, the female extracts one egg at a time, and apparently fertilises it by passing the egg over the sperm mass. Each egg is wrapped in a gelatinous capsule and carefully attached to rocky substrate on the underside of a ledge or cave (Cronin and Seymour 2000, Hall and Hanlon 2002). Each female potentially lays hundreds of eggs in a single breeding season (Hall and Fowler 2003).

The extremely high cuttlefish densities at Point Lowly appear to have led to the adoption of certain reproductive behaviours not recorded elsewhere across their distribution. Large males either defend egg-laying sites or accompany and guard females as they search for egg-laying sites. Small males (potentially 6 months old) also use colour and shape changes to mimic female cuttlefish as a means of avoiding aggression by large males. This enables them to mate with females when larger males are distracted or engaged in combat displays.

Developing eggs gradually swell as the embryo forms, taking approximately four months to hatch, with the latest in early November (Hall and Fowler 2003). The hatchlings emerge at around 12 mm in length (Cronin and Seymour 2000), and are the equivalent of miniature adults. They feed on tiny crustaceans and move off the reef during their juvenile life stage prior to their return the following winter.

The mass spawning aggregation is believed to be the only cuttlefish mass breeding aggregation of such density in the world and is recognised as one of the more significant and spectacular natural history events in Australian marine waters by national and international marine biologists (R Hanlon, Marine Biological Laboratory, Woods Hole, USA, pers. comm., 6 June 2007). Each year it attracts hundreds of recreational divers, film crews and researchers from Australia and around the world, contributing significantly to the local economy (Hall 2002).

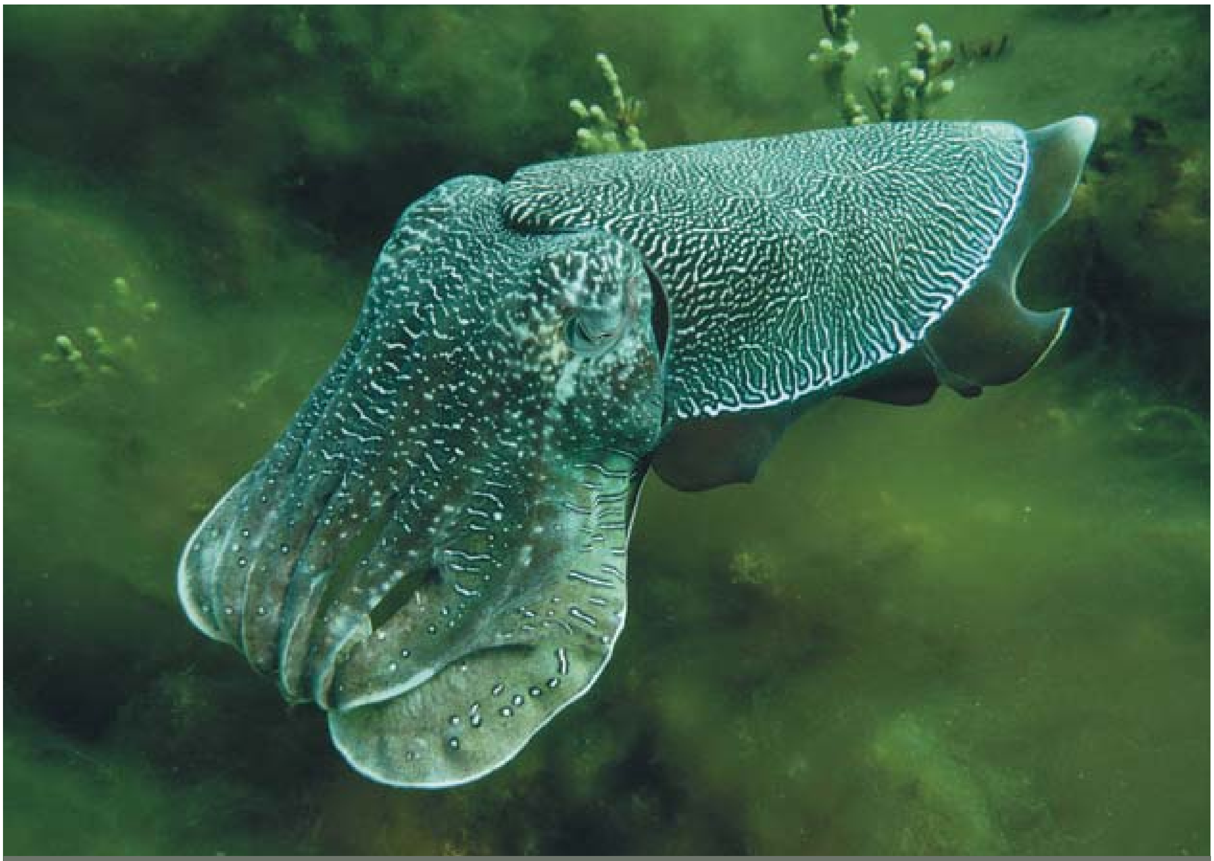
Because cuttlefish are short-lived and only reproduce once, there is no accumulation of spawning biomass from one generation to the next and little buffer against years of poor recruitment or over-exploitation. Any actions that limit their reproductive output (harvesting prior to spawning, interference with spawning behaviours), or recruitment capacity (failure of the eggs or young to reach maturity) during one year will be immediately apparent in the following year (Steer and Hall 2005).

Historically the cuttlefish aggregations supported a small commercial bait fishery with annual catches rarely exceeding four tonnes, but this rapidly increased to approximately 250 tonnes in 1997 in an attempt to develop a niche fishery (Steer and Hall 2005). This is the equivalent of up to 250,000 cuttlefish being removed from approximately 61 ha of reef. Over-exploitation quickly occurred and the population of cuttlefish near Whyalla declined severely in the ensuing years (T Bramley, Whyalla Diving Services, pers. comm., 6 June 2007).

Concerns were raised relating to the sustainability of this unique resource, particularly as fishers were targeting spawning animals. Seasonal closures were introduced in March 1998, initially encompassing the area immediately near Port Bonython, but were expanded in 1999 to include all of the waters enclosed within the area bound by the Point Lowly lighthouse, the Port Bonython Jetty and the OneSteel jetty at Whyalla (Steer and Hall 2005) (see Figure 16.9 in Chapter 16, Marine Environment). The closure was further amended in 2004 to offer year-round protection, banning the collection of all cephalopods within the aggregation area, effective indefinitely.

Following the introduction of the closures, the cuttlefish biomass in the Whyalla/Point Lowly region remained relatively stable between 1999 and 2001 at approximately 200 tonnes (Steer and Hall 2005). A survey in 2005, indicated that the biomass of cuttlefish had decreased by approximately 33% since the previous (2001) survey (Steer and Hall 2005), contrary to anecdotal evidence of increased abundance over the same time period (T Bramley, Whyalla Diving Services, pers. comm., 6 June 2007). Steer and Hall (2005) suggested that the apparent decline in abundance and biomass in 2005 was likely to reflect natural variability and that the long-term effects of illegal fishing remain uncertain. Anecdotal observations from the 2006 and 2007 seasons suggest both increased abundance and return of larger animals (M Norman, Curator of Molluscs, Museum Victoria, pers. comm., 14 March 2008).

A recent survey in 2008, recorded very low numbers of cuttlefish in the aggregation area (less than half the abundances from 1999 to 2001). In the absence of surveys for intervening years it is difficult to assess whether this represents a serial decline in population abundances since 2001 or perchance two poor years amongst other more abundant years. Whilst it may still reflect natural variation in response to irregular environmental conditions (such as extended warmer water temperatures and excessive *Hincksia* sp. growth), the exceptionally low levels recorded in 2008 are of concern, and in the absence of other data are conservatively interpreted as a possible decline in the population since 2001.

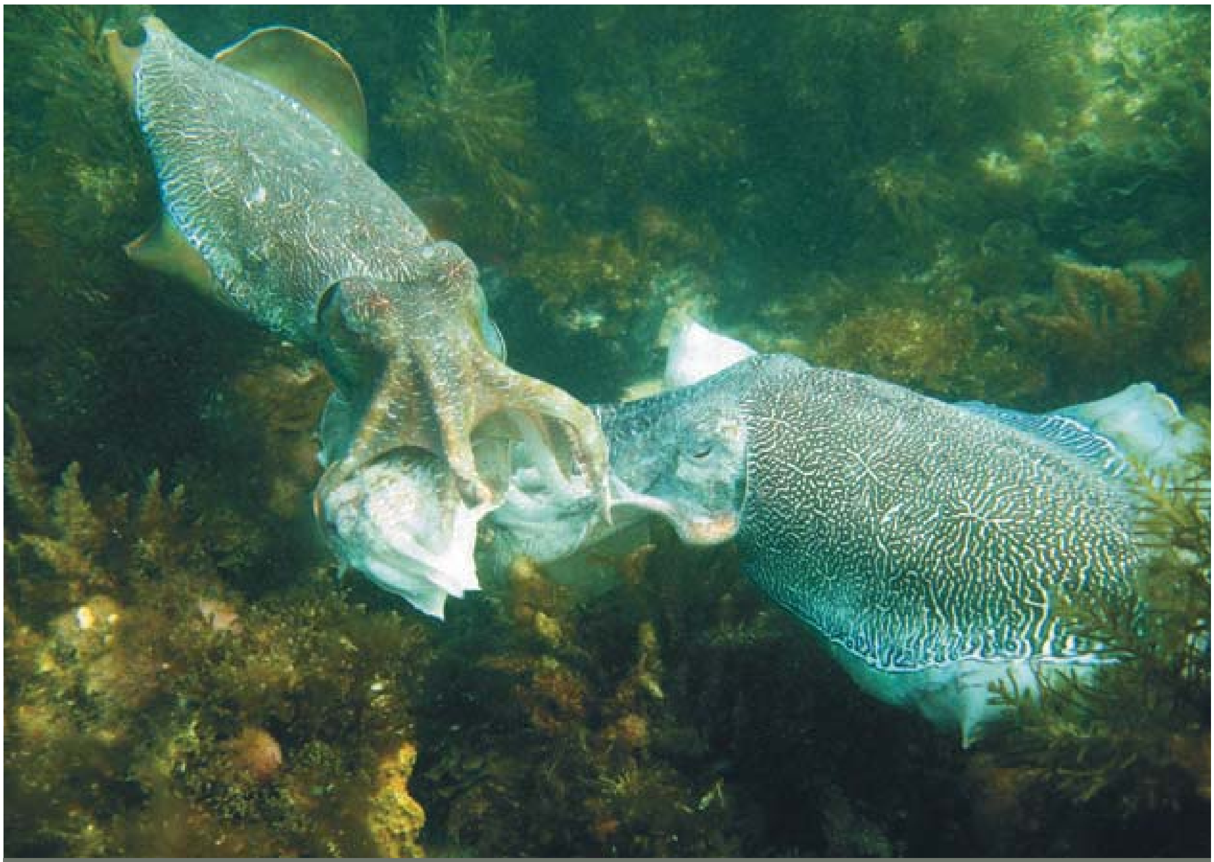


Male Australian Giant Cuttlefish (over reef covered by algae)

Male Australian Giant Cuttlefish (over reef denuded by urchins), partially damaged during mating

Female Australian Giant Cuttlefish

Small male Australian Giant Cuttlefish imitating colour and shape of algae



Small male attemping to mate with female, watched by large male

Mating – head-to-head position with arms entwined; sperm transferred from male (on right) to base of female's mouth

O5.2 POTENTIAL EFFECTS OF BRINE DISCHARGES ON AUSTRALIAN GIANT CUTTLEFISH

Cephalopods typically have a low tolerance to variations in salinity, temperature and pH level, which limits the distribution and abundance of individual species to areas with suitable environmental conditions (Holme 1974; Augustyn 1991). Temperature and salinity extremes limit the distribution of eggs, juveniles and adults (Palmegiano and D'Apote 1983; D'Aniello et al. 1989; Paulij et al. 1990; Vecchione 1991; Domingues et al. 2001; Cinti et al. 2004; Sen 2005). Only one species, the squid *Lolliguncula brevis*, is atypical in that it tolerates low salinity estuarine environments (Hendrix et al. 1981), whereas other species have adapted to greater salinities; *Sepia apama* breeds naturally in salinities of up to 44 g/L in Spencer Gulf and eggs of the cuttlefishes *Sepia dollfusi* and *Sepia pharaonis* are found in salinities of up to 43 g/L in the Red Sea (Howaida Gabr, Suez Canal University, pers. comm., 21 July 2006). If adult cuttlefish are unable to tolerate higher salinities, they are likely to avoid such areas, which would lead to changes in their distribution and community composition if this avoidance was long term.

Cephalopods depend on suitable environmental conditions because:

- they have no capacity to osmoregulate (the process by which an organism maintains a relatively constant internal salinity compared to the higher or lower salinity of its environment)
- they have minimal tolerance to pH change
- there are complex breeding behaviours that are critical to normal fertilisation and egg laying (Hall and Hanlon 2002) – in particular *Sepia apama*
- normal embryonic development depends on a consistent and suitable environment.

The inability of cephalopods to osmoregulate affects physiological processes, including the excretory and respiratory/circulatory systems. Cephalopods typically have a narrow range of salinities within which wastes can be produced efficiently. When exposed to elevated salinities, the production of concentrated wastes consisting of ammonia and uric acid becomes less efficient. Conversely, when exposed to reduced salinity, additional water is absorbed and the excretory system is unable to filter the resultant volumes of blood (Wells 1962, 1978).

Unlike freshwater, standard seawater has a greater capacity to maintain relatively constant pH. Consistent pH and oxygen levels are necessary for the correct functioning of the respiratory and circulatory systems of cephalopods. Oxygen binding to the blood pigment haemocyanin is highly pH dependent. Cephalopods can only tolerate small decreases below the ambient seawater pH of 8-8.2, with mortality occurring at pH ~7.5 (R Hanlon, Senior Scientist, Woods Hole Institute, pers. comm., 6 June 2007). Exposure to low oxygen environments is tolerated only for short periods, by switching to anaerobic pathways of energy production (Melzner et al. 2006). Reduced dissolved oxygen, resulting for example from increased temperatures or salinity induced stratification, or lowered pH resulting from certain antiscaling agents, may create areas unsuitable for cephalopods to function normally.

If salinity or other variables change to the extent that animals are stressed but remain in the area, the complex behaviours leading to breeding (Hall and Hanlon 2002) may be affected. Results from squid maintained in the laboratory have shown that stressed females lay malformed eggs (R Hanlon, Senior Scientist, Woods Hole Institute, pers. comm., 6 June 2007); suggesting that egg quality/viability may also be compromised in stressed *Sepia apama*.

The maintenance of suitable environmental conditions is also necessary for the normal development of cephalopod eggs. Cuttlefish eggs gradually expand during development as a result of the uptake of water across the capsule. Egg expansion aids the diffusion of oxygen to the developing embryo (Cronin and Seymour 2000). Expansion relies on the maintenance of an osmotic gradient (i.e. a greater salinity within the egg in comparison to the surrounding water) (De Leersnyder and Lemaire 1972; Pechenik 1983; Gomi et al. 1986; Cronin 2000; Cronin and Seymour 2000). The higher salinity within the egg is controlled by the developing embryo, which releases large solutes within the egg to maintain the osmotic gradient, enabling water absorption and as a consequence, increased oxygen consumption.

If the salinity of the surrounding water were to change, the development of the embryo is likely to be compromised, as energy will be diverted from development and growth in an attempt to maintain the osmotic gradient. Osmotic stress results in developmental deformation (Paulij et al. 1990), observed in several cephalopod species exposed to both elevated and reduced salinities, and may affect the morphology of the egg, the length of the incubation period, the number of young hatching and their 'success', and the size of the hatchlings (Sen 2005; Palmegiano and D'Apote1983; Cinti et al. 2004; Paulij et al. 1990). Due to the more critical conditions required for egg development, the salinity range tolerated by developing embryos is likely to be much narrower than that of adults.

The maintenance of a suitable environment for the *Sepia apama* aggregation near Point Lowly is paramount to retaining this unique mass aggregation event, and the subsequent Spencer Gulf population. Total avoidance of the area by *Sepia apama* may compromise the viability of the species within Spencer Gulf, as Point Lowly provides a rare stretch of rocky reef suitable for egg deposition, and there is currently little option for *Sepia apama* to move elsewhere should environmental conditions deteriorate.

O5.3 CUTTLEFISH HABITAT

O5.3.1 Extent

Coarse maps of cuttlefish spawning habitat were provide by Steer and Hall (2005) (see Figures O1.2 and O4.1), and have been confirmed through personal communications with local divers, personal observations and a survey. In order to locate the spawning habitat closest to the modelled desalination plant outfall, the dive survey was conducted in October 2007. The south-eastern extremity of Point Lowly was surveyed for available habitat (to 20m depth). No cuttlefish spawning habitat (not even low relief, convex rock) was found below 10 metres.

The use of adjacent habitats by cuttlefish prior to, during and after the spawning season is not well known. During cuttlefish population surveys (see Appendix O5.5), however, a number of ad hoc searches were undertaken in habitats adjacent to the reef (seagrass and silt/sand). Only a single cuttlefish was found, in seagrass a few metres from the spawning reef. Further surveys dedicated to these habitats were conducted in late July 2008, while cuttlefish were still present. A pair of divers undertook timed 20 minute transects offshore from Black Point, Stony Point and Point Lowly (eastwards), to a maximum depth of approximately 10 m. The visibility was 4–5 m at the first two sites, and 2–3 m at Point Lowly. No cuttlefish were observed.

No cuttlefish were observed during previous surveys of offshore silt/sand environments two weeks prior to the breeding season, in May 2006 (see Appendix O1). Similarly, no cuttlefish were found during monthly beam trawls targeting a non-specific range of species in False Bay from 1999–2001, over shallow seagrass and unvegetated substrata (McDonald 2008).

O5.3.2 Artificial habitat

Previous population surveys have shown that cuttlefish use artificial habitat, consisting of rock breakwaters, at the OneSteel Harbour, in Whyalla (Hall 2002). A pilot study was undertaken to investigate the potential for establishing artificial habitat to mitigate habitat loss associated with the construction of the desalination plant.

Two small artificial habitats constructed from sandstone pavers were placed in Fitzgerald Bay, 50m from the breeding reef habitat at 10 m depth, and 10 m from the reef at 5 m depth. Each habitat was approximately 1050 mm x 400 mm x 600 mm high, and had six crevices, each of different sizes (see Plate O5.1 and Table O5.1). The benthic sediments formed the floor of the bottom crevices.

Table O5.1 Crevices in artificial cuttlefish habitats

Crevice number	Position	Width (mm)	Height (mm)
1	Top left	350	100
2	Middle left	350	200
3	Bottom left	350	80 (estimated)
4	Top right	600	100
5	Middle right	600	200
6	Bottom right	600	80 (estimated)

The artificial habitats were inspected after six weeks. For both habitats, eggs were present in only the bottom crevices (see Plate O5.2). It is uncertain whether this preference was based on the height of the crevice or its location adjacent to the sediment.

Plate O5.1 Artificial habitat deployed in Fitzgerald Bay

Plate O5.2 Australian Giant Cuttlefish eggs on underside of bottom paver

O5.4 REFERENCES

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APPENDIX O5.5

Estimated abundance and biomass of Giant Australian Cuttlefish *Sepia apama* at the spawning aggregation area in northern Spencer Gulf, South Australia (report by Dr Karina Hall, 2008)

See overleaf for report.

Estimated abundance and biomass of giant Australian cuttlefish *Sepia apama* at the spawning aggregation area in northern Spencer Gulf, South Australia

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August 2008

Report prepared for the
Olympic Dam EIS Project

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1. Introduction

This report details the results of an underwater survey of the abundance and biomass of giant Australian cuttlefish, *Sepia apama*, in the Black Point to Point Lowly area (hereafter referred to as the aggregation area) and an additional area to the north (Backy Point) in northern Spencer Gulf, South Australia, during June 2008. Underwater surveys in the aggregation area began in 1998, in response to concerns over a rapid rise in commercial fishing effort between 1993 and 1997 that was targeted on this unique spawning aggregation of cuttlefish. Between 1998 and 2001, annual surveys were completed by the South Australian Research and Development Institute (SARDI) as part of their stock assessments (Hall, 2000; Hall, 2002; Hall, 1999; Hall and McGlennon, 1998). Since then, only one survey has been done by SARDI, in 2005, which was commissioned by the Coastal Protection Branch of the South Australian Department for Environment and Heritage (DEH) in response to anecdotal concerns over low abundances in 2004 (Steer and Hall, 2005).

This 2008 survey was undertaken as part of the Olympic Dam EIS Project. The key objectives of the survey were: (i) to extend the existing baseline for the abundance and biomass of the cuttlefish spawning population in the aggregation area (Steer and Hall 2005); (ii) to determine the current status of the population, specifically whether it is in decline or is subject to natural fluctuations in population size; (iii) train divers from ARUP/HLA in the methods (as per Steer and Hall 2005) and facilitate verification of the repeatability of the methods; (iv) transfer undocumented knowledge on survey protocols and methods to ARUP/HLA divers; and (v) establish cuttlefish population baselines for other locations in Upper Spencer Gulf (e.g. Backy Point, Point Riley).

2. Methods

Cuttlefish densities were surveyed in the aggregation area between 2nd and 5th June 2008 according to the methods developed by Hall and Fowler (2003). The aggregation area was divided into three sub-areas based on fishing history (Fig. 1). These were: (i) a "closed-closed area" that was originally closed to fishing before the 1998 season; (ii) an "open-closed area" that was originally left open to fishing in 1998, but was later closed half way through the season; and an "open-open area" that has always remained open to fishing (Fig. 1). These sub-areas were further divided into three to five sites to allow for discontinuities in hard substrate. On average, sites consisted of 600 m of coastline, but ranged from 280 m to 1.2 km (Hall and Fowler, 2003). One additional site (Backy Point) 12 km north of the main aggregation area was also surveyed and two closed-closed sites (SANTOS Jetty and OneSteel Wall, near Whyalla), were not surveyed due access issues. Data for Backy Point were excluded from 2008 totals to facilitate comparisons with estimates from previous years.

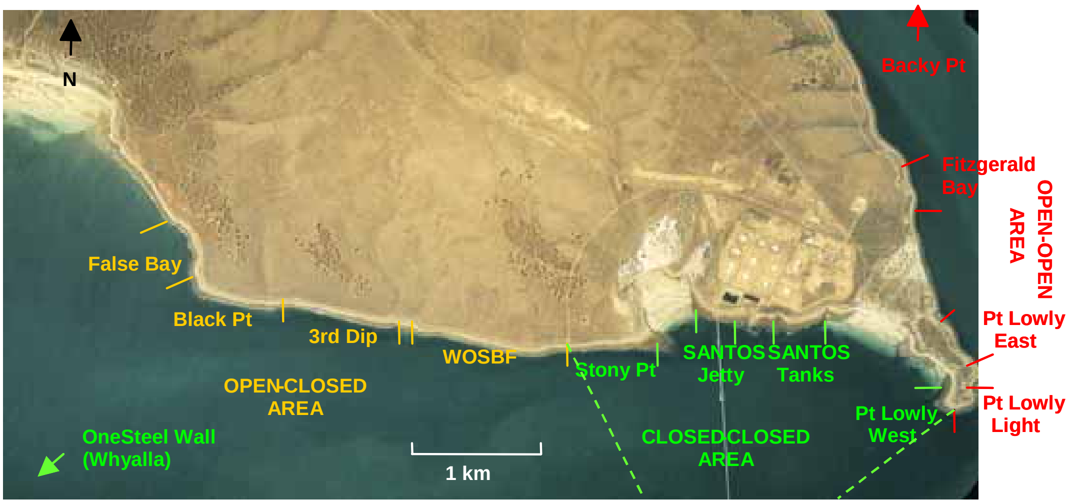

Fig.1. Aerial photograph of the main spawning aggregation area with the locations of sampling sites indicated. Sites in the open-closed area are indicated in yellow, closed-closed area in green and open-open area in red.

Four SCUBA divers worked in pairs to complete four 50 x 2 m strip-transects in each habitat within each site. One diver in each pair counted and estimated the mantle length (ML, to the nearest cm) and sex of all cuttlefish that were encountered within each transect. This provided an average density of cuttlefish 100 m^{-2}. To correct for observer bias, at the end of the survey, each diver estimated the ML and sex of 30 cuttlefish underwater that were subsequently captured with a landing-net and measured and sexed accurately on the surface. Estimated lengths were corrected for observer bias and then converted to weights according to the average length-weight relationship (Hall and Fowler, 2003), to estimate the average weight of cuttlefish 100 m^{-2}. Abundance and biomass estimates were calculated for each habitat in each site by multiplying the average density and average weight, respectively, by the corresponding area of habitat (as determined by Hall and Fowler 2003). Total abundance and biomass estimates for each sub-area and for the entire aggregation area were extrapolated from these site estimates. Data from previous surveys are reproduced in this report to place 2008 results in context (Hall and Fowler, 2003; Steer and Hall, 2005).

3. Results

3.1 Abundance

In June 2008, the estimated total abundance of cuttlefish in the aggregation area was 75 295 (Table 1). This represents the lowest abundance ever recorded in the area, since surveys began in 1998, and a 43 and 57% decrease in abundance compared to the most recent surveys in 2005 and 2001, respectively. The abundance in 2008 was even lower than that reported in 1998, when a large proportion of animals were removed from the open-closed area by commercial fishing before surveys were done.

Table 1. Annual estimates of cuttlefish abundance (± SD) in the whole aggregation area and each sub-area during peak spawning (1998 to 2001, 2005 and 2008). No surveys were completed in 2002 to 2004, or 2006 and 2007. [a] Data from Hall and Fowler (2003); [b]Data from Steer and Hall (2005). Data for Backy Point were excluded from 2008 totals to facilitate comparisons with estimates from previous years.

Area	Year					
	1998[a]	**1999 [a]**	**2000 [a]**	**2001 [a]**	**2005[b]**	**2008**
Closed-closed (± SD)	33 064 (± 7 375)	42 381 (± 20 170)	47 413 (± 7 353)	53 628 (± 10 191)	32 715 (± 15 260)	18 197 (± 10 097)
Open-closed (± SD)	51 999 (± 11 685)	133 055 (± 27 704)	122 134 (± 35 747)	121 752 (± 18 679)	92 895 (± 20 165)	53 020 (± 12 192)
Open-open (± SD)	3 570 (± 1 885)	7 205 (± 3 251)	1 559 (± 841)	1 782 (± 1 309)	2 175 (± 1 302)	4 077 (± 1 697)
Whole aggregation area (± SD)	**88 634** (± 13 945)	**182 642** (± 34 422)	**171 106** (± 36 505)	**177 161** (± 21 318)	**127 785** (± 25 322)	**75 295** (± 15 921)

3.2 Biomass

The estimated total biomass of cuttlefish in the aggregation area decreased from 184.3 t in 2001, to 121.6 t in 2005 and just 80.6 t in 2008 (Table 2). Overall, this represents a 56% decrease in total biomass since 2001 (Fig. 2).

Compared to estimates from 2005, the decrease in biomass was marginally greater in the open-closed area (38%) compared to the closed-closed area (31%); whereas since 2001, there has been a greater overall decrease in closed-closed area (Table 2). In contrast, there was a gradual increase in the open-open area, but this area accounts for only a small proportion of the total biomass (Table 2).

The spatial distribution of biomass among sites and habitats in 2008 differed from that in 2005 and other previous years (Fig. 3). In particular, at Black Point biomass decreased by 78%, from 64.8 t in 2005 to just 14.3 t in 2008. This site has historically supported the highest biomass in the aggregation area, even when the site was fished in 1998, and total biomass was low in 2005 (Fig. 3b). Similarly, two other sites in the open-closed area (False Bay and 3rd Dip) that previously held relatively high biomasses, also recorded minimums in 2008 (Fig. 3a,c). Conversely, biomass at the remaining site (WOSBF), which was unusually low (5.5 t) in 2005, increased by 83% in 2008 (to 32.2 t) and was the highest of any site (Fig. 3d). In addition, there was also an unusually high proportion of cuttlefish in the algal habitat at this site in 2008.

Table 1. Annual estimates of cuttlefish biomass (t ± SD) in the whole aggregation area and each sub-area during peak spawning (1998 to 2001, 2005 and 2008). No surveys were completed in 1997, 2002 to 2004, or 2006 and 2007. Commercial cuttlefish catch (t) from Marine Fishing Area 21 (which includes the aggregation area) are also indicated as potential biomass removed from the open-closed and open-open sub-areas. [a] Data from Hall and Fowler (2003); [b]Data from Steer and Hall (2005). Data for Backy Point were excluded from 2008 totals to facilitate comparisons with estimates from previous years.

Area	**Year**						
	1997	**1998**[a]	**1999** [a]	**2000** [a]	**2001** [a]	**2005**[b]	**2008**
Closed-closed (± SD)		39.1 (± 9.7)	51.3 (± 25.9)	44.7 (± 6.4)	51.1 (± 10.5)	27.7 (± 13.9)	19.1 (± 11.7)
Open-closed (± SD)		55.8 (± 14.0)	158.9 (± 33.4)	133.0 (± 39.5)	130.5 (± 25.5)	92.1 (± 28.2)	57.4 (± 15.7)
Open-open (± SD)		3.4 (± 1.7)	8.3 (± 3.7)	1.4 (± 0.9)	1.7 (± 1.4)	1.8 (± 1.1)	4.0 (± 2.1)
Whole aggregation area (± SD)	Not surveyed	**98.2** (± 17.1)	**218.5** (± 42.5)	**179.1** (± 40.1)	**183.3** (± 27.6)	**121.6** (± 31.5)	**80.6** (± 24.5)
Commercial catch	244.4	109	3.7	N/A	1	N/A	N/A
Whole aggregation area		**207.2**	**222.2**	**179.1**	**184.3**	**121.6**	**80.6**

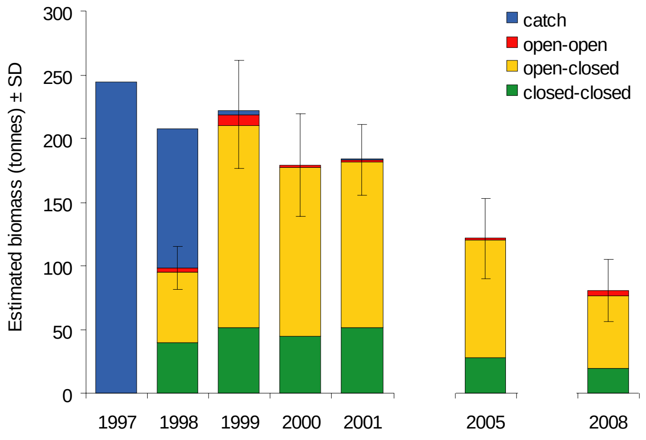

Fig. 2. Annual estimates of cuttlefish biomass (± SD) in the aggregation area during peak spawning (1998 to 2001, 2005 and 2008), with proportion in each sub-area and that accounted for by catch (in Marine Fishing Area 21) indicated by different colors. Commercial fishing occurred within the open-closed area during half of 1998. No surveys were completed in 1997, 2002 to 2004, or 2006 and 2007. Data for 1998 to 2001 from Hall and Fowler (2003), and for 2005 from Steer and Hall (2005).

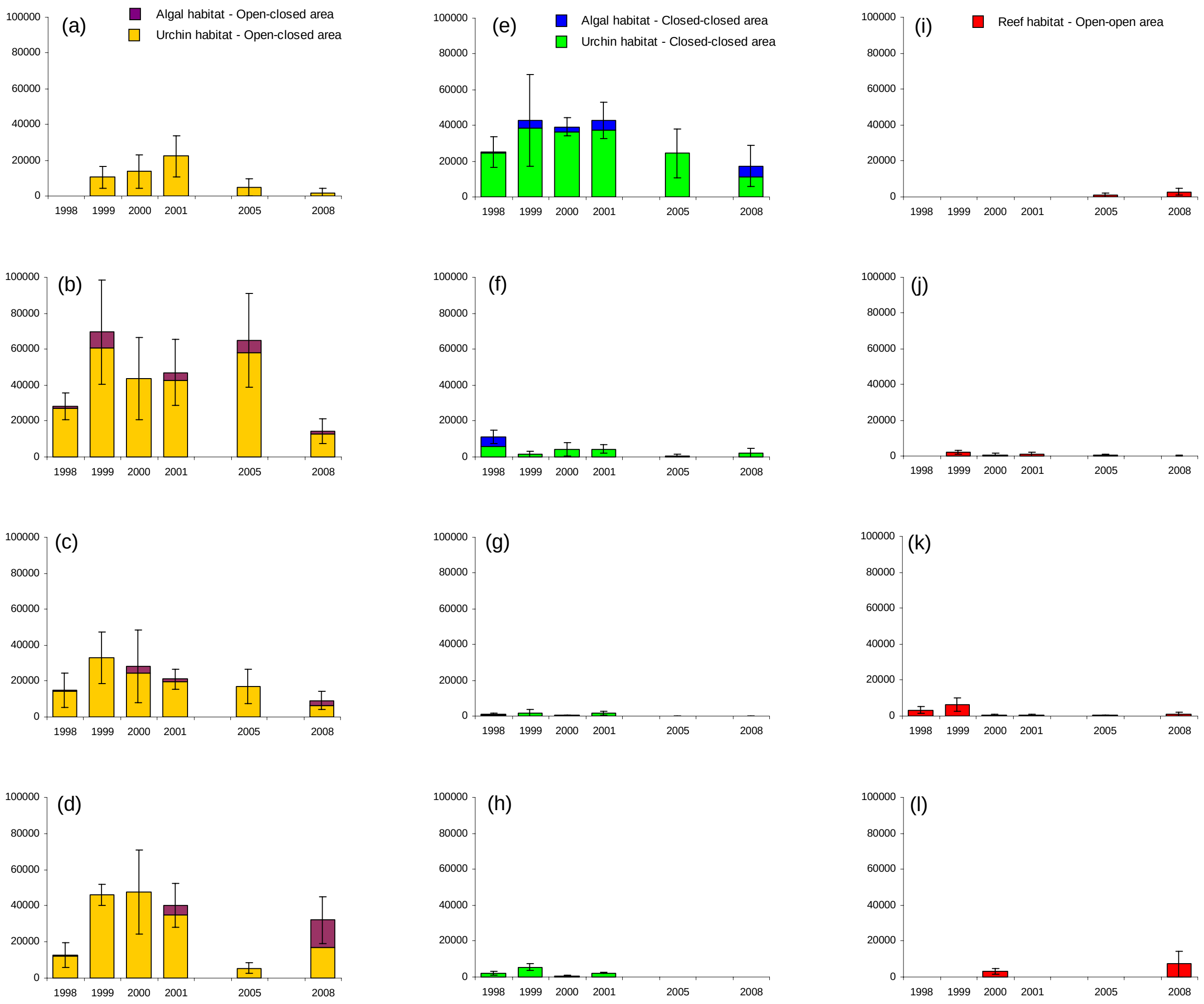

Fig. 3. Annual estimates of cuttlefish biomass for each site (1998 to 2001, 2005 and 2008) in the open-closed area (a-d), closed-closed area (e-h) and open-open area (i-l). Commercial fishing occurred within the open-closed area during half of 1998. Sites were: (a) False Bay (not surveyed in 1998); (b) Black Pt; (c) 3rd Dip (from Black Pt); (d) WOSBF (west of the SANTOS boundary fence); (e) Stony Pt; (f) SANTOS Tanks; (g) Pt Lowly West; (h) OneSteel Wall (near Whyalla, not surveyed in 2005 and 2008); (i) Pt Lowly Lighthouse (only surveyed in 2005 and 2008); (j) Pt Lowly East (not surveyed in 1998), (k) Fitzgerald Bay; and (l) Backy Point (12 km north of the main aggregation area, only surveyed in 2000 and 2008). Data for 1998 to 2001 from Hall and Fowler (2003), and for 2005 from Steer and Hall (2005).

In the closed-closed area, only one site (Stony Point) has consistently supported relatively high biomass, which averaged approximately 40 t between 1999 and 2001 (Fig. 3e). In 2005, this biomass decreased to 24.5 t, and in 2008, was just 17.2 t. However, it still accounted for most of the biomass in this sub-area.

In the open-open area, the biomass at two sites (Point Lowly Lighthouse and Fitzgerald Bay) increased in 2008, and accounted for the overall increase for this sub-area (Fig. 3i,k). In 2008, Backy Point was also surveyed, and although there were very high densities of cuttlefish, this equated to only 7.3 t of biomass, due to the small area of reef present (Fig. 3j). This site was previously surveyed in 2000, when a smaller biomass of 3.3 t was recorded.

4. Discussion

The results of this survey suggest that the estimated abundance and biomass of giant Australian cuttlefish in the main aggregation area in 2008 was over 50% lower than that recorded between 1999 and 2001. The survey in 2005, also indicated a decrease of 34 to 37% in both biomass and abundance relative to previous estimates (Steer and Hall, 2005). Although some algal habitats were omitted in the 2005 survey, which may have accounted for a small proportion of biomass and abundance, these were included in the 2008 survey.

These results conflict with anecdotal reports that cuttlefish abundances increased during 2006 and 2007, to resume levels comparable to those of between 1999 and 2001 (pers. comm., T. Bramley, Whyalla Diving Services, June 2008). This has prompted concerns that the two recent surveys may have fallen by chance in two particularly poor years. Cephalopod populations are known to be highly unstable over time, with large variations in abundance in response to changes in environmental conditions (Rodhouse, 2001; Boyle and Rodhouse, 2005). Due to the wide variation in water temperatures over which *Sepia apama* eggs develop and hatch, there is potential for considerable natural variation in recruitment and subsequent spawning biomass (Hall and Fowler, 2003). But given that three consecutive surveys between 1999 and 2001 recorded little variation in abundance and biomass, and that the two most recent surveys have recorded sequentially lower estimates, the only conservative assessment is that there has been a decrease in population size in recent years.

There were several peculiarities noted during the 2008 survey that may have influenced results, but probably not to the extent required to account for the severe declines recorded. Nevertheless they do warrant discussion. In particular, there were very dense patches of *Hincksia* sp. present at some sites during the survey that were not as obvious in previous years. However, this was based on observation alone since no quantitative data on ephemeral macroalgal densities have been collected during any of the cuttlefish surveys. The presence of *Hincksia* sp. appeared to affect cuttlefish distribution in the area, with individuals conspicuously absent in patches of especially dense macroalgae. There were also more cuttlefish recorded in the deeper algal habitats at some sites than during previous surveys, which may have reflected the lower densities of *Hincksia* sp. with depth. Notwithstanding these possible effects on cuttlefish distribution within the area, and even the potential exclusion of cuttlefish from some usual habitat, it is unlikely that this could produce such an extreme decline in estimates.

Anecdotal evidence also suggests that in 2008 water temperatures remained elevated for longer, and that the cuttlefish arrived later and were slower to increase in density compared to other years (pers. comm., T. Bramley, Whyalla Diving Services, June 2008). However, a similar scenario was also recorded in 2000, when cuttlefish arrived two weeks later than usual (Hall and Fowler, 2003). This resulted in an altered temporal pattern in abundance and biomass at some sites during the 2000 season, with a less distinct peak in numbers in early June, and a second smaller peak later in August (Hall and

Fowler, 2003). But although a marginal decrease in total abundance and biomass was recorded in 2000, it was of smaller magnitude than that recorded in 2008.

In summary, the survey in 2008 recorded very low levels of abundance and biomass of cuttlefish in the aggregation area. In the absence of surveys for intervening years it is difficult to assess whether this represents a serial decline in population abundances since 2001 or perchance two poor years amongst other more abundant years. Whilst it is possible that this does reflect natural variation or an aberrant response to irregular environmental conditions (such as extended warmer water temperatures and/or excessive *Hincksia* sp. growth) the exceptionally low levels recorded in 2008 are of serious concern, and must be conservatively interpreted as a possible decline in the population since 2001. As such it is imperative that further time-series monitoring of the cuttlefish abundance and biomass be undertaken in the aggregation area.

This spawning aggregation is unique for cuttlefish around the world due to the exceptionally high densities of animals present in one localised area (Hall and Fowler, 2003). It is likely that the high densities have been a strong influence in the sexual selection of a diverse range of complex reproductive behaviours within and between sexes (Hall and Hanlon, 2002). The results of this survey suggest that the densities of the population may have already decreased by over 50%. It is unknown what effect this might have on the mating system or future life history evolution of this unique population (Hanlon, 1998). Furthermore, recent research suggests that the aggregation population may be genetically distinct from others in South Australia and as such would be more vulnerable to local extinction (pers. comm., B. Gillanders, University of Adelaide, August 2008). The factors responsible for the current decreases in numbers are unknown and clearly warrant further investigation to prevent any further declines.

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